Off-Peak Flashing Operation of Traffic Signals

An Abridgement of Current Literature

TRAFFIC AND SAFETY DIVISION
NEW YORK STATE DEPARTMENT OF TRANSPORTATION
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ABSTRACT

This report attempts to provide a state-of-the-art review of past experience and research of off-peak flashing operation of traffic signals. Sections of available literature were excerpted, synthesized and/or condensed into a package of data and guidelines intended for use by NYSDOT regional offices. This paper depends primarily on the following two reports for material:

A STUDY OF CLEARANCE INTERVALS, FLASHING OPERATION AND LEFT-TURN PHASING AT TRAFFIC SIGNALS

VOL 1: SUMMARY REPORT, FHWA - RD-78-46, and
VOL 3: FLASHING OPERATION, FHWA - RD-78-48

It is recommended that the guidelines and criteria presented herein be used to develop a uniform policy of off-peak period, flashing operation of state traffic control signals.

I. INTRODUCTION

A. Background

Concern for travel time, delay and energy conservation has resulted in increased awareness of the effects of traffic signal operation. There is interest on the State and National level in considering operating in the flashing mode (yellow/red) during off-peak periods. This area of traffic control has become an FHWA Action Item in recent years. Although the main consideration for off-peak flashing is to minimize vehicle delays at intersections, concomitant results point to reductions in emissions and gasoline consumption by vehicles and reduction in electrical consumption by traffic signal devices.

Up to now, the NYSDOT has not had guidelines for converting traffic signals to off-peak period flashing operation. Regional traffic and safety engineers have requested the main office to develop a statewide policy for off-peak period flashing operation, recognizing that some signals may only be warranted during peak periods, when traffic volumes are highest. In many cases, the volumes during off-peak periods do not justify regular three-color operation of traffic signals, especially during nighttime hours. Typically, volumes during such periods would normally be controlled by stop or yield signs. In such situations, part-time flashing operation is generally desired except during peak periods when regular operation is warranted.

The Safety Operations Unit was given the task of developing guidelines and criteria for off-peak, flashing operation of state traffic control signals. Review of existing literature and past experience with flashing operation provided sufficient information for an effective policy. This report excerpts abridgements, tables, figures, recommendations and guidelines from previous research which can be applied in New York State.

B. Goal and Objective

The goal of this study is to establish a safe, uniform policy of off-peak period, flashing operation of state traffic control signals. The objective is to provide guidelines and criteria to be used in the development of such a policy.

C. Scope of Study

Information retrievals from the Highway Research Information Service (HRIS) and other sources were used to review past research on flashing operation. Although this experience included some full-time flashing operation, off-peak or part-time operation was investigated and emphasized. All pertinent information was excerpted, abridged and/or synthesized into this study report.

II. PAST EXPERIENCE

The following material was developed by the firms of TJKM and Mohle, Perry and Associates during a Federal Highway Administration sponsored research study in the subject areas of clearance intervals, flashing operation and left-turn phasing. This report describes their research on flashing operation.

A. State-of-the-Art Questionnaire

A questionnaire was sent to 360 public agencies throughout the United States to determine their practice on the use of flashing operation. Over 50 percent of the 232 respondents indicated they use flashing operation. There was a significant difference in answers by regions of the country, flashing operation being most prevalent in the Northeast and Midwest and least prevalent in the West. Most agencies that use flashing operation do so for isolated, pretimed signals. Some agencies flash arterial systems (46 percent of those that flash), network systems (36 percent), semi-actuated signals (27 percent), and fully actuated signals (16 percent).

Slightly over 50 percent of the agencies that use flashing operation have warrants for its use. The most common warrant was when hourly volumes drop below 50 percent of the installation warrants described in the Federal Manual on Uniform Traffic Control Devices (MUTCD). Most agencies that use flashing operation just use yellow/red (main street/side street). A few just use red/red and some use both. Red/red and mixed flashing was more prevalent in the West than in the rest of the country.

Thirty-two agencies said they had studied the effects of flashing operation in the agency. Most of these said there were safety problems with flashing operation. In all cases cited where an agency had changed its method of operation in the recent past, that change was to remove flashing operation or to replace the yellow/red flash with a red/red flash.

B. Driver Survey

Drivers in the Los Angeles, San Francisco, Chicago, and Hartford metropolitan areas were asked for the meaning of flashing yellow and red signals. Ninety percent of these surveyed knew the correct meaning of the flashing yellow light, and 97 percent knew the correct meaning of the flashing red light. Inexperienced drivers and older drivers were more prone to give incorrect responses. A large number of drivers made errors on two questions regarding their expectation of traffic on the cross street when they had a flashing light. Only a little more than 50 percent of the drivers correctly responded that if they had a flashing yellow signal, the cross street would be required to stop.

To the corresponding question regarding facing a flashing red signal, only a minority of drivers gave the correct, but admittedly tricky answer, "I cannot tell from looking at the signal what they will do". Most drivers thought the cross street traffic would behave as if they saw a flashing yellow signal; 28 percent, however, believed that cross street traffic would have to stop, an answer that could get them into a hazardous situation at a flashing yellow/red signal.

III. FIELD TEST OF FLASHING OPERATION

In order to determine how flashing operation affects safety and operations, before and after studies were conducted on data from a large number of intersections around the country. The largest source of data was a computer tape containing records of all accidents in the City and County of San Francisco from January 1, 1974 to April 30, 1977. During that period, San Francisco was in the midst of a major program to convert a large proportion of signals to nighttime flashing operation.

In addition to this data, accident and traffic operations data was collected from 94 intersections around the country. The intersections were selected to obtain a variety of geographic, geometric, traffic and signalization characteristics.

