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Using Traffic Signal Control to Limit Speeding Opportunities on Bidirectional Urban Arterials

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Abstract

Although controlling speed on urban arterials is important for safety, conventional traffic calming techniques cannot usually be applied on arterials, and many jurisdictions prohibit automated speed enforcement. Moreover, unlike unidirectional arterials, bidirectional arterials with short intersection spacing are not amenable to green waves that can remove the incentive to speed. This research explores the ways that traffic signal coordination creates – or limits – speeding opportunities on bidirectional arterials. Two measures of speeding opportunity are proposed: number of unconstrained vehicles, meaning vehicles arriving at a stopline on green and with no vehicle less than 5 s ahead of them, and number of speeders in a traffic microsimulation in which 20% of the vehicles have been assigned a desired speed in the "speeding" range. Theoretical analysis, confirmed by two case studies, show how speeding opportunities are related to degree of saturation, cycle length, specified progression speed (as in input to signal timing software), intersection spacing, and recall settings. The important role of clusters of intersections with near-simultaneous greens, a byproduct of bidirectional coordination with short intersection spacing, is examined. Clusters with many intersections are shown to create a strong speeding incentive, and cluster size can be reduced by lowering the cycle length and the progression speed. Case studies show it is sometimes possible to substantially reduce speeding opportunities with little or no increase in vehicular delay by lowering cycle length, lowering progression speed, dividing an arterial into smaller "coordination zones" with each zone having its own cycle length, and by abandoning coordination altogether.

In an effort to improve traffic safety and livability, many cities, often under the banner of Vision Zero (*1*), are paying increasing attention to speed control. According to NHTSA, 28% of the traffic fatalities in the United States between 2005 and 2014 were speeding related (*2*). Speeding on multimode roads (arterials, collectors, and locals) account for 83% of speeding-related fatalities (*3*). On urban roads, speeding is particularly dangerous due to the prevalence of vulnerable pedestrians and cyclists. In addition, by discouraging walking and cycling, speeding reduces livability and contributes to auto dependence with its negative effects on public health, congestion, energy resources, and climate.

The default method of speed control is setting and enforcing speed limits. Recently, for example, New York, Boston, and several other cities lowered their default speed limits from 30 to 25 mph. However, enforcement on urban roads is very difficult to accomplish by conventional methods. Speed cameras offer an effective solution if widely deployed, but they are politically controversial and are forbidden in many states. Without intense enforcement, drivers tend to ignore speed limits, choosing a speed at which they feel safe based on road geometry and other factors of the road environment such as intersection frequency (*4*).

Road geometry can be very effective at controlling speed, and is the basis for traffic calming devices such as speed humps, chicanes, and neighborhood traffic circles (*5*). However, these methods are unsuitable for arterials for several reasons including emergency vehicle response, bus service, and a desire to offer attractive speeds in order to discourage travel on local streets. And while the concept of "design speed" can be used to control speed on curvy roads, there is no such effect on most urban arterials because they have little curvature.

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Where traffic volumes can be carried with a single lane per direction plus turning lanes, road diets have been highly effective at reducing speed (*6*), because with a single lane per direction, would-be speeders become impeded by vehicles ahead of them. But how can speed be controlled on multilane arterials?

It has long been recognized that on one-way arterials with close intersection spacing, traffic signals timed to offer a green wave can control speed by eliminating the incentive to go any faster than the progression speed. However, on two-way arterials, it is impossible to offer green waves in both directions when intersection spacing is short (*7*), as it is often on urban arterials. In fact, some believe that traffic signals contribute to the speeding problem by giving drivers an incentive to beat the red light when they see a signal that has been green for a while, or has just turned yellow (*8*). In practice, traffic signal timing is applied mainly to regulate conflicts, increase capacity, and decrease delay, with little or no attention given to speed control.

Research Objective and Measures of Speeding Opportunity

Though it may be impossible to provide green waves that positively control speed as easily on two-way arterials as on one-way roads, traffic signal timing may nevertheless play an important role in creating or limiting speeding opportunities. The objective of this research is to see how traffic signal timing on two-way urban arterials with short intersection spacing affects speeding opportunities, and to explore ways in which signal timing can reduce speeding opportunities without substantially increasing delay.

To speed, drivers must have both the desire and the opportunity. Absent constraining geometry or a strong threat of legal enforcement, it is natural for a substantial fraction of drivers to have the desire to speed, and so we focus on speeding opportunities. Stoplines are chosen as points of speed measurement, because intersections have the greatest potential for conflict with other road users (*9–11*). At a stopline, approaching drivers have an opportunity to speed if the signal is green and they are not impeded by a vehicle ahead of them.

Two measures of speeding opportunity are proposed:

- **Number (or fraction) of unconstrained vehicles:** A vehicle is considered unconstrained if it arrives at the stopline while the signal is green and its headway with respect to the vehicle ahead of it in the same lane is greater than 5 s. This quantity can be measured both in the field and using traffic simulation.
- **Number (or fraction) of speeding vehicles:** For traffic microsimulation, this quantity is heavily influenced by the use of a "desired speed" setting chosen by the user. To standardize this measure for microsimulation analysis, we propose assigning to 20% of the vehicles a desired speed within the range considered to be "speeding," and assigning to the remainder a desired speed not considered "speeding." In microsimulation, if the vehicles assigned a high desired speed have the opportunity to speed, they will.

