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Traffic Control in Oversaturated Street Networks

An NCHRP staff digest of the essential findings from the final report of NCHRP Project 3-18(2), "Traffic Control in Oversaturated Street Networks," by Louis J. Pignataro, Kenneth W. Crowley, Bumjung Lee, Edmund J. Cantilli and Douglas R. Campion, Department of Transportation Planning and Engineering, Polytechnic Institute of New York.

THE PROBLEM AND ITS SOLUTION

Many communities now experience severe traffic congestion on the street systems of central business districts or other high-activity centers. Their development trends, typically toward increasing land-use density in such areas, may lead to worsened conditions in the future. Thus, the application of traffic engineering techniques becomes increasingly important. Unfortunately, the operations and control techniques that function effectively with lesser traffic volumes deteriorate when saturation exists for any length of time. Defining the scope and magnitude of this oversaturation problem, determining how it may best be combatted with existing methods, and beginning a research process leading to improved operation and controls for oversaturated networks, were established as the purposes of this research.

Six specific objectives were listed:

1. Define the measures of network oversaturation and determine the scope and magnitude of the problem.
2. Define the root causes of the problem.
3. Evaluate the relative effectiveness of existing traffic operations and control techniques used to combat the problem.
4. Prepare guidelines for applying present traffic operations and control techniques of demonstrated effectiveness.
5. Describe alternate concepts of advanced traffic control techniques for improving traffic operation efficiency in oversaturated networks.

6. Formulate a detailed plan and program for systematic development, testing, and application of improved traffic control in oversaturated networks.

The approach taken by the research agency was to establish three phases for the project. Phase I covered the first objective and produced an interim report (its contents are included in the final report.) Phase II was primarily concerned with examination and evaluation of existing traffic control techniques. Phase III dealt with the description of advanced methods of traffic control and with the formulation of a detailed plan and program for test and application of the recommended procedures. (This plan, modified after NCHRP review, formed the basis for a project continuation to investigate further the effectiveness of non-signal and minimally responsive signal control policies in combatting oversaturation.)

The first task was to classify and characterize "oversaturation." To do this, traffic performance was defined on the basis of a queue-formation mechanism applied at one approach to a signalized intersection. A state of no queue formation was defined as "uncongested operation." On the other hand, the term "congested operations" was used to characterize the full range of operations involving any queue formation. The term "saturated operations" defined that part of the range of congestion wherein queues form but their adverse effects in terms of delay and/or stops are local. "Oversaturated operations" were characterized as that part of the congestion range where queues grow to the extent that the upstream intersection performance is adversely affected.

FINDINGS

Consistent with the three-phase structure of the research, the project findings are reported here in three sections.

Phase I Findings

Questionnaire Results - The scope and magnitude of the oversaturation problem was assessed by sending 569 questionnaires to cities, counties, and states in the United States and Canada. Responses totaled 205, with one-half of the states and one-third of the cities responding. Most state and county returns indicated a lack of direct involvement with congestion problems. The best rate of returns came from cities with populations of more than 500,000, 80% of which cooperated with the survey. Figure 1 shows the variation of saturation reported by city size, for all intersections, for CBD signalized intersections, and for all intersections on the arterial system. Whereas the largest cities report the smallest extent of saturated intersections, the smallest cities evidently experience the longest durations of saturated conditions. In the intermediate-size cities, about one-third of the intersections experience saturation, typically for periods of 30 to 60 min during the weekday.

Figure 2, showing the queue length characteristics at congested intersections, gives an indication of the range of oversaturated intersection experiences by city size. Except for cities of more than 500,000 population, roughly one-quarter of the congested intersections experience oversaturation; i.e., with queues affecting the upstream intersection being formed.

The response to a question about the means used for timing signals is summarized in Table 1. Manual techniques (e.g. time/space diagram development) rather than more sophisticated computer-based methods are most widely used, even in the largest cities.

Questionnaire responses revealed that a wide variety of both operational and physical measures have been brought to bear to combat problems of congestion and oversaturation. Table 2 itemizes the types of measures used and the extent to which they are employed. More than 100 of the respondents indicated that systematic application of these techniques to alleviate congestion was being undertaken through the TOPICS program. Although operational schemes are clearly favored in cities with less than 500,000 population, physical measures are the solutions reportedly most employed in the largest cities. This may well reflect that larger cities have, or believe they have, already exhausted their options for signal system improvement.