A. Accidents

1. San Francisco

Since virtually all signals in San Francisco began flashing after midnight, the group of accidents occurring between midnight and 6 A.M. could serve as a control to determine whether there was a general trend in the San Francisco accident pattern during the three and one-third years of available data. From looking at the midnight to 6 A.M. data, it could be concluded that property damage only accidents were decreasing slightly. This reduction could possibly be due to a lower reporting frequency of property damage only accidents.

For the midnight to 6 A.M. group, the 520 intersections in systems included in the conversion program were selected. For each intersection, the type of change made between the before and after periods was identified. Accident rates per year were then calculated for intersections grouped by the type of change made. The results are shown in Table 1. As can be seen, there is a dramatic and significant increase in accidents for the 375 intersections from regular to flashing yellow/red operation. Almost all of this change was due to an increase in right-angle accidents per year per intersection. When the intersections were grouped according to location, signal system and geometry, it was found that right-angle accidents were significantly higher for four-leg, right-angle intersections; for other other types of intersection geometry, sample sizes were quite small.

TABLE I ACCIDENT ANALYSES AND RATES PER YEAR AT 520 INTERSECTIONS IN SAN FRANCISCO

GROUP		Total Intersections	ACCIDENT CATEGORY								
			Property Damage Only	Personal Injury	Fatality	Rear-End	Right-Angle	Approach Turn	Pedestrian/ Bicycle	Other	Total
Change	Regular to Yellow/Red Flash	375	.09/.27 ↑	.09/.20 ↑	0/.00	.02/.04	.13/.40 ↑	.01/.01	.01/.03	.02/.01	.18/.48 ↑
	Regular to Red/Red Flash	36	.02/.21	.16/.11	0/0	0/.04	.18/.23	0/.01	0/.01	0/.03	.18/.31
	Regular to Regular	107	.17/.17	.16/.16	0/0	.06/.03	.22/.24	.03/.03	.02/.01	.01/.02	.33/.33
	Yellow/Red to Red/Red Flash	2	.79/1.23	1.39/0	0/0	.20/0	1.59/1.23	.20/0	0/0	.20/0	2.18/1.23
All Intersections		520	.10/.25 ↑	.11/.19 ↑	0/.00	.03/.04	.16/.36 ↑	.01/.01	.01/.02	.01/.01	.22/.44 ↑

LEGEND:

b.bb/a.aa ↑↓ — Accidents per year expressed as BEFORE/AFTER. Categories in which the chi-square test showed a significant difference at a significance level of .05 are indicated by arrows which show the direction of the difference.

0 — No accidents of the type indicated were observed.

.00 — One or more accidents were observed but the calculated rate was less than .005.

As can be seen in Table 1, accidents at the 36 intersections changed from regular to flashing red/red operation also increased, but these changes were not significant. At the 107 signals not put on flashing operation, the accident pattern remained virtually the same in the before and after periods. For the two signals changed from flashing yellow/red to flashing red/red operation there was a statistically insignificant decrease in accidents.

2. Other Locations

Accidents at selected study locations outside San Francisco were analyzed, grouping intersections by several criteria and calculating average accident rates per million entering vehicles. Results for the flashing yellow/red locations are shown in Table 2. Also shown are the results of statistical tests to determine whether the changes were significant. As in San Francisco, total accidents and right-angle accidents are signicantly higher with flashing yellow/red operation. The general pattern of increase held for a majority of metropolitan areas and for most types of lane uses, signal systems and intersection geometrics. Total accidents were also increased at the higher speed intersections, those with both main and side street speeds greater than 30 MPH. Most of the increase is due to the increase in right-angle accidents at these locations. The result stresses the importance of adequate sight distance in rural, higher speed locations.

The statistical results in Table 2 suggest criteria for using flashing yellow/red signal operation based on the main street to side street volume ratio. There was a significant increase in right-angle accidents in the volume ratio group of 2-3 where the rates increased from no accidents under regular operation to 2.17 per million entering vehicles under flashing operation. There was also a significant increase in personal injury accidents in the volume ratio group of 2-3 where rates increased from no accidents to 1.20 per million entering vehicles under flashing operation. No significant increase in any type of accident category occurred above the volume ratio group of 2-3. Hence, the use of flashing operation at intersections that have main street to side street volume ratios of less than 3, would seem to significantly increase the liklihood of right-angle accidents.

Analyses performed on the approach volume for the first flashing hour showed the two-way main street volume to be relevant to accident experience. A significant increase in right-angle accidents occurs in the 150 to 200 vph and the 200 to 250 vph groups and a significant increase in total accidents occurs above 250 vph. These results imply the criterion of not using flashing operation when the two-way main street volume is greater than 150 vph.

3. Removal Criteria

It is possible that some intersections placed on flashing operation using rational criteria will still have an inordinarily high accident

TABLE 2 ACCIDENT RATES (PER MILLION VEH.) & ANALYSIS RESULTS AT NON-SAN FRANCISCO STUDY INTERSECTIONS - CHANGE: REGULAR TO YELLOW/RED FLASHING

