Congestion-Based Control Scheme for Closely Spaced, High Traffic Density Networks

E. B. LIEBERMAN, A. K. RATHI, G. F. KING, and S. I. SCHWARTZ

ABSTRACT

The development and field testing of a traffic control policy designed for congested conditions in the high-density sectors of the Manhattan central business district (CBD) are described. Rather than providing progressive movement in the conventional sense, the primary objective of this control policy is to minimize the frequency and extent of intersection spillback. In the Manhattan CBD, queues develop along the cross streets; these queues often spill back into the upstream intersections, physically blocking the movement of traffic along the north-south arterials. The traffic control policy described yields signal timing for the one-way cross streets that exhibit a backward progression and flared green times that increase in the direction of traffic flow. The arterial traffic is serviced by a signal-timing pattern that exhibits zero relative offsets. The NETSIM traffic simulation model was used to test different concepts during the development phase of the effort. The new policy was then compared with the existing timing plan, by using NETSIM, and the results indicated that the number and duration of spillback blockage were markedly decreased, with a concomitant reduction in vehicle travel time and number of stops, coupled with an increase in vehicle trips serviced. A before-and-after field study yielded similar results, with the new policy providing a 20 percent reduction in overall travel time.

A study designed to identify high traffic density sectors (HTDSs) in mid-Manhattan and to develop methods for alleviating congested traffic conditions was performed. During the course of this study a new traffic control policy was developed, which expressly addresses the problem of overflow queues causing intersection spillback. This approach was adopted in response to simulation studies and field observations that indicated that recurring spillback was the primary factor responsible for traffic congestion.

Described are the sequence of activities and the rationale of the traffic signal control policy. Representative field results are presented.

PREVIOUS RESEARCH

Congestion on and saturation of street networks are familiar occurrences in central business districts (CBDs) and other high-activity centers of many urban areas. Under congested conditions, both capacity and operational efficiency are severely degraded, resulting in suboptimum utilization of the available facilities.

The treatments designed to reduce congestion and oversaturation in urban grids can be classified into the following three categories (1):

- Signal--minimal response signal control policies
- Signal--highly responsive signal control policies
- Nonsignal--other treatments in a signalized environment

The minimal-response signal control policies affect cycle lengths, splits, and offsets, and are applicable in an environment in which little day-to-day variation in the traffic pattern exists.

The well-accepted criteria for optimum cycle length at an intersection are minimization of delay and of congestion (2). Gazis and Potts (3) studied the problem of minimizing delay at oversaturated intersections. For fixed-time settings, they demonstrated that when saturation flows in the two critical directions were equal, the minimum delay was given by the settings that cause competing queues to disappear at the same time.

Optimum signal split is a function of relative demand on the competing approaches, platoon coherence, and constraints on minimum green time to satisfy pedestrian demands. The definition of congested or oversaturated traffic operations at an intersection implies that green time for a given approach is terminated before all demand is satisfied (3). Traffic can therefore be serviced during the entire green interval. It is possible, however, that lack of platoon coherence near the end of the green interval may cause traffic demand to be less than service capacity rates.

The highly responsive signal control policies involve detector-based, computer-controlled systems in which cycle length, split, and offset are varied, from cycle to cycle, in response to the existing traffic conditions. These policies are appropriate for environments with no discernible traffic pattern. Queue-actuated control (1), minimum delay via split switching (4), and queue proportionality in real time (5) are some of the highly responsive signal control strategies applicable in a congested environment.

Although the traffic-responsive signal control

E.B. Lieberman, A.K. Rathi, and G.F. King, KLD Associates, Inc., 300 Broadway, Huntington Station, N.Y. 11746. S.I. Schwartz, New York City Department of Transportation, 28-11 Queens Plaza North, Long Island City, New York, N.Y. 11101.

policies offer the greatest potential for combatting congestion, the costs associated with detectoriza-tion and computer-controlled systems are beyond the resources of most jurisdictions. Furthermore, it must be realized that as traffic demand approaches saturation and oversaturation, the responsive systems often act as fixed-time settings.

Nonsignalized treatments such as parking control, regulation of turns, and lane arrangement are designed to increase capacity. Two of the most frequent violations that aggravate the congestion problems are intersection blockage and violations of parking regulations. In NCHRP Report 194 (1), a detailed discussion is provided on various nonsignalized treatments and their effectiveness in reducing congestion in urban street networks.

SELECTED HIGH TRAFFIC DENSITY SECTORS

A review (6) of previous studies supplemented by traffic density data, collected on videotape using aerial surveillance, identified several HTDSs in Manhattan's CBD. These sectors were first screened to identify and delineate candidate sectors for additional study. The selection criteria used included feasibility criteria and infeasibility criteria.

Criteria for the identification of HTDSs that are candidates for metering (feasibility criteria) are

1. Effective red time (when the signal indication is green, but the existence of spillback precludes vehicle movement through the intersection) identified at multiple intersections;
2. Congestion (i.e., queuing), which involves several contiguous streets, often resulting in queues extending through intersections (spillback), which impedes cross-flow throughput; and
3. Opportunity for traffic diversion, storage upstream of the HTDS, or both.

