Urban Freeway Congestion: Quantification of the Problem and Effectiveness of Potential Solutions

by Jeffrey A. Lindley

Urban congestion is a serious and worsening national problem, one which is receiving increasing attention from transportation engineers, planners, and researchers, as well as other local, state, and national officials. Urban freeways, which carry nearly 30% of all traffic in urban areas, are particularly affected by growing urban congestion. In 1983, about 55% of urban freeway travel during the peak hour occurred under congested conditions, according to a U.S. Department of Transportation report.[1] This figure is up from 41% in 1975, and it is expected to increase even further as urban freeway volumes continue to increase.

One of the difficulties in examining the problem of urban traffic congestion and its potential solutions is that no detailed quantification of either the size of the problem or its projected future growth has been available. As a result, the relative effectiveness of various types of solutions to the problem cannot be described.

The Traffic Systems Division of the Federal Highway Administration's Office of Research, Development, and Technology has focused on urban traffic congestion as not only an immediate problem, but also the most serious long-term traffic research problem facing the United States. This paper is a result of a major staff research study of traffic congestion on urban freeways. A first-order priority of the study was to undertake an analysis of the problem.

The Highway Performance Monitoring System (HPMS) was chosen as the basic source of data for this study. The HPMS data base is maintained and updated annually by the Federal Highway Administration and consists of detailed geometric, traffic, and other data for a representative sample of roadway sections throughout the United States. The urban freeway sections of the HPMS data base are based on a sampling of approximately 50% and can be used to represent the total highway system through the use of state-supplied expansion factors.

The data used in this study were for 1984 and were limited to freeways in urban areas with populations greater than 50,000. This data set consisted of 8,036 sample sections representing 15,335 miles of urban freeway.

The 1984 data were entered into a microcomputer for computation of travel and congestion statistics; predictions of future urban freeway congestion statistics were calculated using state-supplied estimates of annual average daily traffic for each sample section in 2005 [see "Methodology" sidebar].

A Growing Problem

Urban freeway congestion annually consists of over 1.2 billion vehicle-hours of delay, over 1.3 billion gallons of wasted fuel, and over $9 billion in user costs per year. These figures are predicted to grow to near 6.9 billion vehicle-hours of delay, 7.3 billion gallons of wasted fuel, and over $50 billion (a more than 400% increase) by 2005. Urban freeway travel is expected to grow by nearly 49% (about 1.9% per year) during this time period. (See Table 1.)

Almost 12% of all freeway travel in urban areas occurs under recurring congested conditions. This level is predicted to rise to almost 24% by 2005. Incident delay currently comprises about 61% of all urban freeway delay, a figure that may increase to approximately 70% by 2005.

The results of our analysis were broken out for the 37 urban areas with populations greater than 1 million persons (see Table 2). With a few exceptions, such as Indianapolis, where it is unreasonable to expect there is absolutely no recurring freeway congestion, the individual urban area results for 1984 appear to be very reliable, particularly on a comparative basis. Approximately 91% of all urban freeway delay currently occurs in the 37 urban areas listed. By 2005, all of these major urban areas will experience significant increases in freeway congestion.

The study results were also tabulated in terms of a congestion severity index, namely, total delay per million vehicle miles of travel (Table 3). This was done to eliminate the effects of varying urban area populations, freeway system sizes, and travel amounts in determining the urban areas where freeway congestion is currently at its worst. The 1984 ranking of urban areas, particularly near the top, appears consistent with media reports of known urban freeway congestion problem areas. As indicated in this table, if no improvements are made, freeway congestion in rapidly growing sunbelt cities, such as Charlotte, San Antonio, and Miami, will become more severe than in the larger cities, such as New York, Los Angeles, and Chicago, by 2005. Congestion in the 37 urban areas with current populations greater than 1 million persons will decline to approximately 84% of all urban freeway delay as congestion in smaller urban areas increases.