GROUP				ACCIDENT CATEGORY								
CRITERIA	CATEGORY	Intersections for Statistics	Intersections for Rates	Property Damage Only	Personal Injury	Fatality	Rear End	Right Angle	Approach Turn	Pedestrian/ Bicycle	Other	Total
City:	Other San Francisco Bay Area	24	19	2.51/3.86	1.15/1.32	0/0	1.20/.40	.56/2.72 ↑	.32/.43	0/.19	1.57/1.44	3.65/5.18 ↑
	Sacramento and Stockton	13	13	.35/2.92	.84/.59	0/0	.13/.94	.84/2.33	0/0	0/0	.22/.23	1.19/3.50
	Minneapolis/St. Paul	2	0									
	Chicago Metropolitan Area	9	3	0/0	0/0	0/0	.85/1.26	.21/0	.64/1.26	0/0	1.06/1.26	2.75/3.79 ↑
	Columbus Metropolitan Area	5	0									
	Pittsburgh Metropolitan Area	5	0									
Location in Urban Area:	Central Business District	8	4	1.85/3.88	.63/.93	0/0	1.27/.49	.63/1.08	0/1.13	0/0	.59/2.11	2.49/4.81
	Industrial	1	1	2.74/7.64	2.74/0	0/0	2.74/1.09	0/5.46	0/0	0/0	2.74/1.09	5.47/7.64
	Outlying Business District	15	10	3.35/4.68	1.66/1.60	0/0	1.26/1.47	.82/2.70 ↑	.60/.17	0/.31	2.32/1.63	5.00/6.28
	High Density Residential	19	17	.50/2.42	.64/.77	0/0	.24/.12	.64/2.65 ↑	0/.11	0/.03	.26/.27	1.14/3.19
	Low Density Residential	15	3	0/0	0/0	0/0	.85/1.26	.21/0	.64/1.26	0/0	1.06/1.26	2.75/3.79 ↑
Intersection Geometry:	Four Leg; Right Angle	46	32	1.48/3.60 ↑	.89/1.06	0/0	.65/.74	.70/2.53 ↑	.06/.37	0/.10	1.07/.98	2.48/4.72 ↑
	Four Leg; Skew	3	0									
	Four Leg; Offset	1	0									
	Three Leg; Right Angle	4	2	3.02/0	3.02/0	0/0	3.02/0	0/0	3.02/0	0/0	0/0	6.04/0
	Three Leg; Skew	2	0									
	More Than Four Legs	1	1	1.59/3.18	0/1.06	0/0	0/0	0/1.06	0/0	0/.53	1.59/2.65	1.59/4.24
	Other	1	0									

LEGEND:

b.bb/a.aa ↑ — Accidents per million entering vehicles expressed as BEFORE/AFTER. Categories in which the chi-square test showed a significant difference at a significance level of .05 are indicated by arrows which show the direction of the difference.

0 — No accidents of the type indicated were observed.

.00 — One or more accidents were observed but the calculated rate was less than .005.

(shaded box) — Categories in which missing volume data precluded calculation of accident rates.

Note: The sample size and the number of accidents in the three severity classes are smaller than in the other classes because of missing data in the severity classes.

TABLE 2. ACCIDENT RATES (PER MILLION VEH.) & ANALYSIS RESULTS AT NON-SAN FRANCISCO STUDY INTERSECTIONS – CHANGE: REGULAR TO YELLOW/RED FLASHING (CONT.)

GROUP				ACCIDENT CATEGORY								
CRITERIA	CATEGORY	Intersections for Statistics	Intersections for Rate	Property Damage Only	Personal Injury	Fatality	Rear End	Right Angle	Approach Turn	Pedestrian/ Bicycle	Other	Total
Signal System:	Isolated; Pretimed	8	3	.80 / 1.59	0 / .53	0 / 0	.85 / 1.26	0 / .35	.42 / 1.26	0 / .18	1.38 / 2.15	2.64 / 5.21 ↑
	Isolated; Semi-actuated	3	0									
	Isolated; Fully-actuated	6	1	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0
	Arterial Systems; Pretimed	24	20	1.28 / 3.25	1.35 / 1.44	0 / 0	.74 / .66	.76 / 3.14 ↑	.33 / .18	0 / .08	.76 / .40	2.59 / 4.46
	Network Systems	10	8	2.92 / 5.26	.89 / .53	0 / 0	1.20 / .84	.89 / 1.74	0 / .57	0 / .19	1.71 / 2.46	3.81 / 5.79
	Arterial Sys.; Semi-actuated	7	3	.96 / 1.38	0 / 0	0 / 0	0 / 0	0 / 1.38	0 / 0	0 / 0	.96 / 0	.96 / 1.38
Approach Speed: M = Main St. S = Side St.	M ≤ 30 mph; S ≤ 30 mph	4	3	0 / 0	0 / 2.54	0 / 0	0 / 0	0 / 2.54	0 / 0	0 / 0	0 / 0	0 / 2.54
	M ≤ 30 mph; S = 31-45 mph	4	3	9.14 / 14.94	4.89 / .76	0 / 0	2.37 / 2.79	3.26 / 4.37	.42 / 1.26	0 / .51	5.41 / 5.33	11.47 / 14.26
	M = 31-45 mph; S ≤ 30 mph	4	2	0 / 2.94	0 / 0	0 / 0	0 / 0	.32 / 0	.32 / 0	0 / 0	.32 / 1.47	.96 / 1.47
	M = 31-45 mph; S = 31-45 mph	9	4	3.22 / 2.69	2.93 / 1.21	0 / 0	2.11 / 0	1.42 / 2.16	1.51 / .47	0 / .13	1.11 / 1.14	6.15 / 3.91 ↑
Crossing Width of Main Street: (Includes some intersections in San Francisco)	≤ 40'	17	9	1.14 / 3.32	1.80 / 1.61	0 / 0	1.04 / .42	1.28 / 3.41 ↑	.21 / .63	0 / 0 ↑	.67 / .63	3.20 / 5.10 ↑
	> 40' and ≤ 50'	26	18	.60 / 1.53	.34 / 1.20	0 / 0	.42 / .68	.11 / 1.74 ↑	.34 / 0 ↓	.08 / .15	0 / .16	.94 / 2.73
	> 50' and ≤ 60'	20	12	2.41 / 2.80	.59 / 1.19	0 / 0	1.11 / .70	.59 / .94	0 / .44	0 / .26	1.31 / 1.66	3.00 / 3.99
	> 60' and ≤ 70'	11	8	.93 / 2.89	1.09 / .78	0 / 0	.34 / .38	.45 / 2.80 ↑	0 / .12	0 / 0	1.22 / .37	2.01 / 3.68
	> 70'	5	5	.58 / .83	.40 / 0	0 / 0	0 / 0	.40 / .83	0 / 0	0 / 0	.58 / 0	.97 / .83
Two-Way Main Street Volume in the First Flashing Hour (vehicles/hr)	≤ 50	14	13	.22 / 2.14	.84 / .86	0 / 0	0 / .16	.84 / 2.60	0 / 0	0 / 0	.22 / .23	1.06 / 2.99
	> 50 and ≤ 100	12	10	.29 / 2.51	.36 / 1.83	0 / 0	0 / 1.39 ↑	.36 / 2.94	0 / 0	0 / 0	.29 / 0	.65 / 4.34
	> 100 and ≤ 150	19	12	2.08 / 1.56	.38 / .21	0 / 0	.74 / .54	.38 / 0	0 / 0	0 / .13	1.34 / 1.10	2.46 / 1.77
	> 150 and ≤ 200	12	7	1.85 / 2.67	1.85 / .88	0 / 0	1.62 / .70	0 / 2.46 ↑	1.04 / .68	0 / 0	1.42 / .83	4.08 / 4.67
	> 200 and ≤ 250	4	2	2.63 / 3.80	0 / 3.97	0 / 0	1.91 / 0	0 / 5.87 ↑	0 / .95	.72 / 0	0 / .95	2.63 / 7.77
	> 250	19	9	1.56 / 2.46	.78 / 1.17	0 / 0	.97 / 0	.79 / .96	.07 / .59	0 / .54	.47 / 1.15	2.29 / 3.23 ↑

