INTERSECTION TRAFFIC ENGINEERING APPENDICES

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APPENDIX A: LEADING AND LAGGING FLASHING GREEN ARROWS

Once the decision to install a right turn flash is made, the question of whether the flash should be leading (before the main stage) or lagging (after the main stage) needs to be made. Choosing between lagging and leading green arrows should be based on traffic flows and safety.

A.1. RULE

For the reasons below, the following is the suggested rule:

- If the flash is needed from one side only, and the opposite right turn is possible, the flash **must always be leading**. The through green disc must appear at the same time as leading flashing green arrow from that approach (to ensure both the straight through and the right turn traffic flows are not confused by what would otherwise be an unexpected sequence).
- **In all other cases, the flash should be lagging**.

A.2. REASONS FOR LAGGING GREEN FLASHES

The reasons why a lagging green arrow is better than a leading green arrow, where there is no opposing unprotected right turn, are:

A.2.1. LAG GREEN COMPLIES WITH THE RULE OF THE ROAD

The rule of the road is that right turners give way to traffic from opposing directions. It is of course extremely important from a safety point of view that motorists comply with this rule. It makes sense therefore that a lagging green flash, which gives priority in accordance with this rule, should be preferred. A leading right turn arrow allows right turning to take place before opposing traffic moves, hence violates this rule. For this reason, leading greens should be limited only to where a lagging green is not permitted.

A.2.2. LAG GREEN IMPROVES TURNING SAFETY

This is a difficult area to research, but other than situations involving the "yellow trap", it is usually found that lagging green is safer. The Purdue University 1989 study found "*that, in general, lagging sequences at selected types of intersections can provide safety and delay advantages over the (more common in Indiana) leading sequences*".

Nowhere in the literature was it found that a leading green was safer, despite the alleged advantages of:

- opposing traffic is stopped when the turn is executed;

- most of the turns take place before the main stage and therefore less turners need to take gaps.

Counter arguments are that with a lagging flash:

- turners will not assume opposing vehicles will stop but will wait until they do;
- turners are not pressured to take gaps because they know the flash will follow.

A.2.3. Lag Green Improves Pedestrian Safety

There is consensus that lagging green is safer for pedestrians, e.g. "*An advantage of the lagging right-turn phase is that it provides significantly better separation between right-turning vehicles and pedestrians. This is a particularly important advantage in areas with high pedestrian volumes*" (SA Road Traffic Signs Manual).

A.2.4. Lag Green Meets User Expectations

Drivers and pedestrians waiting at a red signal will often observe the signal on the cross road and expect to get a green signal when the cross-road signal goes red (this may not be ideal, but it is a fact). A leading green arrow gives rise to false starts when the expected green is not given and could lead to collisions.

Furthermore, a driver in a straight or left turning lane does not expect a vehicle in the adjacent right turn lane to get a green signal before him/her, a situation occurring when a leading green is displayed before the main stage. To avoid through drivers proceeding at the same time as right turners in error, if leading right turn flash is given, the green through disc signal should be shown simultaneously.

A.2.5. Lag Green Eliminates Hazardous Late Turns

Motorists turning right at a leading green often continue turning in front of oncoming vehicles even after the termination of the yellow arrow. This aggressive behaviour commonly results in equally aggressive behaviour from motorists on the opposite side who start moving into the intersection as soon as the green for them is displayed. This behaviour can be regularly observed and can result in crashes.

A.2.6. Lag Green Increases Capacity

The most difficult movement at an intersection and the movement with the lowest capacity is the right turn. In the case of a lagging green arrow, motorists move into the intersection and wait for

an opportunity to turn right. As soon as there is a suitable gap, or as soon as the opposing green terminates, they are ready to turn and efficiently use the available time. The front vehicles can often start turning before the flash even begins.

With a leading right turn arrow, right turning motorists are waiting back at the stop line when the arrow starts. At the commencement of the flash, they must observe and react to the (often unexpected) arrow, proceed into the intersection, check that the opposing vehicles are not moving and then only make the turn. Sometimes, especially if they are not aware of, or are not expecting, the leading arrow, there can be additional delay before the motorist realizes (usually by the person behind hooting) that he/she has the priority.

In their paper, "The Effect of a Leading Green Phase on the Start-up Lost Time of Opposing Vehicles" delivered at the SATC 2002, Bester & Varndell showed that the start-up lost time of opposing vehicles was significantly increased when using a leading green. At an intersection in Stellenbosch, it was estimated that an approach could lose up to 13 minutes over a full day due to a leading green. It was however pointed out that some of this lost capacity was regained at the end of the main green through cycle when right turners can utilize the inter-green.