Analysis of Remedial Measures

Effectiveness Analysis

A second objective of the study was to evaluate the potential effectiveness of several types of remedial measures for dealing with urban freeway congestion. Three measures were evaluated: widening the road, implementating surveillance and control systems, and making low-cost modifications to increase capacity (e.g., using the shoulder as a travel lane). These three measures were chosen because they are typically among the most effective in reducing urban freeway congestion and because they could be directly analyzed using data in the HPMS system.

Widening was defined as adding one lane in each direction to a congested freeway, including all necessary geometric and structural changes at ramps, interchanges, bridges, etc. This improvement can be accurately analyzed using data in the HPMS system, because widening feasibility is a coded data item. For each urban freeway section, an assessment of the feasibility of adding lanes to the section was made based strictly on the presence of physical obstructions, severe terrain, buildings, cemeteries, and park land. State practices concerning widening, existing right-of-way width, projected traffic, and political concerns were not considered.[8]

Implementation of a surveillance and control system consists of installing a comprehensive system for the congested segments of a freeway. Such a system was assumed to contain mainline and ramp surveillance through loop detectors, a traffic responsive ramp metering system, and an incident management program. The effects of such systems have been well documented; for this study, their benefits were quantified as a 20% improvement in average travel time on congested segments of the freeway and a 10-minute average reduction in incident duration.[9]

Methodology

To facilitate analysis of the Highway Performance Monitoring System (HPMS) data, a FORTRAN IV microcomputer program was written to calculate travel and congestion statistics.

To permit an hour-by-hour analysis of congestion, each HPMS freeway sample section was first assigned a 24-hour volume profile based on coded peak hour and directional data. These profiles are based on traffic counts performed in 1983 and 1984 for I-66 and I-395 near Washington, D.C.

Next, for each freeway section, total vehicle-miles of travel and a volume/cpacity (V/C) ratio were calculated for each hour of a typical day. A V/C ratio of 0.77 was used to define when congested flow began. This is the boundary between levels of service C and D for 70-mph design speed facilities in the 1985 *Highway Capacity Manual*.[2]

To calculate delay because of recurring congestion, Figure 3-4 of the 1985 *Highway Capacity Manual* was used to estimate average travel speed based on V/C ratio. For 70-mph design speed facilities, average travel speed varies from 30 to 54 mph for V/C ratios between 0.77 and 1.00. Uncongested average travel speed was assumed to be 55 mph, and level of service F (V/C > 1.00) average travel speed was assumed to be 20 mph. Delay was calculated by comparing travel time for congested travel to travel under uncongested conditions.

Delay because of incidents was calculated by assuming incident rates of 200 incidents per million vehicle miles (MVM) for facilities with shoulders and 79 incidents per MVM for facilities with no shoulders.[3] The basic strategy was to calculate average incident occurrence based on the incident "trees" contained in the literature and traffic volumes and then calculate the impacts of each incident on traffic flow. When incidents occur, recurring delay is subtracted from any incident delay to prevent "double counting."

Excess fuel consumption for both recurring congestion conditions and incident conditions was calculated based on a linear extension of the relationship between fuel consumption and average travel speed reported by Raus in 1981.[4]

In addition to performing an overall calculation of urban freeway congestion parameters, individual calculations were performed for the 37 urban areas with populations greater than 1 million persons.[5] Estimates of future urban freeway congestion statistics were calculated based on state-supplied 2005 annual average daily traffic (AADT) estimates for each sample section. These estimates assume no improvements to the existing urban freeway system and no changes in the current peaking characteristics of traffic. They are, however, useful for trend analysis purposes.

To monetarily quantify the impacts of urban freeway congestion, a value of user travel time was calculated using the 1977 American Association of State Highway and Transportation Officials "Red Book" for a 5- to 15-minute delay per trip.[6] The value shown in the Red Book—$2.40—was updated to October 1985 using the Consumer Price Index and assuming an average vehicle occupancy of 1.25 persons.[7] This calculation yielded an average value of travel time of $6.25 per vehicle hour. The cost of fuel was assumed to be $1.00 per gallon.