TABLE 2 ACCIDENT RATES (PER MILLION VEH.) & ANALYSIS RESULTS AT NON-SAN FRANCISCO STUDY INTERSECTIONS - CHANGE: REGULAR TO YELLOW/RED FLASHING (CONT.)

GROUP		Intersections for Statistics	Intersections for Rates	ACCIDENT CATEGORY								
CRITERIA	CATEGORY			Property Damage Only	Personal Injury	Fatality	Rear End	Right Angle	Approach Turn	Pedestrian/ Bicycle	Other	Total
Main Street to Side Street Volume Ratio: For Volume During Flashing Hours	< 1.0	5	5	4.20 / 3.35	.91 / 3.10	0 / 0	1.46 / .91	.91 / 2.79	0 / 0	0 / .30	2.74 / 2.44	5.11 / 6.45
	> 1.0 and ≤ 2.0	10	10	1.14 / 4.55 ↑	2.18 / .84	0 / 0	.77 / .49	1.45 / 4.06	.13 / .66	0 / 0	1.28 / .77	3.62 / 5.99
	> 2.0 and ≤ 3.0	12	12	.57 / 1.66	0 / 1.20 ↑	0 / 0	.12 / .34	0 / 2.17 ↑	0 / 0	.12 / .04	.33 / .30	.57 / 2.86
	> 3.0 and ≤ 4.0	4	4	1.27 / 1.48	.63 / .21	0 / 0	1.27 / 0	.63 / .85	0 / .42	0 / 0	0 / .42	1.90 / 1.69
	> 4.0 and ≤ 5.0	5	5	1.36 / 2.55	0 / 1.64	0 / 0	.39 / 0	0 / 2.51	0 / .16	0 / .31	.97 / 1.22	1.36 / 4.20
	> 5.0 and ≤ 10.0	8	8	1.10 / .81	1.15 / .27	0 / 0	.96 / 0	.33 / .23	.83 / .35	0 / 0	.08 / .35	2.20 / .94
	> 10.0	9	9	.21 / 1.43	.19 / .69	0 / 0	.19 / 1.55	.21 / .27	0 / 0	0 / .31	0 / 0	.40 / 2.12
All Intersections:	Rate/Million Vehicles	58	55	1.58 / 3.37	.99 / .99	0 / 0	.77 / .68	.64 / 2.34 ↑	.23 / .34	0 / .10	1.03 / .98	2.66 / 4.44 ↑
	Total Number of Accidents	58	58	37 / 104	13 / 34	0 / 0	21 / 31	15 / 59	8 / 13	1 / 6	27 / 49	72 / 158

NOTE: Length of before and after periods were different.

rate. It is desirable, therefore, to have an accident experience warrant for taking signals off flashing operation. From the accident data presented in Tables 1 and 2, the average right-angle accident rate under flashing operation was estimated as 0.57 per year for a signal which starts flashing at midnight. It seems reasonable that any signal put on flashing operation according to some rational criteria should have no higher accident rate than the average rate found in this research study (TJKM) where no particularly rational criteria have been used.

The San Francisco data in Table 1 shows that the average right-angle accident rate under flashing yellow/red operation was .40 per year. (This means, on the average, there will be a right-angle accident every 2.5 years during flashing hours) However, the San Francisco data is made up of 218 accidents from intersections that started flashing at midnight, 371 accidents from intersections that started flashing at 2 A.M., and 16 accidents from intersections that started flashing at other hours. The accident rates in Table 1, therefore, would be somewhat higher if all signals started at midnight. Based on the distribution of accidents by hour, it is estimated that the increase would be approximately 42 percent. Applying this factor to the .40 accident per year rate gives an average of .57 right-angle accidents per year during flashing hours for a signal that starts flashing at midnight.

It would seem that one right-angle accident per year would be a warrant for taking a signal off flashing operation. For a given location, however, the number of accidents varies from year to year due to randomness. Therefore, it is necessary to know something of the fluctuation so that the observed number of accidents can be put into proper perspective. The table below, based on the Poisson distribution, shows the probability of finding at least a certain number of accidents in a year for several average accident rates.