Criteria that will prevent the application of metering to candidate HTDSs (infeasibility criteria) are

1. Potential blockage or impedance of major facilities by stored traffic (e.g., hospitals, fire stations, transit terminals, major interchanges);
2. Political considerations that preclude congested conditions in certain areas (e.g., United Nations building, selected embassies and public buildings);
3. Possibility that stored traffic will interfere with, or unduly delay, transit or emergency vehicles; and
4. Metering that could store traffic in tunnels or other locations where increases in vehicular emission or noise cannot be tolerated.

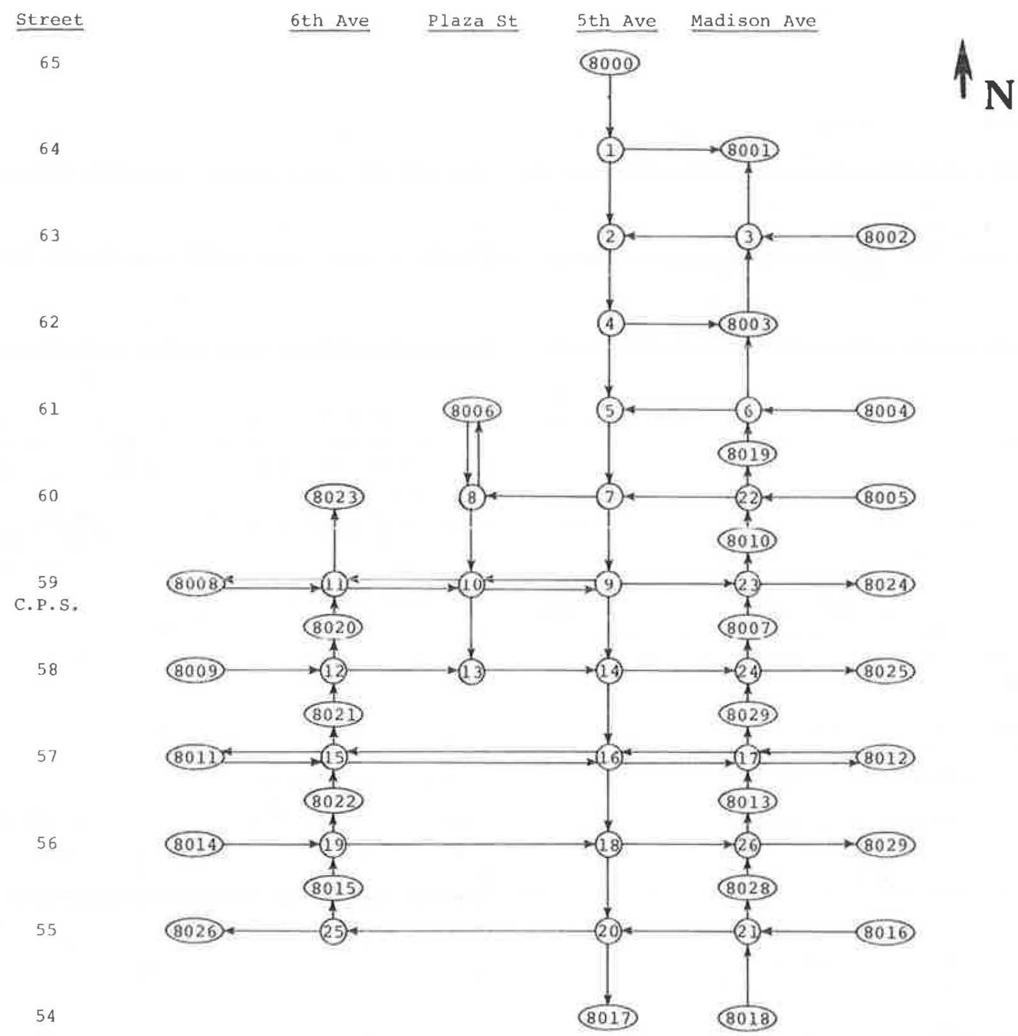

FIGURE 1 Fifth Avenue arterial network.

After detailed analysis (7) and extensive discussions with New York City Department of Transportation personnel, two HTDSs were selected for the application of a new control policy:

- Arterial system: Fifth Avenue between 63rd and 54th streets, including Grand Army Plaza and all entrance and exit links (Figure 1).
- Grid system: the corridor defined by Avenue of the Americas (6th Avenue) on the east, 8th Avenue on the west, from 45th Street on the north to 32nd Street on the south, including all entrance and exit links (Figure 2).

DESCRIPTION OF TRAFFIC ENVIRONMENT

The Manhattan CBD is characterized by a closely spaced signalized Cartesian grid system of primarily one-way streets, as is indicated in Figures 1 and 2. Because of the extremely heavy concentration of activities in a relatively small area, substantial traffic demand exists during both peak and off-peak hours. The high traffic demand in a signalized environment characterized by short streets and extremely high pedestrian volumes leads to significant levels of traffic congestion and associated adverse environmental impacts.

