

Examination of Indicators of Congestion Level

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This research report examines the relationships between many possible indicators of congestion and estimated congestion level in an attempt to identify and validate indicators for areawide congestion measurement purposes. The study estimates the congestion level for 50 large and medium-sized U.S. urban areas with 3 congestion measures. The estimated congestion level for each urban area is then graphically and statistically compared to indicators composed of travel, facility supply, and demographic characteristics to determine close relationships. Two of the congestion measures used in this study, the roadway congestion index and the congestion severity index, produced results with a high correlation to each other. An index-incorporating congestion duration on freeway segments (lane-mile duration index) suffered from unobtainable data for several urban areas and was consequently less comparable between the other two measures. It was determined that two indicators related to travel intensity—daily vehicle-miles of travel per lane-mile and daily vehicle miles of travel per square mile—had the closest correlation to estimated congestion levels. Average annual daily freeway traffic per hourly capacity, previously used as a facility measure, was identified also as having a close relationship to areawide congestion level.

Over the past decade, traffic congestion in urban and suburban areas has grown from a mere annoyance to a severe problem. Although traffic congestion is not a new problem for residents of the central city, it has spread and intensified to envelop the urban fringe and outlying suburban areas. This rapid increase in traffic congestion has become a major concern of transportation professionals nationwide. Current predictions about congestion offer no relief, either. By the year 2005, freeway delay has been projected to increase from between 300 to 500 percent over the 1985 levels (1).

There are several factors that have contributed to the rapid growth of traffic congestion in the United States in the past decade. The number of registered vehicles has increased disproportionately to population and household growth; in turn, vehicle travel had spiraled to more than 2 trillion vehicle-mi by the late 1980s. To compound the increase in travel, construction of new highway facilities has slowed considerably since the near completion of the Interstate system in the early 1970s. Because of increased access to the automobile and the suburban migration of both business and residential properties, a higher percentage of commuters now drive instead of using public transit or walking. This change in commuting patterns in combination with the preceding factors has clogged local street networks and highway facilities.

CONGESTION MEASURES

The type of measure used to quantify the level of congestion on a transportation system should deliver comparable results for various systems with similar congestion levels. These measures should accurately reflect the quality of service for any type of system, whether it be a single facility or an entire urban area. A congestion measure should also be simple, well-defined, and easily understood and interpreted among various users and audiences.

Existing congestion measures use assorted variables in equation formats to describe the extent, severity, and duration of congestion. One type of measure uses indicators—or variables closely related to the level of congestion—to quantify congestion. Examples of possible indicators include travel (e.g., vehicle miles of travel), roadway supply (e.g., lane miles of roadway), and population density. Indicators are generally related to the probable causes of congestion. Another type of measure uses variables that are descriptors of the effects of congestion. Vehicle delay, congestion duration, and average travel speed are all examples of variables that characterize the effects of congestion.

This report examines the relationships between many possible indicators and congestion levels in an attempt to identify and validate indicators for congestion measurement purposes. The indicators used in this study include travel characteristics, facility supply characteristics, demographic characteristics, and all combinations thereof.

BACKGROUND

There have been several efforts in recent years to improve the analysis of traffic congestion data. Many of the efforts have concentrated on developing an accurate areawide measure of congestion. However, there has been no clear consensus on which indicator, if any among those currently used, most directly reflects congestion level in urban areas. Additionally, many possible indicators have not been fully examined with regard to their relationship to congestion. The following paragraphs discuss previous research on indicators and measures of congestion.

The level-of-service (LOS) concept as adopted by the 1985 *Highway Capacity Manual* represents a range of operating conditions (2). The LOS, or quality of service, of a facility is determined by traffic characteristics such as vehicle density and volume-to-capacity (v/c) ratio, depending on the facility type. Most congested traffic conditions fall into the LOS F range, a range “used to define forced or breakdown flow.”

It is in this LOS range that the demand of traffic exceeds the capacity of the roadway. Because the v/c ratio theoretically cannot exceed 1.0 (volume cannot exceed capacity), past a certain level of demand this ratio and the LOS concept is of little use in distinguishing between levels of congested flow in LOS F. The vehicular density during forced flow conditions is greater than the LOS F threshold density; consequently, the v/c ratio decreases as the vehicular density increases in LOS F conditions. Although dense travel corridors now experience many hours of the daily rush hour, the v/c ratio has traditionally been used to describe a single peak-hour condition.

