Impact of the signal control strategy on red light running

Sophie Midenet

INRETS-GRETIA Transport Network and Advanced Software Engineering laboratory, the French National Institute for Transport and Safety Research,
2 av Général Malleret-Joinville, F-94114 Arcueil Cedex, France
sophie.midenet@inrets.fr

Abstract. This article concerns red-light running at intersections and deals with the impact of different types of control strategies. Red running occurrences at red onset are observed through multi-camera observation system installed on an isolated intersection that runs under different control strategies. We analyse the variety of conditions produced during the phase change interval, in terms of exposure to violate for approaching drivers on the link and in terms of surrounding conditions: downstream crossing possibilities, opposing stream presence, upstream past crossing conditions. Some specific features have been identified for further impact analysis in the data base, as they depend on the control strategy and impacts red running behaviour. We investigate for instance very short time intervals between the red switchovers of successive signal lines.

1 Introduction

This article concerns red-light running at intersections and deals with the impact of different types of control strategies on this phenomena. Red-light running is known to be a frequent traffic event (one out of three observed cycles with at least one red runner according to Porter and England [11]) as well as a dangerous one (19% of total accidents on signalised intersection according to Hulscher [4], with highest casualties rates than others [12]).

Focusing on red-light running at red switchover (i.e. during the few seconds after the signal turns amber then red), we study red-running occurrences observed under different control strategies. We analyse the surrounding conditions produced by the control strategies at the beginning of the red phase, in terms of exposure to violate for approaching drivers on the link, but also in terms of contextual conditions like downstream crossing possibilities.

This study is based on data collected from a multi-camera observation system that automatically detects red-light running occurrences. The system is installed on an isolated intersection that can run under two types of control strategies: a time-plan based strategy with vehicle actuated ranges on the one hand, and an adaptive real-time strategy based on video sensors measures on the other hand. These two types of strategies highly differ in their means of information about traffic and their decision process for switching the signal states. Thus they lead to various instantaneous conditions in terms of traffic configurations and signals patterns over the controlled area.

Making use of this wide spectrum of situations at red switchovers, our aim is to analyse the role of the surrounding context of approaching drivers in their compliance with traffic signal, besides their speed and distance to stop line. In this paper we present the first step of this study: the identification of contextual elements that occur on four observed signal lines and which could lead to an impact analysis. We plan to derive quantitative results on the effects of each identify element on a further step.

2 Control strategy and red light running at red onset

2.1 Driver's decision at the end of the green phase

Important literature is available regarding the decision process at the end of the green phase for a driver approaching the stop line: [4], [13], [14], [15]. It has been shown that his decision depends primarily on its distance to stop line and on his speed at the onset of amber. Mahalel [8] infers from empirical observations that there exists an indecision zone at some distance of the stop line. Most of drivers clear the line if ahead and stop if behind. The decisions of the drivers that are caught inside are divided. The amber and all-red phases have been defined and designed for the purpose of allowing the decision making process to occur in safe conditions, i.e. before the green signal is given to opposing stream. Most studies involving the impact of control strategy on red compliance deal with the signal sequence: effect of duration of amber and all-red phases ([4], [12]), effect of a flashing green phase before amber ([6]). In our cases the signal sequence is fixed whatever the control strategy: 3 seconds for the amber interval and 2 seconds for the all-red interval, without flashing green before amber.

2.2 Two types of control strategy

The first control strategy that runs on the observed intersection is a time-plan based strategy, with vehicle actuated ranges on each approach. The signal phase's sequence is predefined and remains fixed, but vehicle presence detected by magnetic loops can lead to green phase extension. Similar strategies have been shown to improve signal compliance ([5], [13], [15]). The green extension process impacts on the indecision zone – occupation and position ([13]) -, since the decision for the control system to close the green phase depends on the traffic detected on the link by the magnetic loop.

The observed intersection is alternatively controlled by a real-time adaptive strategy named Cronos [1]. Its algorithm optimizes the entire set of signal according to queue lengths on approaches and spatial occupancy rates on internal sections, measured every second by video sensors. It includes an optimisation method designed to minimize total delay. The signal phase's sequence is not predefined, neither the cycle duration. This strategy continuously looks for optimised sequences and durations of signal states, while preserving a set of safety constraints which define the forbidden duration and correlation between traffic signals. In the case of Cronos the decision to close the green phase of one traffic signal does not only depend on the traffic upon the link but results from a decision process that considers traffic and signal states on the entire intersection. Video sensors enable to cover the whole area: inbound approaches (until about 200m), inner sections and outbound legs.