The first measure does not account for speeding opportunities that arise when the vehicle ahead, though less than 5 s away, is speeding, nor does it account for speeders who may be decelerating as they close in on a slower vehicle. The second measure does not have these weaknesses, but suffers from having an arbitrary fraction of vehicles desiring to speed, and therefore cannot be expected to give a measurement that corresponds directly to a field measurement unless calibrated to match the fraction of motorists desiring to speed (a task we did not attempt).

Speeding Incentives and Opportunities with Two-Way Coordination

On a two-way arterial, ideal intersection spacing is when travel time between adjacent intersections equals half the cycle length, in which case two-way coordination can provide the same green waves as are possible with one-way coordination, and therefore they can provide a means of positive speed control. Offsets follow the "half-cycle alternate" pattern, with each intersection offset half a cycle from its neighbor, as shown in Figure 1*a*. Small adjustments to offsets can also be made to favor one direction over another. As travel time is segment length divided by progression speed, the progression speed for ideal two-way coordination is:

$$vProgression = \frac{S}{C/2} \tag{1}$$

where

$vProgression$ = progression speed,
S = segment length or intersection spacing, and
C = cycle length.

Using lead-lag phasing, deviations from ideal spacing equal to half the split of a left-turn phase can also produce ideal bidirectional green waves (*7*), also shown in Figure 1*a*.

With ideal spacing and a progression speed at or below the target speed, there is no incentive or opportunity for the platoon leader to speed. In fact, it may be better to set the progression speed a bit lower than the

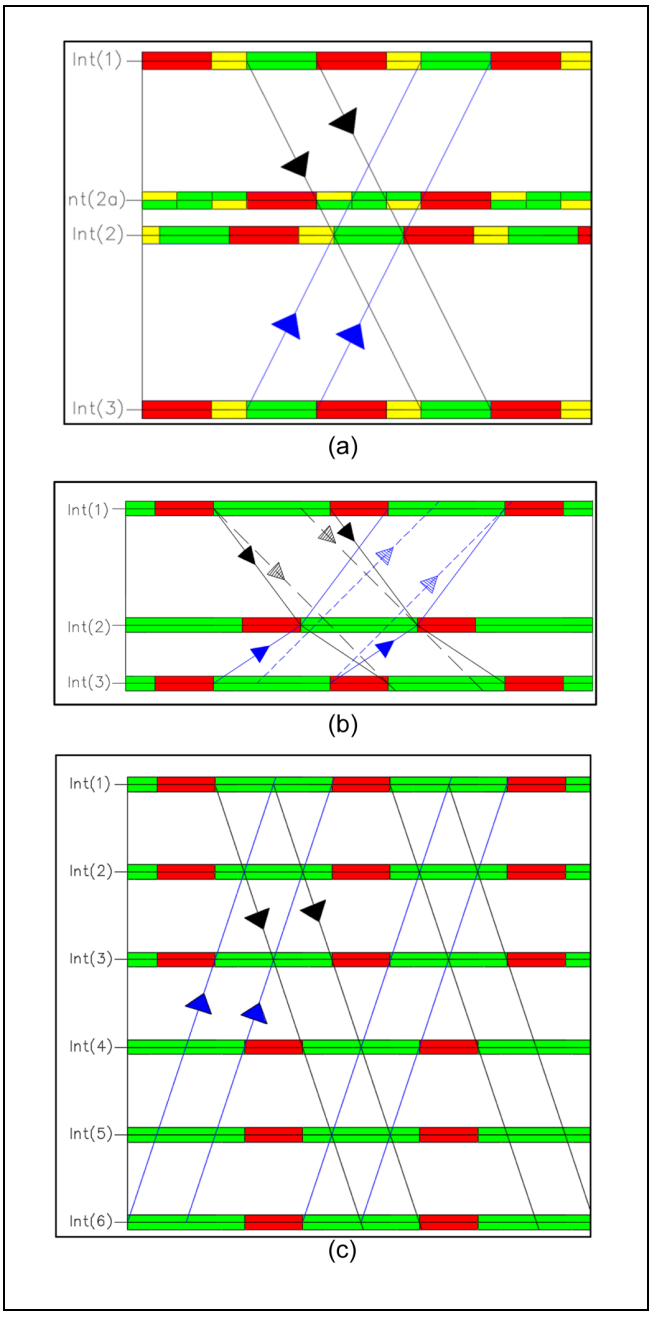

Figure 1. Coordination diagrams for a bidirectional arterial: (*a*) ideal two-way coordination, with lead-lag phasing at 2a. Yellow represents the main street's left-turn phases; (*b*) distorted progression envelope due to non-ideal intersection spacing; and (*c*) bidirectional coordination with clusters of three intersections.

target speed. Denney, Curtis, and Head (*12*) have shown how "holes" in the platoon form as vehicles turn off. A slightly depressed progression speed will slow the platoon leaders down enough to fill these holes, resulting in better capacity utilization; if progression speed is not depressed, vehicles following a hole may speed up to fill them.