In an attempt to better describe the duration dimension of congestion, the California Department of Transportation (Caltrans) uses the number of hours of LOS F service (3). For example, LOS F2 represents 2 hr of LOS F service. This combination of the v/c ratio and the duration of congested operation enhances the LOS concept and accounts for the "peak spreading" common in many urban areas, which extends the peak period over several hours. This improved measure is relatively easy to calculate, interpret, and communicate, but has been used only in planning analyses by Caltrans.

An analysis technique developed by Lindley used Highway Performance Monitoring System (HPMS) data, traffic distribution patterns, and *Highway Capacity Manual* calculations to determine freeway travel delay (1). A congestion severity index was defined as the total freeway delay (vehicle hours) per million vehicle miles of travel (VMT). Urban area freeway systems then were ranked according to the congestion severity index. A methodology was developed to include the delay caused by incidents using an accident data base of breakdown types and rates. Delay on principal arterial streets was not included in this analysis. In Lindley's calculations, the congestion threshold was defined at a v/c ratio of 0.77 or higher (LOS D or worse) during 1 or more hr/day. This definition of the beginning of congestion is consistent with values reported to Congress on the status of national highways by the Department of Transportation and values recommended for urban freeway design standards by AASHTO (4,5).

Early research by Lomax and Christiansen investigated the use of several variables as indicators of areawide congestion level (6). Among those presented as possible indicators were traffic volume per lane, percentage of congested (ADT greater than 15,000) freeway lane miles, K -factor, and peak-hour travel distance. Trends in these possible indicators were calculated for 1975 to 1980 for five urban areas in Texas. The study concluded that VMT per lane was perhaps the most reliable indicator and developed a congestion standard that combined weighted values for freeway and principal arterial street VMT per lane.

Subsequent research by Lomax et al. resulted in the development of a roadway congestion index (RCI) (7-11). The indicator of daily VMT (DVMT) per lane mile for both freeways and principal arterial streets is weighted and normalized in the index's equation. Major U.S. urban areas then are ranked according to the RCI value. The threshold of congestion was chosen at a v/c ratio of 0.77 or higher (LOS D or worse) and was correlated to ADT per lane values for freeways and principal arterial streets through basic assumptions about traffic characteristics.

In a recent report by Cottrell, a lane-mile duration index (LMDI_F) is presented as a measure of recurring freeway

congestion in urbanized areas (12). The LMDI_F represents a summation for an urban area of the congested freeway lane miles multiplied by the respective duration of LOS F service. The use of the duration of LOS F service in intermediate calculations of LMDI_F is similar to Caltrans' reporting of LOS F1, F2, and so on. Traffic distribution patterns in the HPMS Technical Manual were used to relate the value of average annual daily traffic volume per hourly capacity (AADT/C) to congestion duration (13). Previous research by Lisco determined that peak-period delay occurred when the AADT/C value reached 8 to 10 (14). In his analysis, Cottrell chose LOS F as the congestion threshold, which he correlated to an AADT/C value of 9. The analysis excluded arterial streets and did not consider the effects of incident delay.

As evidenced by the foregoing, no clear consensus exists on where congestion begins or which indicator or measure most accurately reflects congestion level on an areawide basis.

METHODOLOGY

This study attempted to identify indicators that can be used for congestion measurement purposes. For the purposes of this report, an indicator is considered to be a variable directly related to the level of congestion. Three previously developed congestion measures were used to estimate the congestion level in 50 large and medium-sized U.S. urban areas. Possible indicators of congestion were chosen, and the relationships between the indicators and congestion level were examined for 1989. The study methodology is described in detail in the following sections.

Use of Existing TTI Data Base

Researchers at the Texas Transportation Institute (TTI) have compiled congestion-related statistics in an extensive data base. The data base currently contains annual summary statistics from 1982 through 1989 for 50 large and medium-sized U.S. urban areas with populations generally greater than 500,000. These urban areas may be found in Figure 1.