A low-cost modification improvement generally consists of using one of the shoulders as a travel lane or reducing existing lane widths to provide an additional lane. Such projects are typically performed where physical widening is not possible or as a temporary measure until a more extensive widening project can be funded. Evaluation studies of this type of project indicate this type of improvement results in increases in capacity approaching those associated with full-scale widening projects, with little or

Table 1. Urban Freeway Congestion Statistics

	1984	*2005*
Freeway miles	15,335	15,335
Vehicle-miles of travel (millions)	276,645	410,987
Recurring congested vehicle-miles of travel (millions)	31,486	98,280
Recurring delay (million vehicle-hours)	485.0	2,048.6
Delay due to incidents (million vehicle-hours)	766.8	4,857.5
Total delay (million vehicle-hours)	1,251.8	6,906.1
Total excess fuel consumption (million gallons)	1,377.5	7,317.1
Total user cost (billion dollars)	9.2	50.5

Table 2. Urban Area Freeway Congestion Statistics, 1984 and 2005

Urban Area	*Freeway Miles*		*Annual Vehicle-Miles (Millions)*		*Annual Recurring Congested Vehicle-Miles (Millions)*		*Annual Recurring Vehicle-Hours Delay (Millions)*		*Annual Incident Vehicle-Hours Delay (Millions)*		*Total Annual Excess Fuel (Million Gallons)*	
	1984	*2005*	*1984*	*2005*	*1984*	*2005*	*1984*	*2005*	*1984*	*2005*	*1984*	*2005*
New York	1,141	1,141	26,740	32,567	3,660	6,658	62.7	117.5	155.7	282.5	231.4	430.2
Los Angeles	647	647	27,131	33,768	5,370	9,406	78.3	180.8	94.7	229.1	191.3	438.1
Chicago	397	397	9,843	11,850	1,155	2,384	19.7	47.4	24.6	79.4	48.4	135.3
Philadelphia	362	362	6,238	9,573	428	1,727	4.9	35.1	10.2	73.8	17.4	115.9
San Francisco	602	602	22,071	29,791	4,262	9,638	72.9	208.5	95.6	349.6	182.1	589.6
Detroit	298	298	6,665	12,049	885	3,735	16.2	89.3	35.5	421.5	55.3	533.3
Boston	342	342	8,090	11,207	983	2,971	10.0	57.3	34.8	180.7	52.5	253.4
Houston	245	245	8,576	17,455	2,103	9,708	39.5	252.1	55.8	704.6	102.4	994.5
Washington	263	263	6,543	8,562	694	2,290	8.5	41.6	18.9	88.2	31.2	138.4
Dallas	418	418	9,763	20,223	1,039	7,637	16.3	169.0	28.9	578.0	49.6	791.1
Miami	195	195	4,599	8,158	203	3,182	0.3	69.2	2.5	163.7	5.1	247.4
Cleveland	332	332	5,046	6,635	348	824	6.1	15.6	4.3	11.6	11.2	28.8
St. Louis	248	248	5,086	7,148	413	1,182	3.8	19.3	4.4	16.0	9.8	38.7
Atlanta	249	249	6,456	9,130	743	1,915	15.8	45.5	16.7	56.8	34.6	107.6
Pittsburgh	207	207	2,301	2,927	154	324	1.9	6.5	5.5	14.7	8.4	22.6
Baltimore	195	195	3,974	6,105	285	1,837	2.9	33.1	6.8	58.7	11.3	98.4
Minneapolis	268	268	4,486	6,643	531	1,457	11.2	27.7	9.8	35.6	22.2	68.0
Seattle	230	230	5,874	9,937	925	3,187	18.5	76.3	25.0	197.2	46.8	286.2
San Diego	157	157	4,853	6,831	561	1,282	8.6	23.9	5.1	16.8	15.0	43.8
Tampa	37	37	870	1,289	40	277	0.1	4.1	0.4	11.2	1.1	17.0
Denver	179	179	3,390	4,650	456	942	7.5	19.2	7.6	26.5	16.4	48.3
Phoenix	43	43	1,013	1,612	69	372	0.2	6.8	0.8	13.7	1.4	22.2
Cincinnati	165	165	3,012	4,146	285	580	4.3	13.9	3.5	11.9	8.7	26.9
Milwaukee	107	107	2,146	2,848	177	491	1.9	8.5	1.8	7.6	4.3	17.2
Kansas City	277	277	3,324	4,417	172	492	1.9	7.2	5.9	11.8	9.1	21.0
Portland	136	136	2,418	3,521	116	569	0.5	8.8	3.6	24.2	6.0	35.9
New Orleans	60	60	1,702	2,073	340	616	7.7	12.6	10.3	44.7	19.1	61.1
Columbus	133	133	2,239	2,945	154	315	2.5	6.9	2.2	6.8	5.3	14.5
Norfolk	135	135	1,998	3,100	740	556	5.0	10.3	4.0	18.4	9.4	31.1
Sacramento	130	130	3,717	6,047	439	1,271	4.2	30.5	2.5	18.1	7.9	50.9
Buffalo	144	144	1,559	2,134	20	207	0.2	2.3	0.7	6.2	1.0	9.7
Indianapolis	139	139	2,237	3,924	0	572	0	7.9	0.2	12.3	0.2	23.1
San Antonio	150	150	2,768	5,662	391	2,189	5.2	56.7	5.7	157.5	12.6	223.4
Providence	150	150	1,667	2,331	86	238	0.5	4.0	0.6	2.1	1.5	6.7
Charlotte	37	37	665	1,830	71	993	1.3	23.3	2.2	116.5	3.9	146.8
Hartford	123	123	2,165	2,499	207	294	1.9	5.2	7.0	12.4	10.7	19.1
Salt Lake City	99	99	1,501	2,771	101	495	2.0	10.7	1.2	5.4	3.4	17.0
	9,040	9,040	212,726	308,358	28,606	82,813	445.0	1,754.6	695.0	4,065.8	1,248.0	6,153.2