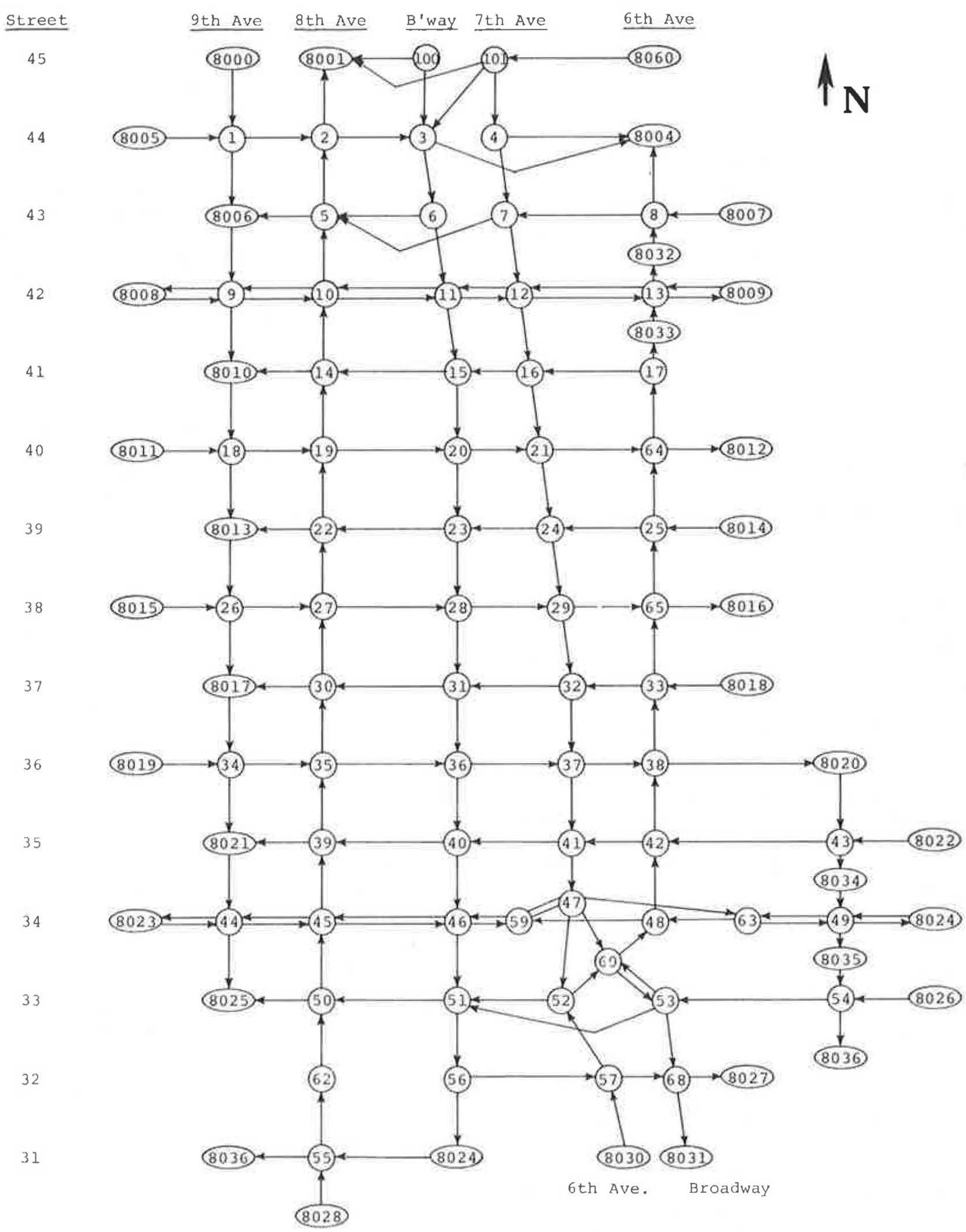

FIGURE 2 Grid network.

Congestion occurs throughout most of the workday. Intersection spillback arising from overflow queues is frequent, particularly in the vicinity of business activity centers. The problem is exacerbated by frequent illegal curb parking and double parking, violation of the WALK and DON'T WALK signs by pedestrians, and truck loading and unloading operations.

Congestion is particularly intense inbound in the morning on the north-south avenues, during the day on east-west crosstown streets, and on outbound avenues in the evening. Traffic often backs up into the surrounding street system during these peak periods, spreading delays and the problem of air pollution over a wide area.