The data base statistics of interest to this study were those relating to travel, facility supply, and demographic charac-

Albuquerque NM	Atlanta GA	Austin TX	Baltimore MD
Boston MA	Charlotte NC	Chicago IL	Cincinnati OH
Cleveland OH	Columbus OH	Corpus Christi TX	Dallas TX
Denver CO	Detroit MI	El Paso TX	Fort Worth TX
Ft. Lauderdale FL	Hartford CT	Honolulu HI	Houston TX
Indianapolis IN	Jacksonville FL	Kansas City MO	Los Angeles CA
Louisville KY	Memphis TN	Miami FL	Milwaukee WI
Minn-St. Paul MN	Nashville TN	New Orleans LA	New York NY
Norfolk VA	Oklahoma City OK	Orlando FL	Philadelphia PA
Phoenix AZ	Pittsburgh PA	Portland OR	Sacramento CA
Salt Lake City UT	San Antonio CA	San Bern-Riv CA	San Diego CA
San Fran-Oak CA	San Jose CA	Seattle-Everett WA	St. Louis MO
Tampa FL	Washington DC		

FIGURE 1 Study cities—50 large and medium-sized U.S. urban areas.

teristics. The possible indicators examined were composed of one, or a combination of two, of these three basic characteristics related to congestion. Values for the indicators and most other data needed to calculate congestion measures were extracted from the existing TTI data base. It did become necessary, however, to extract data necessary for calculation of $LMDI_F$ values from the HPMS data base (15).

Estimation of Level of Congestion

To examine the relationships between the various possible indicators and congestion levels, the relative congestion levels for each urban area had to be calculated. This was done by choosing several congestion measures currently in use. The congestion levels calculated from these measures were then compared to ensure similar results among the measures. The choice of several comparable measures also prevented bias toward any particular indicator. The congestion measures were chosen with consideration given to previous results, data availability, and ease of interpretation. Each of the three measures chosen for this study are described in the following paragraphs.

Roadway Congestion Index

The RCI was initially developed by Lomax and others at TTI to study mobility trends in major Texas cities. The RCI analysis was gradually expanded to include 50 urban areas throughout the United States. Urban areas in this analysis are consistent with the boundaries as defined by the Bureau of the Census. The major source of data for the calculation of the RCI comes from the HPMS data base. This data base is supplemented with information collected from local metropolitan planning organizations (MPOs), state departments of transportation (DOTs), cities, counties, and other local or regional agencies for each area.

In calculation of the RCI it is assumed that delay, and consequently congestion, begins to occur at LOS D, corresponding to a v/c ratio of 0.77 (2). This was determined to be equivalent to approximately 15,000 vehicles per lane per day on freeways, and 5,750 vehicles per lane per day on principal arterial streets. On an areawide basis where averages over many facilities may be misleading, it was determined that lower values were more appropriate. The values of 13,000 vehicles per lane per day for freeways and 5,000 vehicles per lane per day for principal arterial streets were used then on an area basis for the congestion threshold. In the RCI equation, DVMT per lane mile for freeways and principal arterial streets is weighted by the respective amount of DVMT for each urban area. The congestion levels are then normalized (using 13,000 for freeways and 5,000 for principal arterial streets) with an RCI greater than 1.0 representing undesirable areawide congestion. The RCI value for each urban area is calculated with the following equation:

$$RCI = \frac{[(\text{freeway DVMT}/\text{lane-mi}) \times \text{freeway DVMT}] + [(\text{prin. art. DVMT}/\text{lane-mi}) \times \text{prin. art. DVMT}]}{(13,000 \times \text{freeway DVMT}) + (5,000 \times \text{prin. art. DVMT})} \quad (1)$$

Congestion Severity Index

The congestion severity index (CSI) was originally developed by Lindley as a measure of freeway delay per million vehicle miles of travel (1). The measure was modified for this study to include principal arterial street delay, because it was thought that this functional class makes substantial contributions to areawide congestion levels. Delay for both freeways and principal arterial streets was calculated using procedures developed by Hanks and Lomax in the "Roadway Congestion" series (9-11). In combining the delay for the two different functional classes, it was believed that delay on freeways and principal arterial streets was roughly equivalent; consequently, the delay values were not weighted with respect to functional class. The CSI value for each urban area is calculated with the following equation:

$$CSI = \frac{\text{total freeway delay (veh-hr)}}{\text{freeway VMT (million)}} + \frac{\text{total prin. art. delay (veh-hr)}}{\text{prin. art. VMT (million)}} \quad (2)$$

Lane-Mile Duration Index

The lane-mile duration index, $LMDI_F$, was recently developed by Cottrell as a measure of recurring freeway congestion in urban areas. The analysis technique used the HPMS data base to calculate an AADT/C for urban area freeway segment. This AADT/C value was then related to a congested percentage of ADT by using traffic distribution patterns in the HPMS Technical Manual (13). The congestion duration is the product of the AADT/C value and the congested percentage of ADT. The $LMDI_F$ for each urban area, then, is the summation of the product of congested lane miles and congestion duration for all area freeway segments. Cottrell's methodology was used to calculate $LMDI_F$ values, and the following equation applied for each urban area (12):

$$LMDI_F = \sum_{i=1}^m [\text{congested lane-mi}_i \times \text{congestion duration}_i (\text{hr})] \quad (3)$$

where i is an individual freeway segment, and m is the total number of freeway segments in an urban area.