Measures of Oversaturation - Many measures of effectiveness are in current use to characterize particular aspects of traffic performance. They may be categorized by use, such as measures useful in describing the state of the point or system under consideration, and those useful in aiding control of the point or system under consideration. Or measures may be classed in either of two categories: those describing conditions at specific intersections or points within the system, and those describing over-all conditions in the system or in subsections of a larger system. Some measures may have utility as both descriptors and controls, some may have utility for both point and system control, and some may serve to characterize both local and system effects. Table 3 gives those that were considered for this project.

A set of queue-related measures was selected as being most promising for study: queue length, queue length to link length ratio, and link length minus queue length. The last of these — in other words, the clear distance from the end of the queue to the upstream intersection — was found from field trials to be the best single measure of oversaturation. Where vehicle detector installations are unable to provide this preferred measure, average queue length over a cycle may be useful as a substitute measure.

Phase II Findings

Phase II was concerned with defining the root causes of the oversaturation problem, evaluating existing techniques for combatting it, and developing guidelines for applying existing techniques to the problem.

Four causes of congestion were identified from a literature review and from the responses to the survey previously discussed. Land-use policies were seen as the primary cause; pedestrians ranked second; bus and commercial vehicle operations ranked about equally in third place. Such causes ar obviously compounded when the pattern of the street network limits or precludes the choice of alternate routes to bypass congested locations.

The following techniques were considered the most effective measures for abbreviating oversaturated traffic operations: alternate routing signs (particularly for incident-generated congestion), parking and loading restrictions, choice of bus stop locations, turn restrictions, one-way streets, unbalanced flow, exclusive bus lanes, and traffic signal controls. Except for alternate route designations, the traffic engineering tools of signs and markings were concluded to be of little value, whereas, in the opinion of the research agency, the effective use of traffic signals offers the greatest promise.

Further studies of the effectiveness of both signal and non-signal techniques will be carried out in the project continuation. In terms of the signal-related effort prime emphasis will be given to minimal response signal systems (i.e., systems without extensive detection or computer support). A two-pronged approach using both analytic development and computer simulation will be used. The results of these efforts will form the basis for developing specific guidelines for applying the range of possible measures available to combat oversaturation.

In general, it was found that operational measures leading to increased link storage were more effective in delaying or eliminating oversaturation than were measures aimed at increasing intersection capacity. Field studies revealed that the latter were of varying effectiveness.

Some particular findings with respect to signal techniques are as follows:

1. Short cycles are often more effective than long cycles because they prevent the buildup of excessively long queues.
2. Under many conditions, two-phase timing is more effective than three-phase or multi-phase operations in reducing queue buildups and delay.
3. A simultaneous offset plan upstream from the critical intersection and progressive offset downstream is effective in reducing queues at the critical intersection.
4. Use of a reverse progression reduces queue length at the critical intersection more than forward progression or simultaneous offsets, but it leads to increases in system delay.

Assuming no basic changes in the patterns of vehicular demand, some fundamental orders of priority for applying countermeasures could be defined as follows: (1) discourage traffic from entering the congested area or encourage the use of alternate routes; (2) implement both physical and operational measures to increase link storage; (3) make effective use of the three traffic signal parameters of cycle lengths, splits, and offsets in order to minimize queue lengths.

Phase III Findings

The emphasis in Phase III was to develop and evaluate advanced traffic control techniques aimed both at eliminating (or at least delaying) the onset of oversaturation and at treating oversaturation when it does occur. The type of technique desired was to be of a traffic-responsive nature, designed not only for treating critical intersections but also for minimizing disruption to over-all system operations.

Three relevant advanced control concepts were selected from a review of the literature: (1) smooth flow theory, (2) Gazis saturated intersection policy, and (3) Longley's control strategy. The research agency additionally proposed a fourth concept, termed "queue-actuated signal control."

Each of the four techniques was subjected to an extensive simulation evaluation using three different test networks. Two were hypothetical, the third was a model of the Flatbush Avenue Extension. Table 4 ranks the techniques in order of effectiveness in three performance areas. The queue-actuated policy, ranking best over-all, was found to have the following characteristics:

1. It can be applied to a critical intersection within a coordinated system, as well as to isolated intersections.
2. It is the most positive method among those examined in preventing blockage.
3. It minimizes delay through a critical intersection under heavy flow conditions, but it usually tends to increase delay under lower-volume flows.

4. It provides continuous demands by purposely creating queues, thus maintaining a higher utilization of green time and higher productivity.

APPLICATIONS

Research conducted as part of this study has demonstrated that many existing operations and control techniques can be applied to the reduction or elimination of oversaturation. The questionnaire results show that many of these techniques are in common use today.