PROBABILITY OF FINDING INDICATED NUMBER OF ACCIDENTS OR MORE IN A GIVEN YEAR

ACCIDENT RATE	0	1	2	3	4	5
0.6	1.000	.451	.122	.023	.003	.000
1.2	1.000	.699	.337	.121	.034	.008
1.8	1.000	.835	.537	.269	.109	.036

As the table shows, an approximately "average" intersection, where the accident rate is 0.6 per year during hours of flash, there is a .451 probability of one or more accident occurring at that intersection in a given year. Choosing one accident per year as a warrant, even though it is 67 percent higher than the approximate average rate, would cause 45 percent of the signals to be taken off flashing even if their accident experience was average.

Two or more accidents per year at an average intersection are much less likely, with a probability of only 12 percent. Even for an intersection whose long term accident rate is 1.2, that is twice the average, finding two or more accidents at that location in any year has a probability of only 34 percent. It seems reasonable, therefore, to conclude that any intersection with two right-angle accidents per year during flashing hours after midnight should be considered a candidate for being removed from flashing operation. The final decision to remove these signals from flash, however, should consider volumes, adjacent signal operation, and other factors discussed in this report.

If a signal has three or more right-angle accidents per year in the flashing hours after midnight, it seems that it should definitely be removed from flashing operation. Three or more accidents per year have only a 2 percent probability at an average intersection and only a 12 percent probability at an intersection with a long-term accident rate twice as high as the average.

An accident warrant based on the number of accidents per year has the advantage of simplicity of use for a short term study period, but it does not consider the large effect of exposure on accidents. Flashing operation exposure is affected by two factors, times the signals are flashing, and traffic volumes during these times. A warrant based on exposure is preferable if long term data (3 years) is available. Table 2 gives rates per million entering vehicles for accidents occurring during hours of flash. An average rate for right-angle accidents with yellow/red flashing operation was 2.34 per million vehicles and 0.64 per million vehicles with regular operation. An intersection that had a rate twice that for regularly operated signals (approximately 1.25) should be a candidate for having flashing operation removed.

As with a warrant based on number of accidents per year, however, a warrant based on accident rate must consider how this rate varies due to randomness. The table below, determined from the Poisson distribution, shows the accident rate which would occur a given percentage of the time when the actual accident rate was 1.25.

PROBABILITY OF FINDING INDICATED ACCIDENT RATE OR HIGHER WHEN REAL RATE IS 1.25	NUMBER OF ACCIDENTS USED TO CALCULATE ACCIDENT RATE				
	1	3	5	7	10
.20	3.7	2.1	2.0	1.7	1.6
.10	3.7	2.5	2.2	1.9	1.8
.05	5.0	2.9	2.5	2.1	2.0

For example, if the accident rate were based on only 3 accidents, there would still be a 10 percent probability of finding a rate of 2.50 or more accidents per million vehicles if the actual, long term accident rate were 1.25.

The table suggests a good right-angle accident rate to use as a warrant for removal is 2.0 accidents per million vehicles, if the number of accidents used to calculate the rate is between 3 and 5, and 1.6 if the number used to calculate the rate is greater than 5. The short-term warrant would present a quick decision-making tool where long-term (3 year) data is not available. The short-term rate, it should be noted, generally corresponds with a higher per vehicle rate than the long-term warrant, due to the greater statistical fluctuation possible in short-term periods.

B. Conflicts

Conflicts were measured by the "GMR Traffic Conflict Technique" developed by Perkins and Harris. In this technique, a conflict is defined as either a braking or weaving of a vehicle made in response to the unexpected action of another vehicle or pedestrian. Conflicts were summarized by whether they were caused by the crossing movement of a vehicle or pedestrian (crossing conflict) or whether they were caused by a vehicle going in the same direction (rear-end conflict).

Both the rear-end and crossing conflicts were found to be higher for flashing yellow approaches than for non-flashing approaches. Furthermore, the change in the sum of the two types of conflicts was statistically significant. The increase in rear-end conficts can be explained by certain drivers slowing so much that they cause following drivers to brake or weave. Rear-end accidents might be expected to be higher under such conditions, but the analysis of both the San Francisco and other data indicated that only a very nominal and insignificant increase in rear-end accidents was observed.

The increase in crossing conflicts indicates that drivers with a flashing red light sometimes enter the intersection when drivers with a flashing yellow light are so close that they must brake or weave. This increase in conflicts is undoubtedly related to accidents since with both the San Francisco and other data, right-angle accidents — the type between vehicles with crossing paths -- increased significantly.

C. Violations

For regular operation, a violation was defined as a vehicle entering the intersection on a red phase. For flashing operation, a violation was defined as a vehicle not coming to a stop at a flashing red signal; vehicles which were rolling slowly and were virtually stopped were considered as stopped and hence not classified as violators.

For each intersection it was found that where control was changed from regular to flashing yellow/red, the number of violations per hundred vehicles on the street with flashing yellow went down from .01 to .00 and on the street with flashing red went up from .01 to .06. Both changes were statistically significant. The changes were also what one would expect since it is impossible to violate a flashing yellow signal, but easy to violate a flashing red one. The total violations for the main and side streets combined showed that the .01 reduction in violation rate for the main street where volumes are relatively high counteracted the .05 increase for the side street, where volumes are much lower, so that the net effect was no change.

D. Spot Speed

Approach speeds under regular and flashing operation were measured on the main street approaches at each of 89 test locations. Data was collected using radar speed meters. Speeds were measured when vehicles were about 300 feet from the intersection.

For approaches changed from regular to flashing yellow, the mean approach speed increased from 28.1 to 28.9 MPH which was statistically significant. From looking at the data it could be observed that while this tendency existed for all speed ranges, it was most prevalent for the lower speed approaches, those with a mean speed below 30 MPH.

E. Stopped Time Delay

From looking at the empirical data and at the curves of delay versus volume produced by analytical models, it was thought that for each type of control strategy, a single, representative value of delay could be used over the small range of volume levels where off-peak, flashing operation is contemplated. Where it was believed there was sufficient field data, this value was selected by averaging the observations. Such was the case with flashing yellow/red, flashing red/red, pretimed arterial, pretimed network, and fully actuated signals. For the two kinds of semi-actuated signals (isolated, cycle) the average was selected from analytical models. For pretimed, isolated intersections the choice of an average value was based on the results of a previous research study.