Choosing Possible Congestion Indicators

It has been generalized that congestion is related to three basic types of variables: travel, supply, and demographic characteristics (16). The indicators chosen for this study were composed of one, or a combination of two, of these three basic types of variables. The indicators were chosen with consideration given to data availability, intuitive relation to the causes of congestion, and logical results. With the exception of one, all indicators were extracted or calculated with data from the existing TTI congestion data base. The indicators that were examined in this study are as follows:

Travel characteristics: DVMT, transit trips, and passenger miles of travel.

Supply characteristics: lane miles and transit revenue miles.

Demographic characteristics: population size, population density, registered vehicles, registered vehicles per square mile, and registered vehicles per capita.

Travel-supply characteristics: DVMT per lane mile and AADT/C.

Travel-demographic characteristics: DVMT per square mile, DVMT per registered vehicle, DVMT per capita, transit trips per capita, and, passenger miles per capita.

Supply-demographic characteristics: lane miles per capita, lane miles per square mile, registered vehicles per lane mile, and revenue miles per capita.

The transit indicators were totals for bus and heavy, light, and commuter rail. The other indicators, with the exception of AADT/C, were calculated for both freeways and principal arterial streets.

Examination of Congestion Relationships

There were two basic steps in the examination of the congestion relationships. The first was a graphical comparison of all possible indicators to the three congestion measures. Each indicator for freeways, principal arterial streets, and the total of both was graphed against each congestion measure, with each urban area representing a datum point on a scatterplot. Each graph was then inspected for variability of data points and ease of constructing a best-fit line, whether it be linear or exponential. This graphical comparison gave a sense of the relationship between the indicator and the estimated congestion level.

The second step in examination of the congestion relationships was a limited regression analysis. This analysis determined the coefficient of determination, r^2 , a statistical measure that represents the proportion of variability that is accounted for in a relationship. In general, an r^2 -value of .5 or greater was interpreted as a close relationship. Although it may be argued that an r^2 value is not a statistically complete treatment, it was thought that the use of a graphical comparison combined with the r^2 -value provided enough information to infer whether some type of relation existed.

RESULTS

Estimation of Congestion Level

The congestion level was estimated using the three measures whose equations were presented in the methodology section of this paper. The measures were calculated for the 50 urban areas for 1989, the most recent year for which data were available. The HPMS data base composition prevented determination of $LMDI_F$ for 19 urban areas in California, Connecticut, Florida, Hawaii, Michigan, Ohio (Cleveland only), Oregon, and Washington. In the past, HPMS reporting procedures did not require states to report traffic data for each urban area individually; consequently, these states chose to submit traffic data with several urban areas grouped into one

data set. The use of several transportation agencies' data by TTI in the development of their congestion data base prevented similar deficiencies in calculation of the roadway congestion index and the congestion severity index. A summary of the measures and ranking for the 50 urban areas in this study for 1989 may be found in Table 1. It should be noted that the $LMDI_F$ values in Table 1 do not correspond exactly to the $LMDI_F$ values as reported by Cottrell (12). Although a significant effort was made, this study was not able to replicate Cottrell's results.

An important criterion for the measures used to estimate congestion level was comparability of results. On comparing the measures, it was discovered that the roadway congestion index and the congestion severity index were closely related, with an r^2 -value of .72. Both measures include freeways and principal arterial streets, but the roadway congestion index uses a travel-to-supply ratio and the congestion severity index uses a delay-to-travel ratio. In a graphical comparison (Figure 2), an RCI value of 1.0 was related to a CSI value of 24,000 (vehicle hours per million vehicle miles of travel) by means of a calculated regression line. The relationship between these two measures and the lane-mile duration index was less distinguished but nonetheless comparable (r^2 -values of .60 and .45 for the CSI and the RCI, respectively).