no increase in accidents.[10] Low-cost improvements were considered for all congested freeway sections in the study if the paved right-of-way could be modified so one additional lane could be provided in each direction while retaining at least 11-foot lanes and an 8-foot shoulder on one side of the roadway.

Cost Analysis

Costs for each improvement type were calculated. The calculated unit costs and assumed useful life for each improvement type are given in Table 4. These costs are based on those for recent similar projects, updated for inflation.[9,11–13] Costs for each improvement type were analyzed and converted to annual costs using an investment interest rate of 10%. Annual cost benefits of improvements were quantified by using the figures of $6.25 per vehicle-hour for user travel time and $1.00 per gallon for gasoline [see Methodology sidebar]. The three types of improvements were considered for all congested freeway sections, but only those improvements whose total annual benefits exceeded total annual costs were considered implementable.

Widespread implementation of low-cost geometric improvements will result in the greatest total benefits for users of the urban freeway system (see Table 5); more than $4.6 billion could be saved annually. In comparison, widespread implementation of widening and surveillance and control projects would result in approximately $3.1 and $3.0 billion in savings per year, respectively.

Combined Improvement Analysis

The improvement in 1984 congestion levels attainable from a combination of the three improvement types was also calculated. To perform this calculation, surveillance and control projects were allowed to be implemented on the same freeway section as were widening or low-cost geometric improvement projects, if cost effective. Widening or low-cost geometric improvements projects were selected for each freeway section based on relative cost effectiveness. Thus, for the combined improvement analysis, a congested freeway section could have no improvements, a single type of improvement, or a combination of improvements. The results of this analysis are shown in Table 6. As one would expect, combining improvement types results in annual monetary savings to freeway users that are greater than any of the three individual improvement types. However, the savings/cost ratio is lower than for surveillance and control or low-cost geometric improvement projects.