CAUSES OF CONGESTION

To develop a control strategy to reduce congestion, the initial step was to determine the root causes of congestion in the selected HTDSs. Field observations of traffic conditions and simulation of traffic operations by using NETSIM (8) indicated that the dominant factor affecting traffic flow along the north-south arterials within the selected HTDSs was the recurring spillback of cross-street queues. This spillback intermittently blocks traffic flow on the north-south arterials, thus effectively reducing the available capacity there. As a result, the throughput along these arterials is reduced to a fraction of the theoretical arterial capacity based on the number of available lanes and green time.

The intersection spillback due to overflowing cross-street (east-west) queues is caused by the following factors:

- Inadequate green time for cross streets.
- Extensive parking activity along cross streets, which restricts vehicle movement.
- Very long discharge headways by traffic on cross streets. These low discharge rates reflect the one lane available combined with the impedance experienced by turning vehicles encountering heavy pedestrian traffic.
- Poor pedestrian signal discipline.
- Limited storage capacity (i.e., short streets) on some cross streets.
- Circulation patterns:
  a. The north-south arterials in these HTDSs act as distributors, wherein more vehicles turn onto the cross streets from the arterials than turn onto the arterials from the cross streets. Thus, the volume of traffic departing the arterial along the cross streets is often greater than that on the cross-street approach to the intersection. Consequently, vehicles turning from the arterial onto the cross street often encounter queues that block their progress and effectively remove a lane from service.
  b. Because most cross streets service one-way flow and alternate in direction, the process described in the preceding pattern leads to one arterial link losing its right-most lane, the next losing its left-most lane, and so on. Thus, the through-arterial traffic exhibits a weaving pattern, a high incidence of lane changing, and poor lane utilization.
- Through vehicles on cross streets that discharge during their green phase often encounter a long queue on the receiving cross street. All too frequently, this traffic cannot clear the intersection within the green phase because of excess demand relative to the available storage capacity on the receiving cross street. The result is an intersection spillback condition that blocks the arterial flow.

EXISTING TRAFFIC SIGNAL CONTROL POLICY

Existing traffic control consists of a single-dial, pretimed system. A computer-based signal control system is in the design stage. With few exceptions, all intersections operate on a two-phase, 90-sec cycle. Signal offsets are designed to provide progressive movement along all north-south arterials, which generally service one-way traffic. The ratios of green time to cycle length for these arterials are generally in the range of 0.55 to 0.6; the cross streets, most of which service one-way traffic flow, receive the remainder of the green time.

In this grid network of one-way traffic flow, the resulting control of the east-west cross streets exhibits signal offsets that vary from one street to the next. This characteristic is the outcome of the signal closure condition, which states that the sum of offsets around every closed loop is a multiple of the signal cycle. Thus, because adjacent arterials are servicing traffic in opposite directions with progressive offsets, the cross streets have signal offsets that cannot provide a high level of continuous movement.

Progressive offsets along the arterials are appropriate when (a) queue lengths are small relative to street length (approximately 230 ft for the networks selected) and (b) no blockage has occurred for several cycles. For situations that produce relatively long queues (100 ft or longer) for many cycles in sequence, offsets designed to maintain progressive movements, without consideration of standing queues, are not optimal and can actually amplify congested conditions. This offset design, in the absence of any blockage due to spillback, is as follows:

1. The queue on the upstream feeder link along the arterial receives the green indication before the approach with the long queue.
2. The through vehicles discharging the feeder approach reach the tail of the queue on the receiving link well before this queue starts to move. Thus, these discharging vehicles must stop after moving less than 150 ft, thereby generating a new shock wave.
3. The motorists on the feeder approach perceive a red indication controlling the traffic on the downstream approach at the time they are provided with a green signal. Because the motorists anticipate that they will have to stop again, their rate of discharge from the feeder link is often sluggish (i.e., long headways).
4. This sluggish rate of discharge reduces the throughput of the feeder link and of all vehicles entering the feeder link from farther upstream.

In the presence of intersection blockage, the whole issue of providing optimal offsets along the arterial becomes moot.

REVISED CONTROL POLICY

A new control policy for the selected HTDSs operating under saturated flow conditions was developed with the following considerations:

- Because the intermittent, recurring spillback of cross-street queues is the dominant factor influencing traffic operations, the control policy must explicitly address this spillback phenomenon and act to reduce its frequency, as well as its temporal and spatial extents.
- For the arterials, the control policy must provide signal settings with offsets that take into

account the presence of queues, even in the absence of spillback.

It is recognized that spillbacks are stochastic events that occur randomly over time and space because of fluctuating demand conditions. Definitionally, cross-street queues will overflow the available storage capacity and spill back into its upstream intersection whenever there are repeating net inflows over a sequence of signal cycles.

Control of Cross-Street Traffic To Reduce Spillback

To preempt spillback, the green time provided at the downstream intersection of cross streets must service these inflows. Thus, throughout its length where it acts as a collector of traffic, cross-street traffic must be provided with increasing values of green time. Stated another way, the revised control policy meters the inflow of vehicles along this cross street at its upstream end to permit the green time to be flared (increase gradually from one intersection to the next in the downstream direction).