Examination of Congestion Relationships

As described earlier, there were two steps in examination of the congestion relationships: a graphical comparison and determination of r^2 . The results of these two steps will be presented for the relationships with the highest correlation.

The indicator of DVMT per lane mile, a travel-to-supply ratio, was found to have the highest correlation among all indicators. Because the roadway congestion index uses DVMT per lane mile in a weighted, normalized equation, it was excluded from this comparison. Also, because of the difficulty of combining this indicator for freeways and principal arterial streets without replicating the roadway congestion index, it was analyzed separately for the two different functional classes. A plot of freeway DVMT per lane mile versus congestion level is presented in Figure 3. The r^2 -values for this relationship were .68 for the CSI and .45 for the LMDI. The relationship between arterial DVMT per lane mile and the three congestion measures was less pronounced, with r^2 -values between .35 and .45.

The indicator with the next highest correlation to congestion level was DVMT per square mile of urban area. Travel (DVMT) was combined for both freeways and principal arterial streets in this examination. It was found that the roadway congestion index and the congestion severity index were most closely related to this indicator (Figure 4). The r^2 -values for this relationship were .48 for the RCI but only .27 for the CSI. It was noted throughout the examination that r^2 -values were consistently higher for RCI-indicator relationships than for CSI- or LMDI-indicator relationships.

The third indicator that had a significant relationship to congestion level was AADT/C. Because AADT/C is a facility measure, each HPMS freeway segment in an urban area was classified into a congestion range corresponding to the AADT/C value. In previous research Cottrell assumed that conges-

TABLE 1 Summary of Congestion Measures for 50 Urban Areas, 1989 (11)

Urban Area	Roadway		Congestion		Lane-Mile	
	Congestion Index		Severity Index		Duration Index	
	Value	Rank	Value	Rank	Value	Rank ^a
Los Angeles CA	1.54	1	39,938	8	- ^b	-
San Fran-Oak CA	1.36	2	46,817	3	-	-
Washington DC	1.36	2	52,882	1	2773	3
Miami FL	1.25	4	42,930	5	-	-
Chicago IL	1.21	5	34,015	13	1820	4
Seattle-Everett WA	1.21	5	38,215	9	-	-
San Diego CA	1.18	7	16,472	35	-	-
Atlanta GA	1.14	8	30,044	17	1813	5
Houston TX	1.13	9	37,612	10	3392	2
New Orleans LA	1.13	9	33,616	14	95	21
New York NY	1.12	11	48,924	2	4381	1
San Jose CA	1.12	11	43,494	4	-	-
Boston MA	1.09	13	40,551	6	999	6
Honolulu HI	1.09	13	34,885	12	-	-
San Bernardino-Riv CA	1.09	13	40,197	7	-	-
Detroit MI	1.08	16	35,923	11	-	-
Norfolk VA	1.08	16	32,788	15	469	9
Portland OR	1.07	18	29,406	18	-	-
Philadelphia PA	1.05	19	28,011	22	347	13
Phoenix AZ	1.03	20	28,482	19	446	10
Tampa FL	1.03	20	22,472	27	-	-
Charlotte NC	1.02	22	28,151	21	-	-
Dallas TX	1.02	22	28,234	20	887	7 ^c
Denver CO	1.01	24	23,546	26	212	15
Sacramento CA	1.01	24	22,107	28	-	-
Baltimore MD	0.99	26	20,442	31	545	8
Orlando FL	0.98	27	32,731	16	-	-
Jacksonville FL	0.97	28	19,538	33	-	-
Milwaukee WI	0.97	28	14,694	38	125	19
Austin TX	0.96	30	23,632	25	435	11
St. Louis MO	0.96	30	20,298	32	2	28
Cleveland OH	0.95	32	10,642	43	-	-
Nashville TN	0.95	32	16,669	34	31	23
Cincinnati OH	0.94	34	11,242	41	2	28
Albuquerque NM	0.91	35	12,565	40	135	18
Memphis TN	0.91	35	8,714	46	2	28
Minn-St. Paul MN	0.90	37	20,710	30	393	12
Ft. Lauderdale FL	0.89	38	23,679	24	-	-
Hartford CT	0.89	38	14,600	39	-	-
San Antonio TX	0.89	38	16,181	37	259	14
Fort Worth TX	0.87	41	22,037	29	-	-
Louisville KY	0.86	42	10,768	42	86	22
Indianapolis IN	0.85	43	5,267	48	29	24
Columbus OH	0.82	44	16,237	36	96	20
Pittsburgh PA	0.82	44	25,235	23	142	17
Salt Lake City UT	0.81	46	9,624	45	29	24
Oklahoma City OK	0.78	47	9,921	44	15	26
El Paso TX	0.74	48	5,241	49	12	27
Kansas City MO	0.72	49	7,494	47	159	16
Corpus Christi TX	0.70	50	3,497	50	0	31