Table 3. Congestion Severity Index, 1984 and 2005

	Index		*Ranking*	
Urban Area	*1984*	*2005*	*1984*	*2005*
Houston	11,112	54,810	1	2
New Orleans	10,576	27,641	2	7
New York	8,168	12,282	3	14
Detroit	7,757	42,394	4	3
San Francisco	7,634	18,734	5	10
Seattle	7,406	27,523	6	8
Los Angeles	6,376	12,139	7	15
Boston	5,538	21,237	8	9
Charlotte	5,263	76,393	9	1
Atlanta	5,034	11,205	10	18
Minneapolis	4,704	9,529	11	21
Dallas	4,630	36,938	12	5
Norfolk	4,505	9,258	13	23
Chicago	4,501	10,700	14	19
Denver	4,454	9,828	15	20
Washington	4,188	15,160	16	11
Hartford	4,111	7,043	17	26
San Antonio	3,938	37,831	18	4
Pittsburgh	3,216	7,243	19	25
San Diego	2,823	5,958	20	28
Cincinnati	2,590	6,223	21	27
Baltimore	2,441	15,037	22	12
Philadelphia	2,421	11,376	23	17
Kansas City	2,347	4,302	24	34
Salt Lake City	2,132	5,811	25	29
Columbus	2,099	4,652	26	33
Cleveland	2,061	4,099	27	35
Sacramento	1,803	8,037	28	24
Milwaukee	1,724	5,653	29	30
Portland	1,696	9,372	30	22
St. Louis	1,612	4,938	31	32
Phoenix	987	12,717	32	13
Providence	660	2,617	33	37
Miami	609	28,549	34	6
Buffalo	577	3,983	35	36
Tampa	575	11,870	36	16
Indianapolis	89	5,148	37	31

Congestion severity index = Total delay/million vehicle-miles of travel.

Table 4. Estimated Project Costs

	Type of Improvement		
Item	*Widening*	*Surveillance and Control*	*Low Cost Modification*
Construction and engineering	$5,000,000/mile	$1,000,000/mile	$1,300,000/mile
Maintenance	$ 12,000/year	$ 100,000/year	$ 12,000/year
Resurfacing (@ 10 years)	$ 300,000/mile	N/A	$ 300,000/mile
Useful life	20 years	10 years	20 years

Implications

The results of the analyses in Tables 5 and 6 contain some interesting implications. The first of these concerns the use of widening as a means of alleviating urban freeway congestion. The analysis results indicate widening is cost effective for only about half the total freeway mileage for which surveillance and control projects or low-cost geometric improvements would be cost effective. In terms of monetary benefits, widening is about as effective as surveillance and control projects and considerably less effective than low-cost geometric improvements. Widening has the lowest savings/cost ratio of the three improvement types analyzed. These results are likely due to the high capital cost of widening projects and the fact that, for many of the most congested freeways in the nation, widening is not a feasible alternative.

A second implication of Tables 5 and 6 concerns the impact of the three improvement alternatives on the total problem. Based on the figures in Table 1, the 1984 urban freeway congestion problem "costs" approximately $9.2 billion per year. The most effective of the improvement alternatives analyzed—low-cost geometric improvements—eliminates only about half the problem. Implementing a combination of improvements eliminates about two-thirds of the problem. Thus, considering only these three improvement categories alone and in combination, a large portion of the urban freeway congestion problem is economically untreatable.

A final implication of Tables 5 and 6 concerns the level of funding required to achieve significant improvements in urban freeway congestion. For example, for the combined improvement scenario, under which 1984 urban freeway congestion is reduced by about 70%, an initial capital investment of over $10 billion would be required. This required investment level is much greater than the current annual level of capital outlay for urban freeway projects.[14] Also, this figure includes only improvements necessary to treat 1984 congestion levels. As previously noted, urban freeway congestion is expected to grow quickly in the next 20 years and additional investment in improvements will be required.