Three parameters influence the flare of cross-street green time in the downstream direction:

- The number of arterial links affected by the spillback of a cross-street queue,
- The minimum acceptable spillback recurrence interval, and
- Available storage capacity on the cross street.

The number of arterial links affected by spillback of a cross-street queue is a function of the average speed of the shock wave along the arterial, the length of the arterial link, and the cycle length. The higher the number of arterial links affected by cross-street spillback (by virtue of higher shock wave speeds for fixed-link length and cycle length), the larger the green-time requirement for cross streets to reduce the adverse effects of spillback along the arterial.

Although it would be desirable to eliminate all possibility of cross-street spillback, one must accept as unavoidable a minimum frequency of spillback. To lower the frequency of spillback, stronger metering of cross-street traffic is required.

The available storage capacity in the cross street is essentially the block length (approximately 1/6 mile for the authors' networks) minus some adjustment for standing queue. The greater the available storage capacity, the smaller are the chances of spillback of queues. Thus, the cross-street green flare varies inversely with the block length.

In summary, the revised control policy is designed to improve traffic operations along arterial streets during periods of oversaturation by providing optimal offsets and increased green times along the cross streets. This apparent anomaly in the control policy is effective because it sharply reduces intersection blockage arising from overflow queues along the cross streets.

Control of Arterial Traffic

To provide arterial signal settings that offer offsets that are appropriate in the presence of moderate queues, the queue management control (QMC) concept was applied. QMC, a form of internal metering applied within a congested network, is designed to manage queue lengths to reduce the probability of spillback. QMC, implemented through signal coordination, is based on the following objectives:

1. Assure that every second of green time at the downstream node is fully utilized to maximize throughput.
2. Eliminate effective red (i.e., the time during a green phase when traffic is unable to move because of the presence of queues along the receiving arterial link).

It was indicated in this analysis that in the presence of moderate queues along north-south arterials, the optimal relative offsets along these arterials is approximately zero (simultaneous green). This condition, due primarily to the short link lengths along these arterials, also provided the opportunity for controlling the offsets along the cross streets so as to prevent, to a great extent, the onset of spillback conditions. The metering of cross-street traffic by increasing cross-street green times as one proceeds in the downstream direction, in an environment of simultaneous onset of the green phases servicing the arterial, provides the sought reverse progression (queue clearance) offsets along the cross streets.

The revised signal control policy was therefore responsive to the characteristics of the selected HTDSs:

- Metering of cross-street traffic to maintain a balance between demand and capacity.
- Reversing progression to limit the size of queues along the cross streets, thus limiting the exposure to spillback onto the arterial.
- Existence of near-optimal offsets along the arterials, given the presence of moderate queues on these short links.

Based on these analyses, revised values of the offsets and cycle splits were derived (9). These values were checked and adjusted through repeated simulation runs. It was also recommended that the placement of turn bays of adequate length on selected cross streets be established and enforced. These turn bays will somewhat reduce the capacity of a parking lane, but will ensure that delays experienced by turning vehicles encountering pedestrian traffic will not be transmitted to discharging vehicles moving through the intersection.

The recommended signal settings were then implemented for the Fifth Avenue arterial section. Before-and-after evaluation field studies were performed.

SIMULATION RESULTS

NETSIM was executed to simulate traffic operations with the existing signal timing and with the new control policy for two networks (Figures 1 and 2). The simulation results are given for a variety of traffic performance measures on individual links, on sections (sets of links), and on the network as a whole.

Fifth Avenue Arterial Network

The data in Table 1 indicate considerable improvement in traffic performance under the revised control scheme. The mean speed on the network increased by 31.3 percent (from 4.0 to 5.3 mph) despite an increase of 11.3 percent in the number of vehicle trips. Average delay and spillback durations were appreciably decreased. Link content was also decreased but to a somewhat lesser extent.

TABLE 1 Comparison of Simulated Traffic Performance on Fifth Avenue Arterial Network

	Vehicle Trips (hr)			Delay (veh-min)		
	Control Scheme			Control Scheme		
Section	Current	Proposed	Change (%)	Current	Proposed	Change (%)
5th Avenue, 63rd-55th streets	1,136	1,372	+20.8	992.9	725.5	–26.9
59th Street, 6th-Madison avenues	480	572	+19.2	808.0	580.9	–28.1
58th Street, 6th-Madison avenues	440	440	0	554.5	584.1	+5.3
57th Street, 6th-Madison avenues	620	684	+10.3	367.6	321.9	–12.4
57th Street, Madison-6th avenues	820	896	+9.2	860.7	698.3	–18.9
56th Street, 6th-Madison avenues	456	468	+2.6	508.1	247.0	–51.4
55th Street, Madison-6th avenues	440	472	+7.2	880.6	478.2	–45.7
Network	5,112	5,712	+11.7	5,326.2	4,367.4	–18.0

The traffic performance improved on the cross streets as well as on the Fifth Avenue arterial. The improved performance on Fifth Avenue resulted from the elimination of spillback from the cross streets, which demonstrates how congestion management of one component of traffic can benefit other components as well.