By referring to guidelines for application of existing devices, the practicing engineer can apprise himself of the potential of existing controls for relieving oversaturated conditions. Thus, the engineer faced with problems of oversaturation may weigh the relief given to the problem against the associated costs in upgrading traffic operations and control systems.

The present project has provided approximate measures of effectiveness in this regard. After the analytic development and further simulation tests planned for the continuation phase are completed, it is expected that more specific guidelines can be presented in manual form for the use of those concerned with the problems of traffic movement in urban areas. At the same time, it is anticipated that the advanced control strategies that have been or are likely to be promulgated will be available to agencies for application in constructing computer control systems for traffic signal networks.

TABLE 1
METHODS USED FOR TIMING SIGNALS, BY SIZE OF CITY

City Size (Population)	Average Number of Signals	Number of Cities Using			
		Hand a/	SIGOP b/	SIGRID c/	Computer Calc. of Time/Space Diag.
Less than 50,000	35	21	—	—	1
50,000-100,000	70	39	2	—	4
100,000-250,000	183	25	1	1	2
250,000-500,000	391	5	3	1	—
500,000 +	1,377	5	1	—	1
All		125	7	2	8

a/ Manual computation of signal timing, usually by development of a time/space diagram.

b/ Traffic Signal Optimization Program (a network optimizer).

c/ A predecessor of SIGOP developed for Toronto.

TABLE 2

METHODS USED TO ALLEVIATE CONGESTION THROUGH THE TOPICS PROGRAM, BY SIZE OF CITY

City Size (Population)	Percentage* Using	
	Operational Schemes a/	Physical Schemes b/
Less than 50,000	30	13
50 - 100,000	33	20
100 - 250,000	47	13
250 - 500,000	67	11
500,000 +	12	62

*Some cities may use both schemes. The remainder of cities either failed to respond or use none of the indicated measures.

a/ Including: signal modernization (i.e., optics, multi-dial, traffic actuated, CBD signal interconnection, preferential splits, progressive timing, separate turn signal phases); capacity analysis; parking prohibitions; turn prohibitions; pedestrian constraints; signing changes; police control; reversible lanes; other possibilities (including one-way streets and truck routes).

b/ Including: lane widening, channelization, turning lanes, grade separations, sight distance, pavement skid resistance, signal location, exclusive bus lanes, truck routes.

TABLE 4

COMPARATIVE RANKING OF ADVANCED CONCEPT CONTROL TECHNIQUES

Technique	Rank		
	Ability to prevent or delay oversaturation	Lack of adverse effect on system performance	Productivity of controlled intersection
Smooth-flow theory	1	3	4
Gazis technique	4	— a/	3
Longley's theory	3	2	2
Queue-actuated control	2	1	1

a/ Technique not applicable to system.

TABLE 3

EXISTING AND NEW PARAMETERS OF POSSIBLE UTILITY

	UTILITY AS:	
	DESCRIPTORS	DESCRIPTORS and/or CONTROL PARAMETERS
Intersection (point) measures	Load factor Saturation factor Maximum individual delay vehicle Number of cycles to clear intersection Number of stops/starts to clear intersection	Queue length Total delay Average delay Link length minus queue length Ratio of queue length to link length Input-output Trapped vehicles Volume-capacity (V/C) ratio
System measures	Total delay Average number of stops/vehicle Density Mean velocity gradient Occupancy Total travel time	Density Occupancy Input-output