Unfortunately, the conditions for ideal spacing cannot be met on most urban arterials. For example, for $C = 90$ s and *vProgression* = 40 ft/s or 27 mph, ideal segment length is 1,800 ft, far greater than signal spacing on many urban arterials. If S were actually 600 ft, then, holding C at 90 s, *vProgression* for ideal two-way progression would be 9 mph, a speed that is impractically low.

Degree of Saturation

When the degree of saturation is high, the platoon will fill almost the entire green period, and so nearly all vehicles will be constrained from speeding. With a low degree of saturation, the green interval will continue well beyond the time needed to clear the platoon, and vehicles approaching during that little-used part of the green will not be constrained.

In conventional practice, a low degree of saturation at many intersections is common, even during peak periods. One reason is the requirement of a common cycle length, typically set to meet the needs of an arterial's busiest or most complicated intersection. Intersections with less cross-street traffic or fewer phases end up with a cycle length far longer than they need, with long periods of unsaturated green that create speeding opportunities. Using smaller coordination zones could help diminish this phenomenon.

Non-Ideal Intersection Spacing

Where signal spacing is not ideal, as is the case for most urban arterials, optimal offsets still follow half-cycle synchronization, meaning every intersection's offset is either 0 or $C/2$, with offsets measured from the center of green averaged over the two directions (*13*). However, progression envelopes become distorted, with high progression speed on some segments and low progression speed on others, as illustrated in Figure 1*b*. Segments with high speed progression offer obvious speeding opportunities.

Unequal Green Intervals

Progression envelopes can likewise be distorted, creating associated speeding opportunities, when green intervals at successive intersections are unequal in length. Unequal green intervals are common; intersections where the cross-street demands are light typically give longer green periods to the arterial street. With coordinated-actuated control, arterial green intervals are random as slack time not needed by cross-street and left-turn phases is used to extend the arterial phases. Severe inequality can result where pedestrian phases, concurrent with the cross-street phase but requiring far more time, are pushbutton-actuated.

Short Segments and Intersection Clusters

On many urban arterials, intersection spacing is far too short to apply the ideal two-way progression paradigm,

as discussed earlier. The standard solution, applied implicitly by signal timing software, is to cluster intersections together, with simultaneous green within each cluster, such that the travel time between adjacent clusters, measured between cluster centers, roughly equals $C/2$. Returning to the original example, if $C = 90$ s and $vProgression = 40$ ft/s, it was shown that ideal intersection spacing is 1,800 ft. If intersection spacing is actually 600 ft, then by forming clusters of three intersections, cluster spacing can be 1,800 ft, with two-way coordination as illustrated in Figure 1*c*.

If n = cluster size (i.e., number of intersections in a cluster), then cluster size for a given cycle length, progression speed, and intersection spacing is given by:

$$n = \frac{vProgression^* C/2}{S} \quad (2)$$

Common traffic signal timing software does not formally identify clusters, but clusters are apparent in their solutions. (Because of left-turn treatments and offset adjustments made to favor the peak direction, clusters with simultaneous green are not always obvious; to spot them, analysts should compare the middle of green, taking an average between the two directions.) Clusters of five or more intersections are not unusual; for example, if $C = 120$, $S = 600$ ft, and $vProgression = 50$ ft/s, n will equal 5.

In practice, Equation 2 will be rounded to an integer, because clusters must be made up of an integer number of intersections. The necessity of rounding means that small changes in *vProgression* may leave the optimal (rounded) cluster size unchanged, which in turn is likely to leave other signal timing parameters unchanged, because offsets are based on clusters and splits are largely independent of both clustering and progression speed. For example, if $C = 90$ s and $S = 600$ ft, changing *vProgression* from 30 mph (44 ft/s) to 25 mph (36.7 ft/s) when applying signal timing software is likely to leave the signal timing plan unchanged, as the ideal cluster size for the two cases (3.3 and 2.75) both round to 3.

The simultaneous green offered within a cluster (see Figure 1*c*) creates obvious speeding opportunities, especially with a large cluster size. Within a cluster, drivers may see several green lights ahead of them, giving them an incentive to go as fast as possible knowing that those green lights may not last long. (Lead-lag phasing can be used to smooth the transition between clusters, reducing—but not eliminating—this effect.)

Hypotheses

Based on the preceding analysis of the nature of two-way arterial coordination, the following hypotheses can be advanced:

H_1: Speeding opportunities tend to be greater with lower degrees of saturation, which involve longer periods of unsaturated green.
H_2: Large clusters of intersections with simultaneous green create many speeding opportunities, and arise when a combination of long cycle length and high progression speed make intersection spacing short, relative to the ideal.
H_3: Changes in progression speed that are too small to change rounded cluster size are likely to have little or no effect on optimal signal timing parameters and performance measures such as delay and speeding opportunities.
H_4: Shortening cycle lengths is particularly effective at limiting speeding opportunities because it both lowers the size of intersection clusters with simultaneous green and increases degree of saturation.
H_5: Compared with conventional arterial coordination, it may be possible to substantially reduce speeding opportunities with little or no increase in vehicular or pedestrian delay.