Link-specific comparisons of vehicle trips and spillback durations are given in Table 2. This table contains only the links that exhibited more than 15 percent difference in vehicle trips after implementing the proposed control scheme and experienced at least 50 sec of spillback during the simulated time period with either control scheme.

TABLE 2 Link-Specific Comparisons on Fifth Avenue Arterial Network

Artery	Control Scheme Current	Control Scheme Proposed	Change (%)
Vehicle trips (veh/hr)			
5th Avenue			
61st-60th streets	1,324	1,564	+18.1
60th-59th streets	980	1,404	+43.3
59th-58th streets	952	1,292	+35.7
58th-57th streets	1,048	1,340	+27.9
57th-56th streets	1,016	1,240	+22.0
60th Street			
Park-Madison avenues	196	336	+71.4
Madison-5th avenues	268	544	+103.0
5th Avenue-Plaza Street	512	708	+38.3
58th Street			
5th-Madison avenues	404	472	+16.8
56th Street			
5th-Madison avenues	356	428	+20.2
55th Street			
Madison-5th avenues	448	528	+17.9
5th-6th avenues	388	500	+28.9

Artery	Control Scheme Current	Control Scheme Proposed	Change (%)
Spillback duration (sec)			
5th Avenue			
61st-60th streets	281	157	–44.1
60th-59th streets	49.1	0	–100.0
61st Street			
Madison-5th avenues	119	16	–86.6
60th Street			
Madison-5th avenues	575	295	–48.7
59th Street			
5th-Madison avenues	429	163	–62.0
58th Street			
6th Avenue-Plaza Street	180	0	–100.0
Plaza Street-5th Avenue	411	79	–80.8
5th-Madison avenues	363	0	–100.0
55th Street			
5th-6th avenues	353	0	–100.0

TABLE 3 Comparison of Simulated Traffic Performance on Grid Network

	Vehicle Trips (hr)			Delay (veh-min)		
	Control Scheme			Control Scheme		
Section	Current	Proposed	Change (%)	Current	Proposed	Change (%)
8th Avenue, 31st-38th streets	1,932	1,932	0	567.7	633.6	+11.6
8th Avenue, 38th-44th streets	1,732	1,844	+6.5	252.7	515.0	+103.8
7th Avenue, 45th-38th streets	1,240	1,444	+16.5	959.6	629.5	–34.4
7th Avenue, 38th-32nd streets	924	1,416	+53.2	155.1	304.5	+96.3
Broadway, 45th-38th streets	1,152	1,340	+16.3	855.6	532.6	–37.8
Broadway, 38th-32nd streets	508	752	+48.0	296.6	272.3	–8.2
Avenue of the Americas, 32nd-37th streets	1,356	1,492	+10.0	666.2	429.2	–35.6
Avenue of the Americas, 37th-41st streets	904	1,688	+86.7	597.6	299.1	–49.9
42nd Street, 9th Avenue-Avenue of the Americas	620	624	+0.6	393.1	267.0	–32.0
42nd Street, Avenue of the Americas-9th Avenue	464	480	+3.4	160.0	194.6	+21.6
34th Street, 9th-5th avenues	604	624	+3.3	451.2	282.2	–37.5
34th Street, 5th-9th avenues	896	956	+6.7	1,242.5	1,058.2	–14.8
Network	10,816	12,144	+12.3	11,458.2	8,420.4	–26.5

Mean Speed (mph)			Content (vehicles)			Spillback Duration (sec)		
Control Scheme		Change (%)	Control Scheme		Change (%)	Control Scheme		Change (%)
Current	Proposed		Current	Proposed		Current	Proposed	
5.0	7.4	+48.0	78	63	−19.2	3,224	696	−78.4
2.6	4.2	+61.5	53	−38	−28.3	613	420	−31.5
3.4	3.3	−2.9	36	38	+5.5	854	79	−90.7
7.3	7.8	+6.8	24	20	−16.7	0	0	0
4.1	5.5	+34.1	57	46	−19.3	20	19	−5.0
3.9	8.2	+110.3	34	15	−55.9	0	0	0
2.2	4.2	+90.9	59	31	−47.5	522	215	−58.8
4.0	5.2	+30.0	419.2	353.1	−15.8	3,505	1,218	−65.2

Grid Network

The traffic performance on the grid network also improved considerably after simulated implementation of the proposed control scheme (Table 3). Mean speed on the network increased by 36.5 percent (from 6.1 to 8.3 mph), and vehicle trips increased by more than 13 percent. Delay and vehicle contents decreased by 32.0 and 14.5 percent, respectively. Spillback was almost eliminated from the network.

Number of vehicle trips increased significantly on both sections of 7th Avenue, on Broadway, and on the Avenue of the Americas. Other sections experienced relatively smaller increases in numbers of vehicle trips.