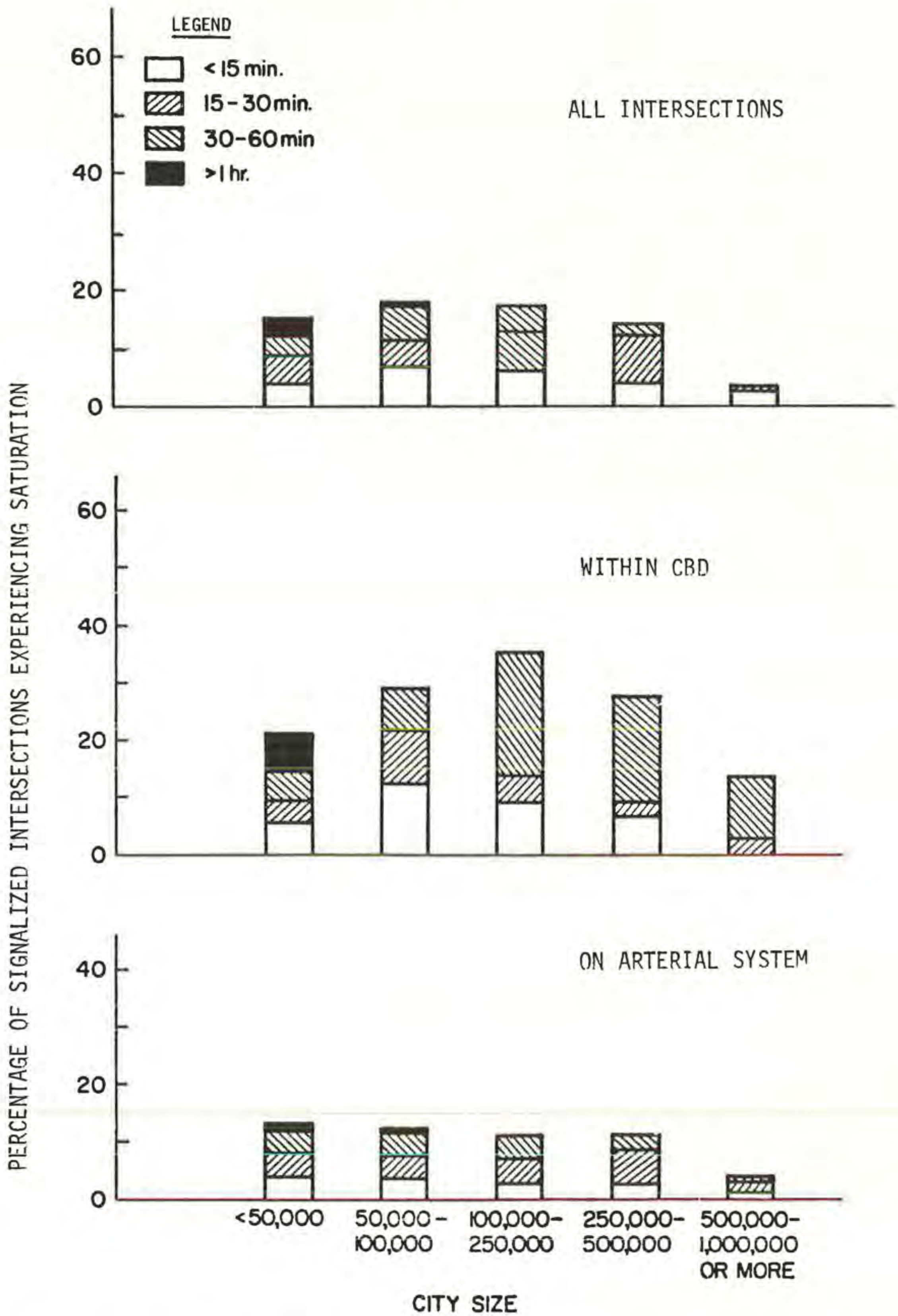

Figure 1. Duration of saturation at particular signalized intersections, by city size.

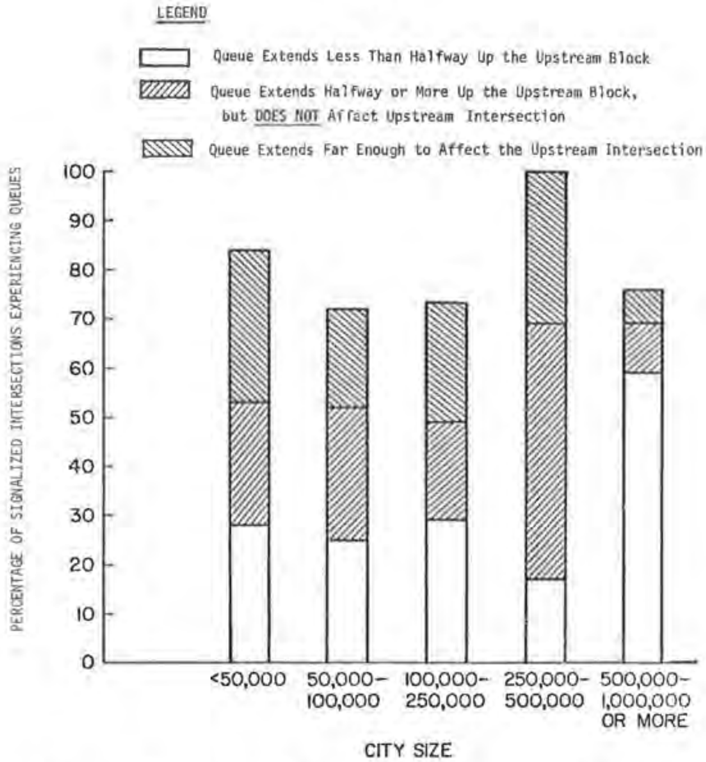

Figure 2. Queue length at congested intersections as a percentage of all signalized intersections experiencing congestion, by city size.