Furthermore, because of the greater turning efficiency, lagging greens can be kept quite short when traffic flows allow. A lagging green can be as little as four or even three seconds long while a leading green should be a minimum of seven seconds to allow for the starting delays.

A.2.7. Lag Green Improves the Efficiency of Vehicle Actuated Signals

If vehicle-actuated control is used at a signalized intersection, a lagging arrow is more efficient. The right-turn phase is only called if a vehicle is detected behind the stop line waiting to turn at the end of the stage. The lagging arrow is therefore only needed if there are right-turners who could not accept gaps or use the inter-green during the permitted phase and are still waiting to execute the right turn. In contrast, the leading arrow will almost always be called at the start of the main green phase because vehicles will have arrived during the red. The signal controller does not know whether these right-turners will be able to accept gaps during the following phase and hence the flash is given. To partially overcome this problem with leading greens, the detector loop is often placed around 10m behind the stop line.

A.2.8. Lag Green Is more efficient when flows are balanced

If the right turn volumes on opposite sides both require a protected phase, it is preferable and more efficient to use a lagging green, due to the scenarios described above.

A.3. ADVANTAGES OF LEADING GREEN FLASHES

The circumstances under which a leading green arrow is preferred are:

A.3.1. LEAD GREEN AVOIDS THE "YELLOW TRAP"

Lagging right turn green flashes running with through movements from one side only at junctions where the opposite right turn is possible (a situation known as the right turn or yellow trap) is extremely dangerous and is not permitted.

The yellow trap occurs when right turning vehicles opposite a lag flash on the other side move into the intersection and wait to turn during the permissive only (no lag flash) "main" phase. Those vehicles see a yellow followed by a red disc signal. As they are now 'stranded', or 'trapped' within the intersection, they will try to clear by turning right in the face of oncoming traffic, not realizing that vehicles coming from the opposite side have a green disc signal. A lagging right turn green and through from one side only is therefore never allowed when right turns from both sides are permitted.

This problem does not arise at T-junctions, diamond interchanges, or cross-junctions where the cross-road is one-way so here the lagging green is again preferred.

A.3.2. LEAD GREEN CATERS FOR UNBALANCED FLOWS

It is a common occurrence, especially during peak periods, that due to tidal flows the majority of through and right turn traffic approaches from the same side of the intersection. In these cases, it is advantageous to be able to display the through green and protected right turn flash at the same time while the opposite side is stopped.

This is the major reason for using leading greens.

A.3.3. LEAD GREEN ALLOWS FOR SHARED LANES AND SHORTER AUXILIARY LANES

In cases where right-turners share lanes with other movements (combined straight and right lane marking) or the auxiliary lane is very short, a leading arrow is preferable. The right-turners in the shared lane or overflowing from the short right turn lane will be able to turn unopposed at the start of the through green, and do not need to wait for gaps in opposing traffic; hence they do not delay through movements when the green signal begins. The likelihood of right turners delaying through vehicles later in the cycle is also reduced, as it is hoped that the majority of right turners will have been catered for during the protected phase.

A.3.4. LEAD GREEN ALLOWS PHASE SKIPPING

It is sometimes desirable to have the protected right turn phase running during peak periods only. During off-peak periods, the reduced number of right turners will clear during the permitted phase. With a leading green, skipping the phase when it is not needed is less likely to lead to problems.

With a lagging green, motorists may not wish to take gaps and might wait for the protected phase to begin. When this phase is skipped, they are 'stranded' in the middle of the intersection. While this can still happen in the leading green case with the stranger who observes the right turn head and expects a protected phase, it is less likely to occur.

In general, however, because of the confusion that it creates, it is not recommended that phases are skipped.

A.3.5. LEAD GREEN ALLOWS PHASE ROTATION

A further advantage of leading green is that can be rotated from one side of the intersection to the other to cater for changing direction of higher demand flows. It may be desirable to have the protected phase on opposite sides of the intersection during AM and PM peak periods for example. This of course is not necessary with lagging greens which serve both sides, neither is phase skipping necessary, but that is only the case when flows are balanced.

A.4. SIGNAL CO-ORDINATION

In certain instances, the green wave in a co-ordinated signal system can be affected by whether the flash is displayed before or after the main phase, especially if the intersection involved is a T-junction. While this is unlikely to be a determining factor, it should be noted that either a leading or lagging green could be fitted into the progression scheme on an arterial. These situations need to be considered on their merits when the co-ordination plan is prepared.