The average delay, mean speed, and vehicle content statistics indicate variability in performance from one section to another (see Table 3). Eight sections exhibited less delay with the revised timing policy, while four sections indicated higher delay. Nine of 12 sections showed higher speeds, while spillback duration over the network was reduced by an order of magnitude.

Overall, performance of the traffic on the grid network has improved, except on the 8th Avenue sections. On this arterial, although the number of vehicle trips increased slightly, the performance of traffic was adversely affected.

The adverse relationship between intersection spillback and traffic performance for systems that exhibit a congested environment is confirmed by these simulation results. Specifically, sharp reductions in intersection spillback and the consequent blockage of traffic translate into lower delay, higher speeds, and improved throughput.

FIELD STUDY

A before-and-after field study (10) was conducted on the Fifth Avenue network to evaluate the performance of traffic under the proposed control policy. Travel times were obtained using floating cars traveling along Fifth Avenue and along many of the cross streets intersecting Fifth Avenue. Traffic volumes were collected by observers stationed along Fifth Avenue.

The before-and-after data were collected for two weeks during April and May 1985. For each segment, more than 15 travel time runs were made during both midday (11:00 a.m. to 2:00 p.m.) and p.m. (3:00 p.m. to 6:00 p.m.) peak hours.

Table 4 shows average travel times on various segments of the Fifth Avenue arterial network both before and after the implementation of the proposed control policy. The network weighted mean is computed as

$$\text{Weighted mean} = \left(\sum_s n_s \bar{t}_s d_s\right) \Big/ \left(\sum_s n_s d_s\right) \qquad (1)$$

where

n_s = number of trips on segment, s;

Mean Speed (mph)			Content (vehicles)			Spillback Duration (sec)		
Control Scheme		Change (%)	Control Scheme		Change (%)	Control Scheme		Change (%)
Current	Proposed		Current	Proposed		Current	Proposed	
10.9	10.2	−6.4	60	65	+8.3	44	36	−18.2
14.7	10.3	−29.9	33	52	+57.6	39	0	−100.0
5.5	8.5	+54.5	75	57	−24.0	314	128	−59.2
13.7	12.0	−12.4	18	33	+83.3	10	20	+100.0
5.8	9.2	+58.6	69	49	−29.0	181	11	−93.9
6.4	9.1	+42.2	22	25	+13.6	0	0	0
6.0	8.9	+48.3	54	41	−24.1	20	1	−95.0
3.9	10.5	+169.2	45	30	−33.3	2	25	+∞
8.5	10.9	+28.2	37	27	−27.0	0	0	0
12.4	11.3	−8.9	16	19	+18.8	94	25	−73.4
9.5	12.8	+34.7	44	31	−29.5	0	0	0
6.0	7.1	+18.3	104	93	−10.6	166	21	−87.3
6.1	8.5	+39.3	989	819	−17.2	2,592	286	−89.0

TABLE 4 Travel Time on Various Segments of the Fifth Avenue Arterial Network (floating car runs)

Sampling Period	Segment	Mean Travel Time (sec) Before	After	Difference	Percentage Difference
Midday	5th Avenue, 62nd-54th streets	133	170	+37	+27.8
	55th Street, Madison-6th avenues	252	169	−83	−32.9
	56th Street, 6th-Madison avenues	163	147	−16	−9.8
	57th Street, Madison Avenue-Broadway	322	263	−59	−18.3
	58th Street, 6th-Madison avenues	199	140	−59	−29.6
	59th Street, 6th-Madison avenues	229	206	−23	−10.0
Network weighted mean		233	194	−39	−16.7
p.m.	5th Avenue, 62nd-54th streets	162	112	−50	−30.9
	55th Street, Madison-6th avenues	287	187	−100	−34.8
	56th Street, 6th-Madison avenues	187	177	−10	−5.3
	57th Street, Madison Avenue-Broadway	298	219	−79	−26.5
	58th Street, 6th-Madison avenues	218	161	−57	−26.1
	59th Street, 6th-Madison avenues	248	267	+19	+7.7
Network weighted mean		234	180	−54	−23.1
All	5th Avenue, 62nd-54th streets	153	145	−8	−5.2
	55th Street, Madison-6th avenues	270	176	−94	−34.8
	56th Street, 6th-Madison avenues	176	162	−14	−8.0
	57th Street, Madison Avenue-Broadway	311	239	−72	−23.2
	58th Street, 6th-Madison avenues	209	153	−56	−26.8
	59th Street, 6th-Madison avenues	236	230	−6	−2.5
Network weighted mean		234	187	−47	−20.1

t_s = mean travel time (sec) on segment, s; and
d_s = segment length (ft).

The data in Table 4 show that the new control policy benefits the cross-street traffic the most. Those cross streets that were most congested before (e.g., 55th Street) exhibited the best improvements.

Fifth Avenue traffic also benefited, but to a somewhat lesser extent. Closer examination of the results indicates that when cross-street volumes were low (Table 5) and spillback did not occur, the current progressive signal timing provided better service than did the proposed simultaneous green indications. However, during the p.m. peak period, when cross-street volumes were much heavier, producing intermittent intersection spillback when the existing control was in force, the new signal timing performed better.