Study Site 1: Massachusetts Avenue

To test the effects of signal timing parameters on speeding opportunities, two corridors in Boston, Massachusetts were studied; both are sketched in Figure 2. The first is a 0.9 mi stretch of Massachusetts Avenue (Mass. Ave.), a 4-lane arterial, between St. Botolph Street and Melnea Cass Boulevard. This stretch involves nine traffic signals, with intersection spacing averaging 660 ft, with signal timing at the two extreme intersections held constant as a boundary condition. At the time of the study, the traffic signals ran coordinated-actuated with a common cycle of 120 s, except at the Southwest Corridor pedestrian crossing, 300 ft south of St. Botoloph Street, where the cycle length was 60 s. As a rule, the intersections have arterial left-turn phases.

A simulation model of the corridor was constructed using VISSIM, using its RBC module for signal control. The period studied was the a.m. peak hour, using traffic volume data supplied by the city of Boston in which the busiest northbound and southbound segments carry 1,317 and 877 vph, respectively. Each simulation run includes a 15-min warm up period, and reported results are averages of five simulation runs. Measures of performance included average network delay (average delay to all vehicles), corridor delay (average delay to vehicles running the full length of the corridor, averaged between the two directions), number of unconstrained arrivals summed over all of the Mass. Ave. stoplines, and average cycle length as a proxy for average pedestrian delay.

Three alternatives were evaluated: coordinated-actuated control (the scheme currently operated, with

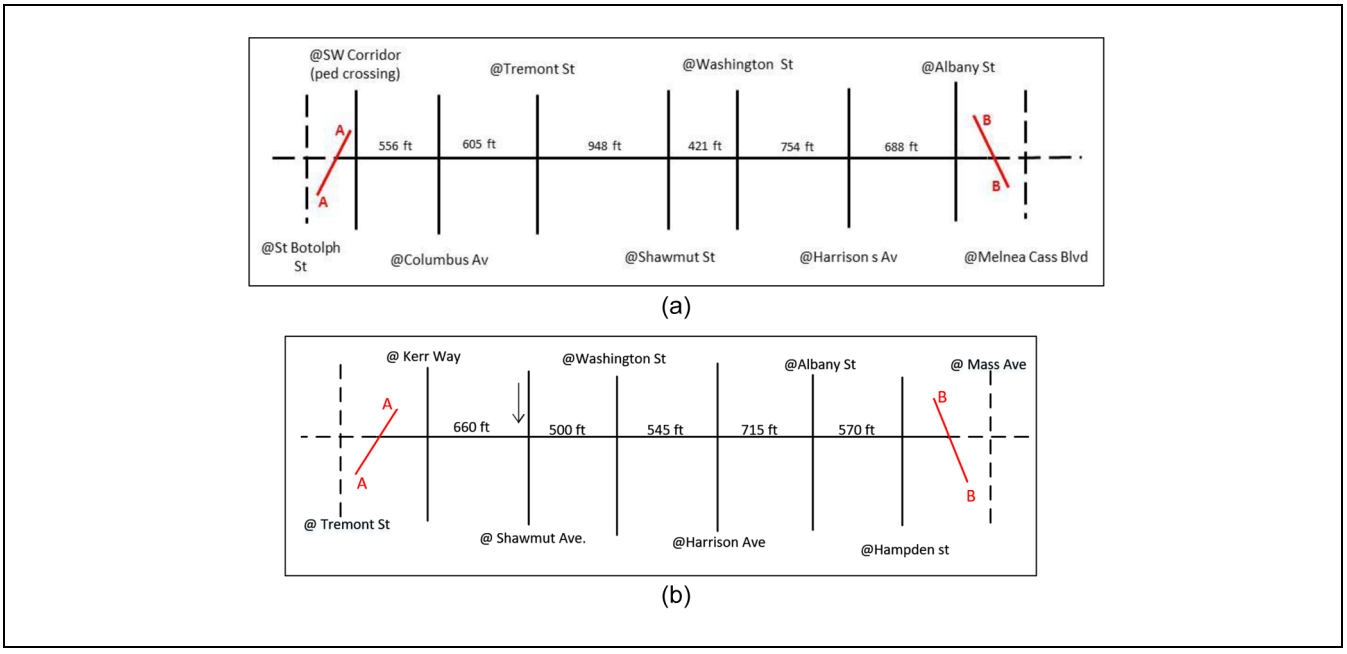

Figure 2. Study Corridors: (*a*) Massachusetts Avenue and (*b*) Melnea Cass Boulevard.

Table 1. Results for Three Signal Timing Plans (Massachusetts Avenue)

Signal timing plan	Average cycle length (s)	Corridor delay (s)	Average network delay (s)	Unconstrained arrivals per h
Coordinated-actuated	113	65	55	2,283
Actuated	78	135	61	798
Zonal coordinated	76	110	48	1,431

timings reoptimized), fully actuated control, and a "zonal coordination" plan. In the zonal coordination alternative, the Southwest Corridor pedestrian crossing ran fully actuated (with pedestrian recall), and the remaining six interior intersections were grouped into three zones of two intersections each, with coordinated-actuated control within each zone, but no coordination between them. Timing plans for the three zones were determined using Synchro, with small manual adjustments, which resulted in cycle lengths of 65 s for the middle zone and 80 s for the other two zones. Segments between zones were at least 750-ft long, long enough to avoid queue interactions.