A.5. CONCLUSION

To provide for national consistency, standardization and safety when determining whether leading or lagging right turn flashes are installed, the following simple rule is proposed:

- If one side only and the opposite right turn is possible, the flash must be leading.
- In all other cases it should be lagging.

A further consideration is that when a protected right turn phase is introduced, especially a lagging phase, it should preferably be shown all day (not skipped).

(This paper was edited from a paper by the same author dated 22 May 2003.)

B. APPENDIX B: THE CHALLENGE OF ALL-WAY STOPS

B.1. INTRODUCTION

Certain authorities have chosen to erect Stop signs on all approaches to an intersection. This results in the all-way Stop or 4-way Stop as it is popularly known.

Various reasons for the introduction of all-way Stops are given, usually perceived or predicted accident problems, or to force vehicles to use other routes, or sometimes to prevent speeding (traffic calming). In many instances public pressure is brought to bear on the local authority to arbitrarily erect Stop signs and this pressure too has been given as a reason for installing all-way Stops.

The professional traffic engineering fraternity generally does not support all-way Stops for justifiable reasons. This paper examines the role of all-way Stops, their effectiveness, and possible alternatives. It also proposes conditions for the installation of yield and stop signs in general.

B.2. ADVANTAGES AND DISADVANTAGES

The following are the claimed advantages and disadvantages of all-way Stops:

B.2.1. ADVANTAGES

- Causes vehicles to seek other routes;
- Reduces collision risk;
- Reduces speeding;
- Assists difficult turning manoeuvres;
- Can resolve poor sight distance problems;
- Pedestrians are assisted;
- Can be used temporarily where traffic signals are warranted;
- Acceptable to public and politicians.

B.2.2. DISADVANTAGES

- Full stop illegally ignored by majority of motorists;
- Respect for Stop control is reduced, reducing safety at other intersections;
- Leads to flouting of the law;

- Enforcement is resented and often Traffic Officers are reluctant to enforce the clearly unreasonable restriction;
- Creates more (deliberate and unnecessary) delay than any other form of control;
- Reduces capacity of the intersection;
- Cost of delay and wasted fuel outweighs alleged and unproven accident benefits;
- Confusing because right of way is not well defined;
- Very dangerous / impossible to restore normal priority control;
- Speeds between intersections can increase;
- Contributor to driver aggression, or road rage (the opposite of traffic calming);
- Can cause traffic to divert to less favourable routes resulting in demands for all-way Stops on those routes too;
- Inflexible; applies for 24 hours a day.

B.3. ADDITIONAL CONSIDERATIONS

The practice of installing all-way Stops has escalated in many of the municipal areas in South Africa. The standard Stop sign is simply erected on all approaches to the intersection, even though the sign is now changed in meaning and the expected motorist response must change too. In most instances, motorists are left to pick up subtle clues to decide how to treat the sign.

The violation rate at all-way Stops can reach ninety per cent (CSIR 1980 unpublished study plus site observations). Certain enforcement authorities use this fact as a ready source of easy revenue.

Right of way, while supposedly first come – first served, is not well defined at an all-way Stop. Sometimes vehicles on the major road believe they have priority over a minor cross street and proceed even if the cross-road vehicle arrived first. When there is a queue and it is not clear who arrived first, there is further confusion, especially on wide intersections.

Some drivers are either overly courteous or excessively cautious and wait regardless, even for those vehicles that clearly arrive after them, hence reducing capacity further and delaying following vehicles. Some motorists wait unnecessarily for all cross traffic to come to a complete stop (or do not realize it is an all-way Stop) before proceeding. Others treat service on a push-in basis, even if it means proceeding in the path of opposing traffic or following the vehicle in front without stopping or waiting.

All methods are generally unsatisfactory, and all violate the proper principle of the Stop sign which is that motorists waiting at the sign must not proceed until the intersection is clear of approaching vehicles that might cross their path.

Motorists accustomed to proceeding in the face of oncoming traffic, as is the procedure at an all-way Stop sign, have caused some catastrophic crashes when they misconstrue a two-way Stop as an all-way Stop somewhere else. The same problem arises when all-way Stops have been reconverted to two-way control and motorists at the Stop street do not stop or wait for cross traffic.

The latter problem, changing all-way Stops back to two-way is dangerous because, after removal of the main road Stop signs, motorists at the Stop on the side street see a car approaching but proceed without realizing the approaching vehicle now has the right of way. This problem is so serious that removing an all-way Stop and is seldom attempted, even when the original conditions necessitating its existence no longer apply. In the late 1980's, the CSIR National Institute of Transport and Road Research did some research into ways of overcoming this but results were inconclusive, and the research was stopped.