The three improvement alternatives all involve improving the "supply" of transportation facilities by increasing capacity or vehicle throughput characteristics. Another potential category of improvements involves reducing the "demand" on the facility. Typically, this involves establishing incentives for ride-sharing or using mass transit.

To analyze the potential impact of demand reduction, the analysis program was revised to simulate the effect of one driver of every five single-occupant vehicles being removed from the peak period traffic stream by forming a carpool or using mass transit. In a typical urban area, this would result in approximately an 18% reduction in peak period traffic. The results of this analysis are shown in Table 7.

Comparing the figures shown in Table 7 to those in Table 1 indicates that, under the reduced demand condition, the total reduction in 1984 urban freeway travel would be about 17%. Recurring congested travel would be reduced by 55%, recurring delay by 67%, and incident delay by 63%. The total annual cost of urban freeway congestion would be reduced from $9.2 billion to $3.3 billion (64%).

Comparison of these figures to those

Table 5. Effectiveness of Improvement Types (1984)

	Type of Improvement		
	Widening	*Surveillance and Control*	*Low-Cost Geometric Improvements*
Improvable miles	1,400	2,625	2,887
Recurring delay reduction (million vehicle-hours)	145.0 (30%)	137.0 (28%)	239.3 (49%)
Non-Recurring delay reduction (million vehicle-hours)	298.7 (39%)	286.0 (37%)	412.6 (54%)
Total excess fuel reduction (million gallons)	407.1 (30%)	308.6 (22%)	607.7 (44%)
Total annual savings (dollars)	3,180,000,000	2,951,000,000	4,682,000,000
Total annual costs (dollars)	941,000,000	699,000,000	641,000,000
Savings/cost ratio	3.4	4.2	7.3

Table 6. Effects of Combined Improvements (1984)

Improvable miles	3,074
Recurring delay reduction (million vehicle-hours)	336.2 (69%)
Non-Recurring delay reduction (million vehicle-hours)	565.6 (74%)
Total excess fuel reduction (million gallons)	843.4 (61%)
Total annual savings (dollars)	6,479,000,000
Total annual costs (dollars)	1,821,000,000
Savings/cost ratio	3.6

Table 7. 1984 Urban Freeway Congestion Statistics with Demand Reduction

Freeway miles	15,335
Vehicle-miles of travel (millions)	230,018
Recurring congested vehicle-miles (millions)	14,145
Recurring delay (million vehicle-hours)	161.6
Excess fuel consumption due to recurring delay (million gallons)	186.6
Delay due to incidents (million vehicle-hours)	284.6
Excess fuel consumption due to incidents (million gallons)	328.8
Total delay (million vehicle-hours)	446.2
Total excess fuel consumption (million gallons)	515.4

in Tables 5 and 6 indicates reducing demand by an average of 18% during the peak period would be more effective in eliminating urban freeway congestion than any of the three supply improvement alternatives analyzed and slightly less effective than the combined implementation of all three improvement alternatives.

Conclusion

Because calculating the cost of reducing demand by this extent is difficult, the actual impact of a widespread implementation of demand reduction strategies is unknown. However, this brief analysis indicates demand reduction strategies should be seriously considered when seeking solutions to urban freeway congestion problems.

This study clearly indicates the scope and magnitude of existing and predicted urban freeway congestion in the United States. It also provides a first cut at estimating the cost and congestion reduction potential of various options generally available. The study results emphasize that more attention must be given to the urban freeway congestion problem if it is to be overcome or even held at present levels. New and innovative improvements must be developed to address the portion of the problem that is currently difficult to treat in a cost-effective manner, and existing solutions must be pursued vigorously.

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To request a copy of the full report of this study, "Quantification of Urban Freeway Congestion and Analysis of Remedial Measures," contact Jeffrey A. Lindley, Research Highway Engineer, U.S. DOT-FHWA, Office of Research, HSR-10, 6300 Georgetown Pike, McLean, Virginia 22101.