Key results are shown in Table 1. Coordinated-actuated control, with its long signal cycle and long green periods, has the most speeding opportunities, while also offering the lowest corridor delay. Fully actuated control has the fewest speeding opportunities, but has the longest vehicular delays. The zonal coordination plan has an intermediate number of speeding opportunities, and although its corridor delay is greater than the unzoned coordination plan, it lowers delay so much for crossing traffic and turning traffic that it achieves the lowest average delay for all vehicles.

These results support both hypotheses H_4 and H_5. The two alternatives with substantially shorter cycle lengths allow substantially fewer speeding opportunities. And by placing less emphasis on corridor delay, one alternative (zonal coordination) was found that reduces speeding opportunities by 37% while simultaneously lowering average vehicular delay; another (full actuation) was found that reduces speeding opportunities by 65% while increasing average vehicular delay by only 11%, or 6 s per vehicle (albeit while increasing average corridor delay substantially).

Field Test Confirmation

A field test was undertaken to confirm the ability of the simulation software to model vehicular movements in a way that accurately represents unconstrained arrivals. The southbound approach to the intersection at Tremont Street was observed from 7:30 to 8:30 a.m. on a weekday, videoing the approach and the replaying the video to

manually count vehicles and classify them as unconstrained or not. The total number of arriving vehicles was about 10% greater in the field study than in the simulation (807 versus 729).

The fraction of arrivals classified as unconstrained was 21.7% in the field study, versus 21.8% in the simulation study. This result confirms the validity of the simulation model for measuring unconstrained arrivals.

Study Site 2: Melnea Cass Boulevard

The second study site is a 0.87-mi stretch of Melnea Cass Boulevard (MCB), a 4-lane arterial, between Tremont Street and Mass. Ave. In the simulation model, control at the extreme intersections was left unchanged in order to provide consistent boundary conditions, leaving six interior intersections, as shown in Figure 2*b*. Intersection spacing averages 600 ft.

Currently, the traffic signals run coordinated-actuated with a common cycle of 120 s in the p.m. peak, with a cluster of five intersections (Kerr Way through Albany Street) whose green is essentially simultaneous. This large cluster means that drivers can see green signals for several intersections ahead of them, giving them a strong incentive to speed to try to get through as many intersections as possible before the green ends. Speeding is a common complaint.

The current layout has left-turn lanes on MCB for only some of the intersections, and has protected plus permitted left-turns throughout. In all of the alternatives studied including the base case, the missing left-turn lanes were added and left turns from MCB are protected only. These changes were made to permit a comparison for operation in the near future when the street is rebuilt with a full set of left-turn lanes and with protected lefts.

The corridor was modeled using VISSIM, using its RBC module for signal control. Two different volumes were assigned to the network: p.m. peak hour, using traffic volumes obtained from the city of Boston, and off-peak, defined as 50% of p.m. peak volumes. Each simulation run covers 60 min following a 15-min warm-up period, and results are averages from five simulation runs. Eighty percent of the vehicles were assigned to a class whose desired speed varies from 28 mph to 32 mph, and 20% to a class with desired speed between 38 mph and 42 mph. Performance measures included average vehicular delay, corridor travel time, unconstrained arrivals at all of MCB's interior stoplines, and number of speeders at all of MCB's stoplines. Delay is measured compared with desired speed, which had the same distribution in all alternatives. Speeders were defined as vehicles with speed exceeding 35 mph.

All of the control alternatives tested use coordinated-actuated control, with timing parameters determined using Synchro. The minimum split of through movements is sufficient for concurrent pedestrian crossings. An initial set of tests with and without lead-lag phasing allowed showed that lead-lag phasing resulted in significantly less delay, with little difference in speeding opportunities, and so all of the control alternatives allow lead-lag phasing.

Cycle Length, Progression Speed, and Cluster Size

As discussed earlier, two-way coordination creates a relationship between progression speed *vProgression*, cycle length *C*, and cluster size *n*, whose unrounded value is given by Equation 2. For MCB with its average intersection spacing of 600 ft, Table 2 shows the values of unrounded *n* that correspond to different choices of *vProgression* and *C*; bold formatting is used to indicate combinations expected to result in the same rounded value of *n*, assuming a bias in rounding in which fractional values above 0.4 are rounded up.

Impact of Volume, Cycle Length, Progression Speed, and Degree of Recall

Table 3 shows the performance measures for two sets of volumes (peak and off-peak), a variety of cycle lengths between 70 and 120 s, and a variety of progression speeds between 15 and 35 mph. Corridor travel time was measured but is not reported for conciseness because it was so strongly correlated with network delay (correlation coefficient 0.99 off-peak, 0.96 peak).