Traffic volume along 5th Avenue is slightly lower during the p.m. peak than during midday, while the cross-street volume is generally much higher during the p.m. peak (Table 5). Because the new control scheme produced improved results along 5th Avenue during the p.m. peak, relative to the existing timing, it thus confirms that the critical factor in expediting main street traffic movement is the treatment of controlling high-volume, cross-street traffic.

DISCUSSION

The revised control scheme was designed to reduce the frequency and temporal extent of intersection spillback by cross-street queues. This scheme is characterized by signal settings that are designed to expedite movement of cross-street traffic, yet provide near-optimal offsets and splits to the north-south arterials.

Currently, the one-way, north-south arterials are provided progressive signal offsets. In the absence of spillback by cross-street queues, the current signal pattern offers excellent service to north-south traffic. When traffic demand increases, however, such spillback blocks traffic along the arterials, disrupts progressive movement, and forms

TABLE 5 Volume Counts at Fifth Avenue (veh/hr)

Time Period	Intersection	Southbound Before	Southbound After	Eastbound Before	Eastbound After	Westbound Before	Westbound After
Midday							
11:30-12:00	5th Avenue and 59th Street	1,608	1,732	592	686		
12:05-12:35	5th Avenue and 58th Street	1,496	1,520	686	750		
12:40-1:10	5th Avenue and 57th Street	1,656	1,558	382	422	332	340
1:15-1:45	5th Avenue and 56th Street	1,616	1,594	478	482		
1:50-2:20	5th Avenue and 55th Street	1,544	1,560			584	616
p.m.							
3:30-4:00	5th Avenue and 59th Street	1,418	1,448	444	630		
4:05-4:35	5th Avenue and 58th Street	1,358	1,418	726	842		
4:40-5:10	5th Avenue and 57th Street	1,458	1,554	820	876	512	516
5:15-5:45	5th Avenue and 56th Street	1,494	1,398	624	650		
5:50-6:20	5th Avenue and 55th Street	1,546	1,470			492	550

standing queues in the presence of green signal indications. Thus, the progressive signal timing is effectively negated by these intersection blockages. It follows that any potential loss of progressive movement arising from the implementation of simultaneous green indications (i.e., zero relative offsets) is more than compensated for by the near absence of spillback. The net effect is beneficial.

The study discussed in this paper has led to the development of control policies that are designed expressly for servicing traffic in high-density areas during peak demand periods. By reducing spillback of cross-street queues within the high-density area, it has been shown that all traffic can benefit. Thus, the control scheme based on the objective of spillback avoidance has been shown to be more effective than the more conventional progressive movement policy in high-density environs. However, during off-peak hours when traffic volumes are low, the progressive movement policy is more effective.

ACKNOWLEDGMENT

This paper is based on research funded by the U.S. Department of Transportation in cooperation with the New York Metropolitan Transportation Council and the New York City Department of Transportation. The contributions of Lee L. Home, Chief, Signals and Communications for NYCDOT, and of his staff, to the success of this study are gratefully acknowledged.

REFERENCES

1. L.J. Pignataro, W.R. McShane, K.W. Crowley, B. Lee, and T.W. Casey. Traffic Control in Oversaturated Street Networks. NCHRP Report 194. TRB, National Research Council, Washington, D.C., 1978, 152 pp.
2. F.V. Webster and B.M. Cobbe. Traffic Signals. Her Majesty's Stationery Office, London, England, 1966.
3. D.C. Gazis and R.B. Potts. The Oversaturated Intersection. Proc., Second International Symposium on the Theory of Traffic Flow, London, England, 1963.
4. D.C. Gazis. Optimum Control of a System of Oversaturated Intersection. Operations Research, Vol. 12, 1964.
5. D. Longley. A Control Strategy for a Congested Computer-Controlled Traffic Network. Transportation Research, Vol. 2, 1968.
6. KLD Associates, Inc. Background and Identification of HTDS. TM-70. New York Metropolitan Planning Council and New York City Department of Transportation, Albany, Nov. 1982.
7. KLD Associates, Inc. Preliminary Analyses of HTDS. TM-76. New York Metropolitan Planning Council and New York City Department of Transportation, Albany, April 1983.
8. E. Lieberman, M. Yedlin, and B. Andrews. TRAF User Guide. FHWA, U.S. Department of Transportation, 1984.
9. KLD Associates, Inc. Metering High Density Sectors of the CBD--Task 4 Activities. TM-85. New York Metropolitan Planning Council and New York City Department of Transportation, Albany, July 1984.
10. KLD Associates, Inc. Metering High Density Sectors of the CBD--Comparison of Traffic Operations Along Fifth Avenue: Metering Control vs. Existing Control. TM-94. New York Metropolitan Planning Council and New York City Department of Transportation, Albany, July 1985.