Along with selecting representative values of delay, representative values of proportion stopping were also chosen. This was done from field data where it was suitable, or from appropriate assumptions in conjunction with the analytical models or results reported in the literature.

Average delay per vehicle as a function of main street to side street volume ratio for each kind of intersection control is shown in Figure 1, while Figure 2 shows the proportion of vehicles stopping. From examining these two figures, certain general conclusions can be reached about how flashing operation affects delay and stops relative to the other forms of signal control:

- Flashing yellow/red produces less delay than any form of regular operation under all combinations of main and side street volumes.

- Flashing yellow/red produces fewer stops than pretimed operation when the volume ratio is:
    - above 1.1 for isolated signals
    - above 2.5 for signals timed along an arterial
    - above 3.0 for signals timed in a network

These conclusions are based on averages found in the TJKM research study. Results for specific locations will vary. Furthermore, the results apply only to low volume levels where mean delay and proportion stopping are relatively unaffected by volume levels.

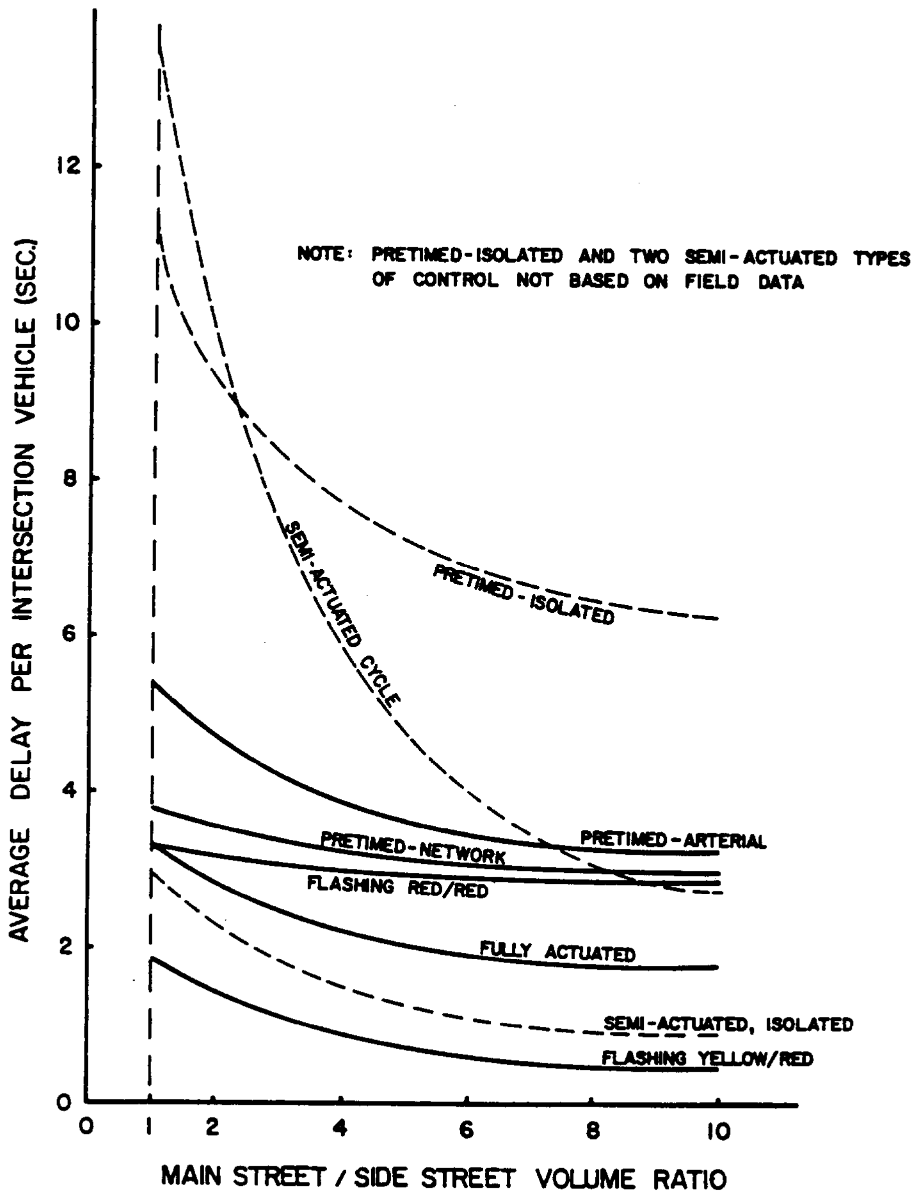

FIGURE 1 AVERAGE DELAY PER INTERSECTION VEHICLE AS A FUNCTION OF MAIN STREET / SIDE STREET VOLUME RATIO

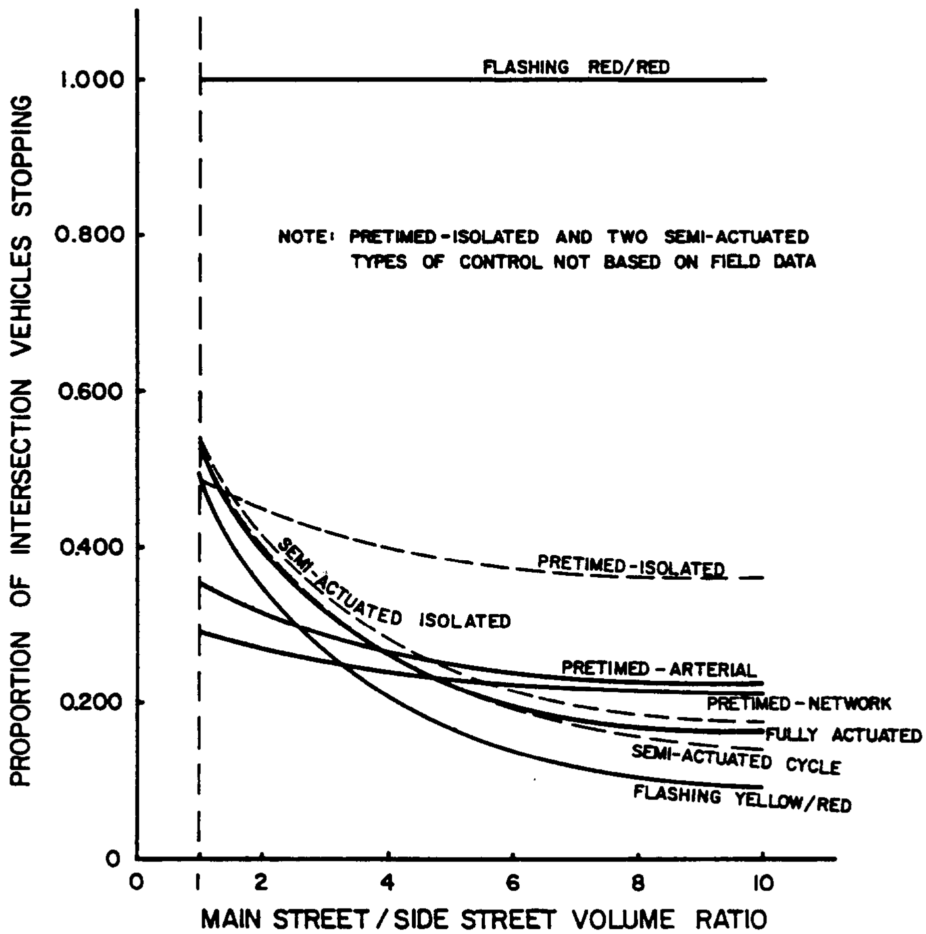

FIGURE 2. AVERAGE PROPORTION OF INTERSECTION VEHICLES STOPPING AS A FUNCTION OF MAIN STREET / SIDE STREET VOLUME RATIO