An important methodological finding is that the two measures of speeding opportunity proposed are strongly correlated, with correlation coefficient 0.97 off-peak and 0.98 peak. The overall average ratio of speeders to unconstrained vehicles is 0.23 off-peak and 0.19 in the peak, close to the specified fraction (0.20) of drivers whose desired speed lies in the "speeding" range. This finding confirms that unconstrained vehicles is a good measure of speeding opportunity; it also suggests that

Table 2. Implied Cluster Size as a Function of Cycle Length and Progression Speed When Intersection Spacing Is 600 ft

	Cycle length (s)			
Progression speed (mph)	70	80	100	120
15	1.3	**1.5**	**1.8**	**2.2**
20	**1.7**	**2.0**	2.4	2.9
25	**2.1**	2.4	3.1	**3.7**
30	2.6	**2.9**	**3.7**	**4.4**
35	3.0	**3.4**	**4.3**	5.1

Note: Bold indicates cells with a common rounded cluster size.

Table 3. Timing Plan Performance for Different Cycle Lengths and Progression Speeds

				Off-peak			Peak		
Cycle length (s)	Progression speed (mph)	Ideal cluster size	Pedestrian delay (s)	Vehicular delay (s)	% unconstrained vehicles	% speeders	Vehicular delay (s)	% unconstrained vehicles	% speeders
70	15	1.3	28	57	12%	2.7%			
	20	1.7	28	33	16%	4.1%			
	25	2.1	28	32	16%	4.1%			
	30	2.6	28	31	22%	5.5%			
	35	3.0	28	33	22%	5.4%			
80	15	1.5	33	54	16%	3.6%	80	9%	1.2%
	20	2.0	33	44	17%	3.7%	46	10%	1.8%
	25	2.4	33	36	22%	5.2%	45	10%	2.1%
	30	2.9	33	30	24%	5.7%	43	11%	2.3%
	35	3.4	33	41	24%	5.7%	50	14%	2.8%
100	15	1.8	43	46	23%	4.7%	57	12%	2.1%
	20	2.4	43	38	23%	4.7%	45	15%	2.9%
	25	3.1	43	37	25%	4.9%	43	15%	3.0%
	30	3.7	43	33	28%	6.0%	43	16%	3.3%
	35	4.3	43	35	32%	7.0%	58	16%	3.3%
120	15	2.2	53	62	23%	5.2%	74	12%	2.1%
	20	2.9	53	48	25%	5.5%	54	15%	3.2%
	25	3.7	53	35	35%	8.5%	54	17%	3.5%
	30	4.4	53	35	36%	8.6%	49	20%	4.0%
	35	5.1	53	35	36%	8.3%	49	20%	4.0%

either of the proposed measures of speeding opportunity can be used with similar fidelity.

Looking at differences in performance, one obvious result is that speeding opportunities are far greater with off-peak volumes than peak volumes, confirming hypothesis H_1.

Another is that speeding opportunities tend to increase with cycle length, illustrated in Figure 3 and confirming hypothesis H_4. Capacity analysis shows that the minimum common cycle that provides sufficient capacity and satisfied pedestrian minima is 70 s for off-peak and 80 s for peak volumes; increasing cycle length beyond that minimum, especially with the low degree of saturation prevalent in the off-peak, substantially increases speeding opportunity.

The impact of changes in progression speed tends to be stepped, as illustrated in Figure 4 for the case of off-peak volumes and $C = 70$ s. In most cases, it makes a difference only when the change in progression speed is enough to alter cluster size, confirming hypothesis H_3.

Figure 4 also shows how three recall options – no ped recall (pedestrians use a pushbutton), ped recall (pedestrian phase is called automatically, our default option), and maximum recall (same as pre-timed operation) – affect speeding opportunities. When not in pre-timed mode, fixed forceoff (as opposed to floating forceoff) is applied to non-coordinated phases, consistent with local practice. Weaker recall settings randomly start arterial phases early, creating additional speeding opportunities that are evident in the results. However, stronger recall settings tend to give more unsaturated green time to cross streets, which may create speeding opportunities there, and so it would be unwise to conclude anything about what are the best recall settings for speed control without studying speeding on the cross streets as well as the arterial.

With regard to hypothesis H_2, Table 3 shows a clear trend of speeding opportunities increasing with cluster size. For the off-peak, the case with the smallest values of n has only 12% unconstrained vehicles, versus 36% for the case with the largest n. This confirms the hypothesis that large clusters of intersections with roughly simultaneous green create speeding opportunities.

Table 3 also shows the vehicular delay, pedestrian delay, and corridor travel time for each signal timing alternative. Corridor travel time is so strongly correlated with vehicular delay in this case study that it is not further discussed. Pedestrian delay is likewise strongly correlated with cycle length. Note that vehicular delay was measured using VISSIM and is based on desired speed, which follows the same distribution with an average value of 32 mph in every alternative, regardless of the progression speed used to select signal timing settings.