^a LMDI_F rank is provided to compare relative positions of urban areas within the LMDI_F analysis. LMDI_F rank should not be compared to RCI or CSI rank.

^b Missing values in this column are due to "grouped" data in HPMS data base.

^c In the LMDI_F analysis, Dallas and Fort Worth are combined as one metropolitan area.

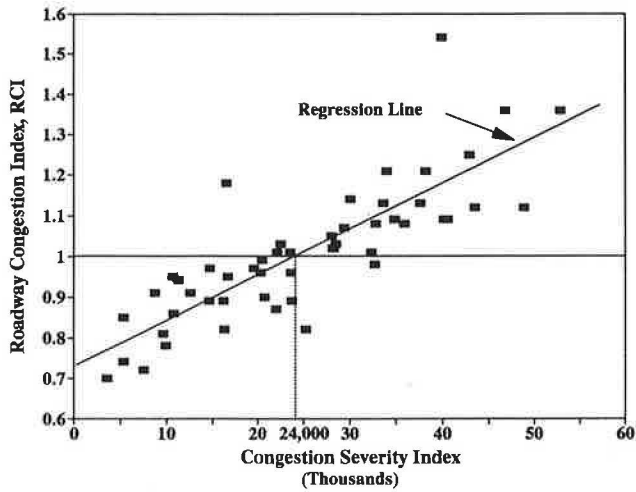


FIGURE 2 Correlation of roadway congestion index and congestion severity index.

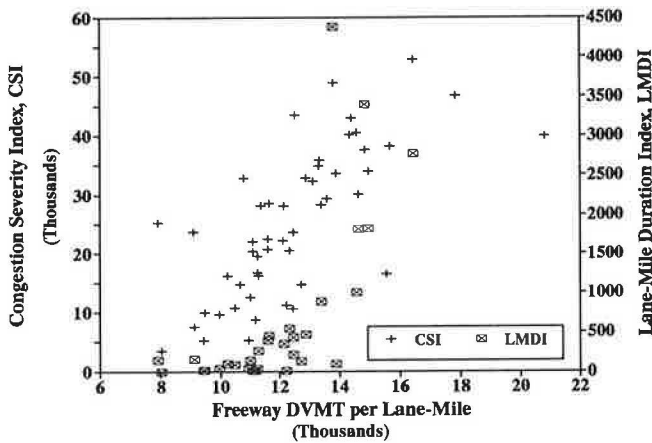


FIGURE 3 DVMT per lane mile versus congestion level.

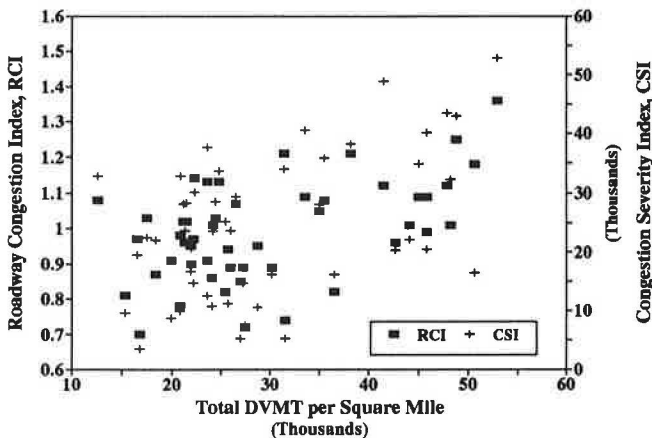


FIGURE 4 DVMT per square mile versus congestion level.

tion occurred on a facility when the AADT/C value was greater than 9 (12). It was beyond the scope of this study to determine the accuracy of this value; consequently, for the purposes of this study, an AADT/C value greater than 9 represented congested conditions. The lane miles for all HPMS freeway segments were totaled in the following AADT/C ranges: less than 9, 9 to 11, 11 to 13, 13 to 15, 15 to 17, and greater than 17. Very few urban areas had freeway segments with an AADT/C value higher than 17.