IV. FUEL CONSUMPTION AND VEHICLE EMISSIONS

Fuel consumption and vehicle emissions were calculated by adding together the amounts due to deceleration, acceleration and idle. Figure 3 and Table 3 show, respectively, the amounts of fuel consumed and the amounts of carbon monoxide, hydrocarbons, and oxides of nitrogen emitted for an average vehicle approaching eight different types of traffic controls at three different speeds. For emissions, it can be seen that flashing yellow/red compares well for the main street, but not so well for the side street. Since fuel consumption and emissions are directly related, flashing operation also compares well for the main street, but not so well for the side street.

Since fuel consumption and emissions for hydrocarbons and oxides of nitrogen depend more on stops than delay, the conclusion in the preceeding section about how flashing operation affects stops relative to other forms of control also apply to how flashing operation affects these three quantities. For carbon monoxide the relative role of emissions at idle is somewhat higher, so a different first conclusion is necessary:

- Flashing yellow/red produces less carbon monoxide emissions than pretimed operation when the volume ratio is higher than indicated below:

Pretimed Signal	30 MPH	40 MPH	50 MPH
Isolated	1.0	1.0	1.0
Arterial	1.1	1.4	1.7
Network	1.9	2.2	2.4

The conclusion about flashing yellow/red being superior to actuated signals is the same as for number of stops.