2.3 Various configurations during the phase change interval

The two control strategies greatly differ in the decision process of closing the green phase. They impact differently on the traffic distribution of the link at the onset of amber, and thus have different effects of the exposure to red-running occurrences ([13]). The direct impact of both control strategies on red-running rates is then expected to be different.

The analysis of our data could reveal indirect impact as well, since the two strategies produce different traffic configurations and signal patterns over the all area. Previous comparative studies on these data ([2], [9]) have shown that the two strategies lead to different configurations:

- in term of waiting traffic : the Cronos strategy enables to save 20% of waiting time on average on the whole area, compared to the other strategy;
- in term of traffic signal state configuration : depending on the optimisation process the Cronos strategy creates a large variety of signal patterns among the set of traffic signals on a complex intersection.

The opportunity of collecting a wide spectrum of traffic configurations and signal patterns enables us to investigate new aspects of signal compliance factors.

2.4 Contextual factors that may impact on late red-running

For a given signal line, we focus on drivers that stands inside or beyond indecision zone when the signal turns amber, and assume similar conditions concerning distance to stop line and approaching speed. Several elements from their surrounding environment, on which the control strategy has direct or indirect impact, can influence their decision to stop or to proceed, among which:

- Surrounding traffic conditions on the link: a driver is more likely to proceed if he follows another vehicle that decides to do so just in front of him;
- Upstream past clearing conditions: if a driver has already wait on red at a close upstream signal line and is not given time enough to reach the following one, he may be more likely to cross the line even after the end of the green phase;
- Downstream flow conditions: if the driver can anticipate that a late clearing enables him to save time for the next steps of the junction crossing; for example, an ending green phase on the next signal line ahead that the driver can perceive may encourage him to cross, in order to save waiting time for both lines;

- Presence on the opposing link: an empty opposing link could favour the decision to proceed since it can be perceived as a situation less risky than when there are vehicles ready to move off.

We assume that the impact of these contextual conditions could be revealed primarily for late red-running drivers standing behind the indecision zone or at the end of it at the amber onset; thus we focus on late red-running occurrences ([7]).

Thanks to the video-based observation system on the experimental intersection, some of these features can be automatically detected and qualified. Considering the large set of observations of green phases ending at a given traffic signal, we analyse the variety of contextual conditions that the control strategies produce at switchovers for similar traffic conditions.

3 The observation system for red-light running at red onset

3.1 The experimental intersection and the observation system

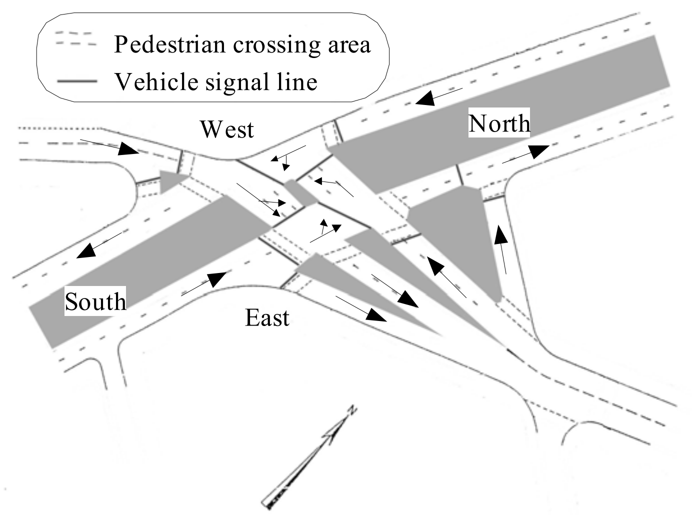

Fig. 1. The experimental site

The experimental site is an isolated intersection in the close suburbs of Paris. It consists in four double-lane inbound approaches and three double-lane outbound legs. The main road runs North-South with high volumes of transit traffic at high cruising speed. The East-West road concerns local traffic with lower volumes. Three special link prevent right-turning traffic from crossing the intersection. It must be noticed that four inner zones for vehicle storage are controlled with traffic signals in the inner area of the intersection.

The experimental area is covered by height video sensors that produce traffic measurements every second. The video covering of the whole scene leads to spatial measures that give robust and precise information concerning the traffic crossing the area. We use several video-based traffic measures available each second like the number of vehicles on zones – spatial occupancy -, the number of stopped vehicles per storage zone behind stop lines – spatial stopped occupancy, or queue lengths on links -. Let us stress on the fact that these second-by-second measures concern flows and not individual vehicles, and that the system do not provide speed measurements.