To make a comparison of this indicator to a congestion measure, 31 of the 50 urban areas were grouped according to the RCI value; areas with "grouped" data were excluded. The RCI congestion ranges were 0.70 to 0.85, 0.85 to 0.95, 0.95 to 1.05, 1.05 to 1.20, and greater than 1.20. The comparison is illustrated in Figure 5. It can be seen that, as the percentage of freeway lane miles in higher AADT/C ranges increases, the RCI congestion range also increases. For example, the percentage of lane miles with AADT/C less than 9 (no congestion) is much less in the RCI range of greater than 1.20 (heavy areawide congestion) than in the 0.70 to 0.85 range (none to low areawide congestion). The implication of Figure 5 is that, as the distribution of freeway lane miles shifts toward a higher AADT/C value, the congestion level increases. Because of the nature of this comparison, an r^2 -value was not available. The congestion severity index and the lane-mile duration index were not included in this comparison because of the lack of a definition of congestion ranges.

The average AADT/C values for each RCI congestion range are displayed at the bottom of each bar for the respective range. This value was determined by weighting the percentage of lane miles for each AADT/C range by the corresponding average AADT/C value for that AADT/C range. The average AADT/C value at the beginning of areawide congestion (RCI range of 0.95 to 1.05) is 7.1. The initial premise of this particular examination was that congestion on a facility begins at an AADT/C value of 9. The discrepancy in these two numbers—7.1 and 9—may be partly attributed to the translation of AADT/C from a facility measure to an areawide average value.

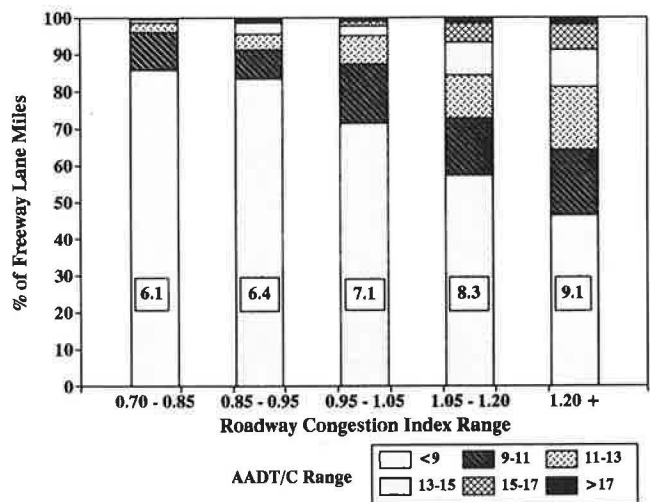


FIGURE 5 Share of freeway lane miles by AADT/C and RCI range.

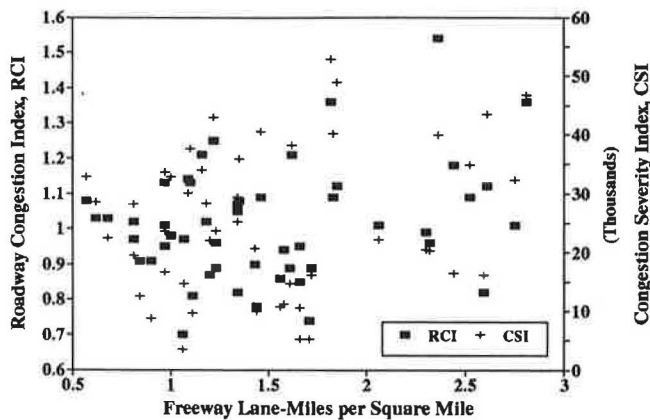


FIGURE 6 Freeway density versus congestion level.

Several indicators had a moderate correlation (r^2 -values between .35 and .45) to congestion level. Those indicators are registered vehicles, DVMT, and population density. Most of the transit indicators fared poorly, having r^2 -values below .1. Surprisingly, many supply-related indicators had low correlations to the level of congestion. For instance, freeway lane miles per square mile (freeway density) is shown in Figure 6. Freeway density is an indicator used often by automobile clubs and other groups lobbying for construction of new freeway facilities because of congestion. Figure 6 shows that freeway density has a low correlation to congestion level, indicating that there may be other variables that more strongly affect congestion level.