There is also the "halo effect" to contend with, when motorists accustomed to all-way Stops pull off inadvertently at two-way Stops. In these cases, the two-way Stop is blamed for causing the accident when in fact the all-way Stop, with its apparently lower crash rate, is the cause of the crash remote from its location. Crashes tend to migrate away from the all-way Stop to other intersections.

B.4. ALTERNATIVES TO ALL-WAY STOP SIGNS

In the author's opinion all-way Stops should be banned in urban areas. Two alternatives are therefore suggested.

The best and ultimate alternative to an all-way Stop is to replace it with a mini-circle. The mini-circle is an all-way Yield and hence replicates the behaviour of most motorists at an all-way Stop. The mini-circle therefore legalizes the movements that most motorists practice.

In addition, given its small size, the mini-circle will also operate on a first come – first served basis. Furthermore, it has all the alleged advantages of an all-way Stop, such as reducing speeding and traffic calming, and has none of the disadvantages.

If a mini-circle is not adopted, then the standard Stop sign should never be allowed to be displayed at an all-way Stop. Because the behaviour expected from the driver changes and because the rules of conduct at all-way Stops are different, the sign should not look like a Stop sign. Adding a 3 or 4 below is also inadequate; a new sign is therefore required.

Two suggestions are:

- retain the existing octagonal shape but replace the word STOP with a 3 or 4.
- replace the octagon with a red circular sign with 3 or 4 in white.

Both suggestions comply with the regulatory colours and sign matrix, however the second is more distinctively different and preferred.

The new sign would achieve three objectives:

1. It alerts the motorist to an all-way Stop situation;

2. It can be defined differently from the standard Stop sign to cater for the different motorist behaviour expected;

3. It can later be removed and replaced with a standard Stop or other sign, which helps alert the motorist to the changed condition.

In addition, the law should be amended to require vehicles to yield, not stop at the new sign.

B.5. WARRANTS FOR ALL-WAY STOPS

B.5.1. INTRODUCTION

All-way Stop signs are allowed by some agencies in the following "non-standard" situations:

1. As a speed control measure;
2. To discourage use of a street;
3. When approach speeds to an intersection are in excess of 64 km/h (40mph);
4. To protect school crossings.

A study by the CSIR in the 1970's found no international agreement on warrants for Stops and all-way Stops, although accident experience appeared frequently.

B.5.2. MUTCD WARRANT

Only the USA specifies an all-way Stop warrant, as follows:

1. Where traffic signals are warranted and urgently needed, the all-way Stop is an interim measure that can be installed quickly to control traffic while arrangements are being made for the signal installation.

2. An accident problem, as indicated by five or more reported accidents of a type susceptible to correction by an all-way Stop installation in a twelve-month period. Such accidents include right and left turn collisions as well as right angle collisions.

3. Minimum traffic volumes:

(a) The total vehicular volume entering the intersection from all approaches must average at least 500 vehicles per hour for any 8 hours of an average day, and

(b) The combined vehicular and pedestrian volume from the minor street or highway must average at least 200 units per hour for the same 8 hours, with an average delay to minor street vehicular traffic of at least 30 seconds per vehicle during the maximum hour, but

(c) When the 85-percentile approach speed of the major street traffic exceeds 40 miles per hour (64 km/h), the minimum vehicular volume warrant is 70% of the above requirements.

B.5.3. STOP SIGNS AS A SPEED CONTROL DEVICE

The MUTCD (USA) specifically states that Stop signs should not be used to control speeds. However, local authorities regularly receive requests for Stop signs to control speed.

Conceptually it appears obvious that Stop signs will reduce vehicle speeds. A study done in Michigan shows however that not only are Stop signs ineffective in this respect, but they are frequently ignored. The results at four study sites in residential areas in Michigan found that there was a tendency for mid-block speeds to slightly increase after Stops were installed but this was not significant. Only one quarter of motorists obeyed the Stop sign.

B.5.4. ALL-WAY STOP SIGNS AS A SAFETY DEVICE

Studies at several locations have revealed that all-way Stops provide greater safety than traffic signals when volumes are low. Volumes on the minor streets must however be at least 35% of that on the major street as intersections with ratios less than that indicate sharp increases in accident rate.

It was also found that excessive use of four-way Stops where two-way Stops were adequate also can result in sharp increases in accident rates. It was proposed therefore to use the lesser control unless found to be inadequate.

APPENDIX C: OTHER REFERENCES

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Lagging v. Leading Green Flashes

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