Because average desired speed is 32 mph, one might expect that the least delay occurs when signal timing has been optimized for a speed of 30 or 35 mph. Indeed,

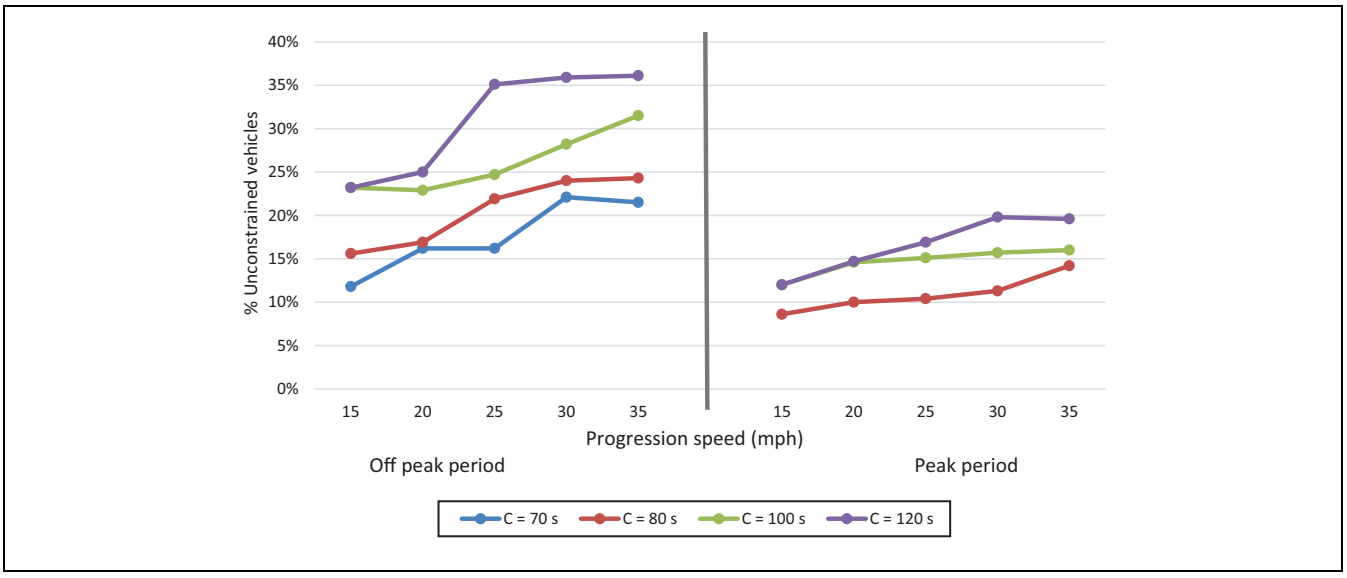

Figure 3. Unconstrained vehicles as a function of cycle length, specified progression speed, and traffic volume.

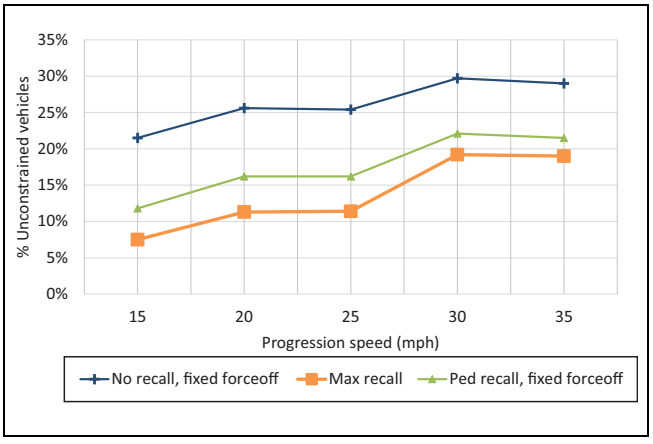

Figure 4. Unconstrained vehicles versus progression speed (off-peak volumes, cycle length = 70 s).

progression at 30 mph gives consistently low-delay results; in contrast, progression at 35 mph clearly tends toward greater delay. This confirms the beneficial effect mentioned earlier of a progression speed slightly below the average speed. Solutions with a progression speed of 15 mph have a large average delay, but most of those with progression speeds of 20 and 25 mph perform well with respect to vehicular delay.

Figure 5 illustrates the tradeoff between average vehicle delay and unconstrained vehicles for all the solutions in Table 3. One can see that for both off-peak and peak, Synchro's recommended timing plan based on default parameters performs well in relation to vehicular delay, but has considerably more speeding opportunities. Off-peak, reducing progression speed from 30 to 25 mph cuts speeding opportunities by 27% while increasing vehicular delay by only 5% (and leaving pedestrian delay unaffected); in the peak, reducing the cycle length from 100 to 80 s cuts speeding opportunities by 28% without any change in vehicular delay (and with a 23% decrease in pedestrian delay).

Conclusion and Further Research

An increasing number of cities recognize that controlling vehicle speeds in vital for improving safety and livability. This research has explored the potential for doing so using traffic signal settings on multilane, two-way urban arterials with close intersection spacing.

The number of unconstrained vehicles, measured at stoplines, was found to be a valid measure of speeding opportunities. A field measurement confirmed that this measure could be reliably measured by traffic microsimulation, and simulation study confirmed that it is strongly correlated with the number of speeding vehicles in a setting in which 20% of all vehicles were specified as having a desired speed in the "speeding" range.