CONCLUSIONS

This report examined the relationships between possible indicators and congestion level as estimated by three congestion measures. The examination included 50 large and medium-sized U.S. urban areas for 1989. The study gathered data from the TTI congestion data base and the HPMS data base.

Indicators of Congestion

This study identified three indicators with a close correlation to congestion level: DVMT per lane mile, DVMT per square mile, and AADT/C for freeways. The indicator of DVMT per lane mile showed the strongest correlation with r^2 -values of .68 and .45 for the congestion severity index and the lane-mile duration index, respectively. The indicator of DVMT per square mile had the next highest correlation, with an r^2 -value of .48 for the roadway congestion index. It was shown that freeway AADT/C had a clear relationship to the roadway congestion index, although an r^2 -value was unobtainable for the type of comparison made.

Several indicators related to roadway supply had low correlations (r^2 -values less than .2) to estimated congestion levels. In particular, Figure 6 shows that freeway lane miles per square mile has a low correlation to congestion. The other supply indicators that have a similarly low correlation to congestion include lane miles and lane miles per square mile. It can be concluded safely that, since supply has a low cor-

relation to congestion level, an indicator relying solely on supply characteristics would serve as a poor indicator for area-wide congestion levels.

It should be noted that the three indicators with the strongest correlation to congestion level are gauges of the travel intensity for a particular urban area. It is concluded that travel intensity is most directly related to congestion level and would be the most useful type of indicator for areawide congestion measurement purposes. This is not to deny, however, the importance of the effects of roadway supply or demographic factors within an urban area on congestion level.

Congestion Measures

Three congestion measures were used to estimate the congestion level for the urban areas in this study. Two of the measures, the roadway congestion index (using the indicator of DVMT per lane mile) and the congestion severity index (using vehicle delay per million vehicle miles of travel), were found to be very comparable in the results they produced. A regression analysis was used to calculate a best-fit line (Figure 2) through the linearly related data ($r^2 = 0.72$). Because the roadway congestion index is normalized, an RCI value greater than 1.0 represents the threshold for undesirable areawide congestion. The analysis indicated that this congestion threshold was reasonable; consequently, an RCI value of 1.0 was related to an approximate CSI value of 24,000 using the calculated regression line. It is suggested, then, that a CSI value greater than 24,000 represents undesirable area congestion.

Ideally, congestion measures should provide an accurate representation of congestion levels for a transportation system. Freeways and principal arterial streets are major providers of mobility in urban areas and were included in two of the three measures in this study. Limited data in the HPMS data base and lack of a sound analytical procedure prevented the inclusion of principal arterial streets in the lane-mile duration index (12). An illustration of the importance of principal arterial streets is presented in Table 2, in which delay is compared between these two different functional classes.

It can be seen that, for several urban areas, delay (undesirable congestion level) occurs primarily on the freeway sys-

TABLE 2 Delay by Functional Classification for 10 Selected Urban Areas, 1989 (11)

Urban Area	Delay (1000 vehicle-hours)	
	Freeways	Principal Arterial Streets
Atlanta GA	133,113 (71 %)	53,928 (29 %)
Chicago IL	246,637 (63 %)	147,008 (37 %)
Detroit MI	165,885 (57 %)	125,612 (43 %)
Houston TX	276,488 (88 %)	38,741 (12 %)
Los Angeles CA	1,119,387 (77 %)	325,949 (23 %)
New York NY	884,915 (72 %)	351,790 (28 %)
Oklahoma City OK	6,116 (38 %)	9,771 (62 %)
Philadelphia PA	66,317 (32 %)	139,422 (68 %)
Phoenix AZ	32,843 (26 %)	95,501 (74 %)
Tampa FL	10,998 (34 %)	20,882 (66 %)

tem. For several areas, however, equal or greater delay occurs on principal arterial streets. This illustrates the importance of principal arterial streets in determination of areawide congestion level.

Further Research

The congestion measures examined in this study attempted to quantify congestion on an areawide basis. For a particular urban area, however, these measures may be somewhat inadequate to quantify the congestion along a particular corridor or route. The increasing use of high-occupancy vehicle (HOV) facilities along highway corridors, in addition to the rapidly developing technologies of intelligent vehicle-highway systems, necessitates the development of congestion measures that accurately reflect travel (car, HOV, bus, and rail) conditions for a particular corridor or urban area.

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