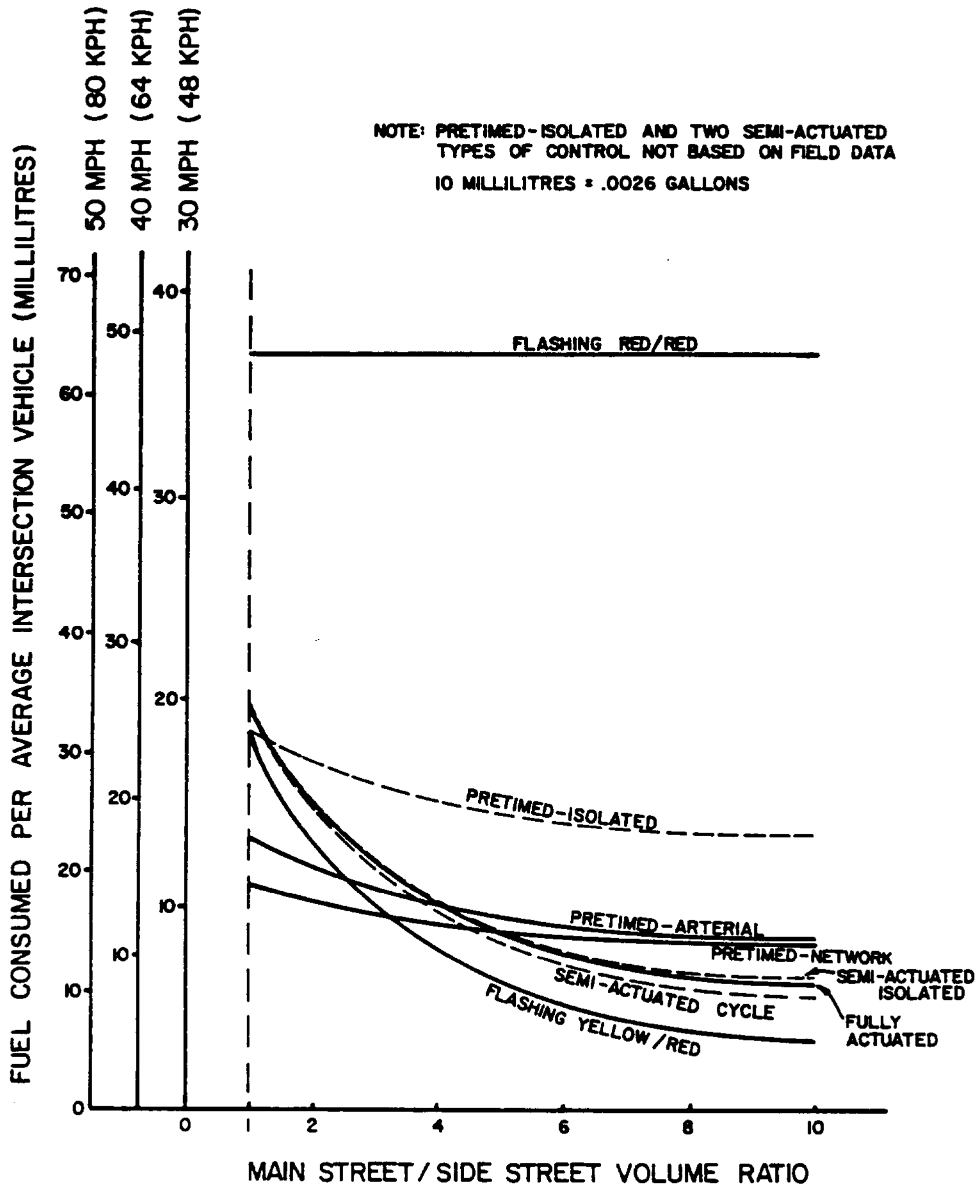

FIGURE 3 AVERAGE FUEL CONSUMPTION PER INTERSECTION VEHICLE AS A FUNCTION OF MAIN STREET / SIDE STREET VOLUME RATIO

TABLE 3 EMISSIONS (IN GRAMS PER VEHICLE) FOR VARIOUS TYPES OF SIGNAL CONTROL

TYPE OF CONTROL	CARBON MONOXIDE						HYDROCARBONS						OXIDES OF NITROGEN					
	30 MPH *		40 MPH		50 MPH		30 MPH		40 MPH		50 MPH		30 MPH		40 MPH		50 MPH	
	Main	Side	Main	Side	Main	Side	Main	Side	Main	Side	Main	Side	Main	Side	Main	Side	Main	Side
Flashing Yellow/Red	0.02	6.50	0.02	9.49	0.02	14.02	0.00	4.72	0.00	7.21	0.00	10.16	0.00	0.59	0.00	0.82	0.00	0.92
Flashing Red/Red	6.27	6.56	9.26	9.55	13.79	14.08	4.71	4.72	7.20	7.21	10.15	10.16	0.59	0.59	0.82	0.82	0.92	0.92
Pretimed, Isolated	2.99	7.70	3.97	9.64	5.47	12.59	1.60	3.24	2.42	4.86	3.40	6.78	0.20	0.40	0.27	0.55	0.31	0.61
Pretimed, Arterial	1.74	4.65	2.33	6.15	3.24	8.41	0.97	2.43	1.46	3.68	2.05	5.16	0.12	0.30	0.17	0.42	0.19	0.47
Pretimed Grid	1.74	3.31	2.33	4.47	3.24	6.22	0.97	1.87	1.46	2.83	2.05	3.91	0.12	0.23	0.17	0.32	0.19	0.36
Fully Actuated	0.74	6.81	0.97	9.79	1.31	14.31	0.37	4.72	0.56	7.21	0.78	10.15	0.05	0.59	0.06	0.82	0.07	0.92
Semi-Actuated, Isolated	0.60	6.87	0.87	9.85	1.27	14.37	0.43	4.73	0.65	7.21	0.91	10.15	0.05	0.59	0.07	0.82	0.08	0.92
Semi-Actuated, Cycle	0.37	11.67	0.54	14.66	0.80	19.18	0.27	4.97	0.41	7.45	0.58	10.40	0.03	0.61	0.05	0.84	0.05	0.94

* 1 mph = 1.609 kph

V. CONCLUSIONS

Results of available literature show that although total intersection delay will depend on the volumes of the two streets, flashing yellow/red generally produces less delay than all other forms of signalized control. Flashing operation is also the most efficient control in terms of fuel consumption and vehicle emissions. However, other results from the literature indicate that flashing operation should not be indiscriminately used. Indications suggest that flashing operation can increase accidents, particularly right-angle accidents. Both rear-end and crossing conflicts were higher for flashing yellow approaches than for approaches with regular, three-color operation. Violations of a flashing red signal were higher than for a solid red signal.

VI. GUIDELINES

The following guidelines for off-peak, flashing operation of traffic signals are primarily based on results of the accident analyses done by TJKM and Mohle, Perry and Associates.

1. Flashing operation may be used when the two-way traffic volume on the main street drops below 150 vehicles per hour.

2. Flashing operation may be used when two-way main street volume is greater than 150 vehicles per hour provided the ratio of main street to total side street volume is greater than 3.

3. At locations converted to off-peak period flashing operation, the accident pattern should be monitored. Signal operation should be changed to regular three-color operation if the accident pattern during the flashing period meets or exceeds the following:

   - A short-term (less than 3 years) rate of 3 right-angle accidents per year during flashing operation.

   - A long term (3 years) rate of 2.0 right-angle accidents per million entering vehicles during flashing operation if the rate is based on 3 to 5 observed right-angle accidents.

   - A long term rate of 1.6 right-angle accidents per million entering vehicles during flashing operation if the rate is based on 6 or more observed right-angle accidents.

In order to adapt these guidelines for use in New York State additional considerations are provided:

1. Flashing operation should not be used where side street drivers have a restricted view of approaching main street traffic. Also, temporary sight restrictions such as parked cars, snowbanks or foliage growth should be accounted for when selecting candidate locations.

2. For continuity of operation, frequent changes between traffic control and flashing should be avoided. The preferred minimum period of flashing operation should be three consecutive hours and, in these cases, the guidelines for flashing operation should be met for each hour.