Both case studies found that compared with conventional arterial coordination, it was possible to substantially reduce speeding opportunities with little or no increase in vehicular delay. Case study experiments confirmed that with standard arterial coordination, speeding opportunities increased with longer cycles, lower degree of saturation, and closer intersection spacing. Speeding opportunities are related to cluster size, that is, the number of consecutive intersections with simultaneous offsets, which is inversely proportional to effective intersection spacing (travel time between neighboring intersections measured in number of cycles). Shortening cycle length is particularly effective at limiting speeding

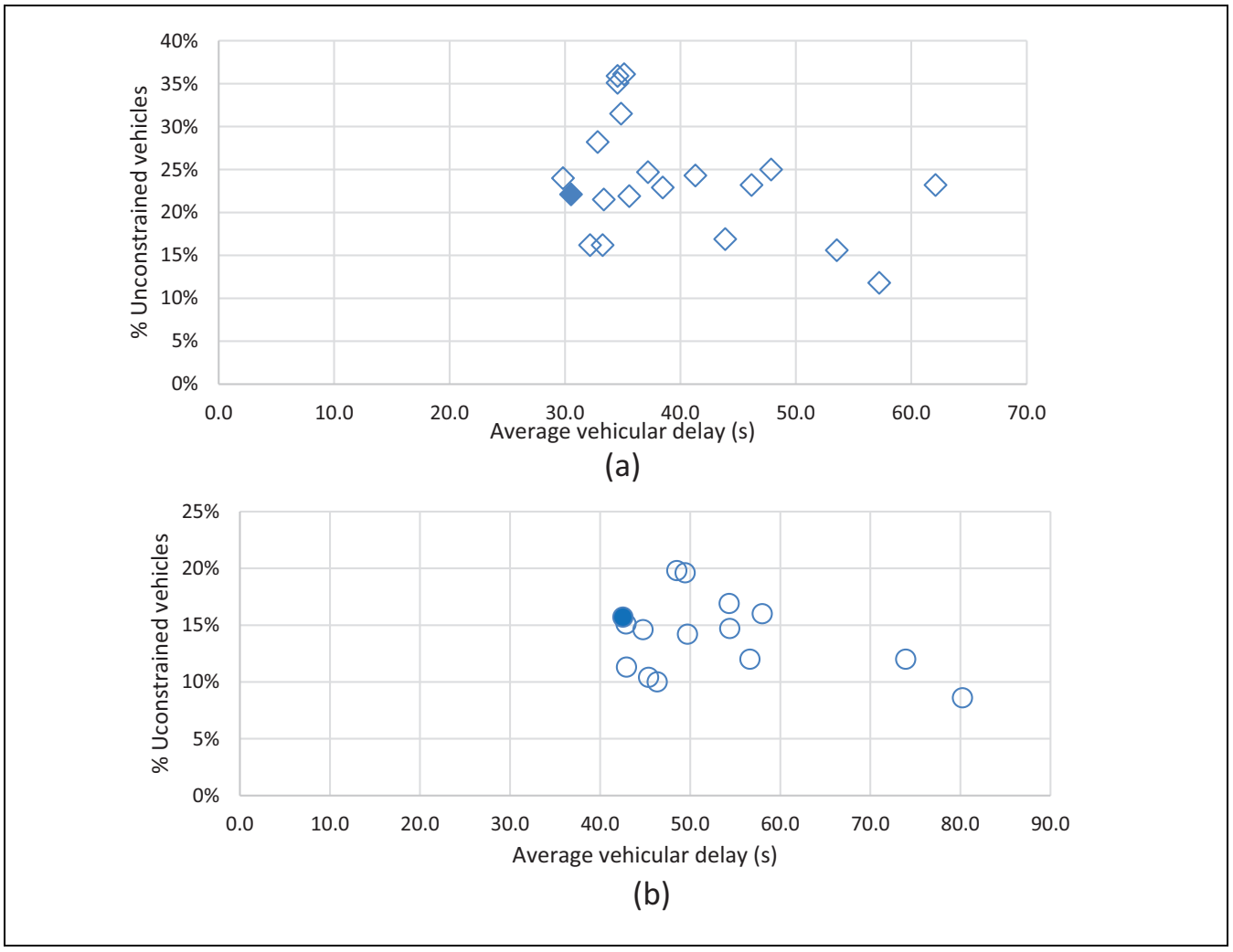

Figure 5. Delay vs. speeding opportunities for timing plans with different cycle length and progression speed. Solid markers indicate timing plans recommended by Synchro: (*a*) off-peak; and (*b*) peak.

opportunities because it both increases effective intersection spacing and reduces periods of unsaturated green; it also has the side benefit of lowering pedestrian delay.

Lowering progression speed – an input to signal timing software – can also reduce speeding opportunities, because it increases effective intersection spacing. However, small changes in progression speed can have no effect at all if they do not lead to a decrease in cluster size. Recall and minimum green parameters that make the length of the arterial through phases less variable also help reduce speeding opportunities.

Abandoning coordination altogether has the strongest effect on reducing speeding opportunities, but the delays and queue interactions this could lead to may be unacceptable. Short of that, breaking an arterial into small coordination zones, with coordination within each zone but each zone free to have its own cycle length, was found in one case study to sharply reduce speeding opportunities without increasing network delay. Adaptive control methods that achieve a degree of coordination without imposing a common cycle, such as self-organizing control (*14*), may also be effective at limiting speeding opportunities while maintaining a good level of service; that question is left for further research.

Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: PF, AH; data collection: AH, JL, WH; analysis and interpretation of results: PF, AH, BC; draft manuscript preparation: PF, AH, JL, WH. All authors reviewed the results and approved the final version of the manuscript.

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