The traffic measures and the traffic signal states are collected continuously and feed a real-time dynamic intersection model. The system enables to follow the movement flows between successive signals across the intersection. Thus, for inner signal lines, the system identifies active incoming movements that clear the line: the left-turning movement or the straight movement. Let us remark that the two incoming movements cannot be active both at the same time in this intersection. Another module of the system focuses on conflict zones, i.e. areas standing downstream two signal lines and alternately opened to one of the two opposing streams. Thanks to pattern recognition techniques it assigns the movements detected on a conflict zone to one of the two conflicting streams; this module enables us to work on signal line clearing and to analyse red-running phenomena.

3.2 Our measure of red running occurrence

Thanks to this observation system, we collect a data set for each signal line to analyse signal change phases and line clearing recordings. As classically done in the literature ([11], [14]) we focus on the last clearing driver prior to the onset of opposing traffic. The variable defined for every cycle is called the Last Clearing Step (LCS); it is the time step of the last clearing for the stream concerned by the end of the green phase. It can take 3 values: NV or V whether it happens before or after 2 seconds of red onset, W if there is no stream during the green phase.

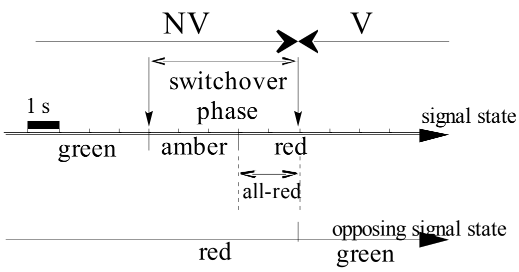

Fig. 2. The phase change interval

The 2s threshold corresponds to the time step when the opposing signal turns green. Let us precise that the red-running module of the observation system actually detects entry movement in the conflict zone; the corresponding clearing movement necessarily takes place a short time before. As we use the module to compare sets of occurrences, a systematic delay in the detection does not matter.

From our data base of traffic data recordings, we constitute sets of comparable observations in order to analyse LCS rates, i.e. percentages of V-types LCS.

First, we classify the data according to the traffic conditions on the whole intersection. We adopt hourly periods to define the observation samples of traffic scenes; hourly windows ensure homogeneous conditions while being large enough to guarantee strategy-independent volumes of traffic. We define several classes of homogeneous traffic conditions by considering hourly windows and four ranges in total hourly volumes.

Second, we have to define classes of comparable switchover conditions in terms of late violation exposure, in order to characterize the vehicle's position and speed just before the V-type phase i.e. during the all-red interval. As the observation system does not give access to individual vehicle positions neither speed indicators, we define rough categories of traffic exposure and assume homogeneous conditions of position and approaching speed among them. For the lines of approaching links we define three levels of exposure - denoted S0, S1 and S2 - depending on a rough estimate of the distance between the signal line and the first approaching vehicle, assessed during the all-red interval; we use predefined 60m long zones. We measure the number of zones upstream the line that remains empty in that interval: 0 if there are vehicles is the closest zone to the line, else 1 if there are some in the second zone, and 2 if both are empty. S1 and S2 types of exposure characterize non-platoon arriving vehicles with at least a 2 seconds gap in the stream. For the inner lines, we also distinguish whether the flow that is being interrupted by the signal switchover is a straight mouvement (S) or a turning mouvement (T), since mean speeds significantly differ between the two cases ([10]).

3.3 Differences in red-running rates and in exposure levels

Our first results show that there are differences among red-running rates between the two control strategies; the rank order between strategies depends on the traffic signal. As expected there are differences in exposure to red violation observed between strategies, both early violation exposure and late violation exposure. It also turns out that the amber onset of an inner line does not always interrupt the same movement, turning movement or straight movement.

4 Analysis of the surrounding context of approaching drivers

More generally the analysis of traffic scene samples reveals many differences in the surrounding conditions during phase change intervals. Looking at the West part of the experimental intersection, we uses a first set of 18 hourly observations and analysed four signal lines in order to identify the spectrum of environmental situations at red switchovers. We have identified several contextual elements that could impact the red running rates; for some of them our data set can be used to constitute pairs of switch-over occurrences to assess its impact.

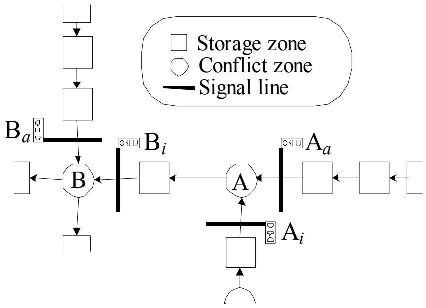

Fig. 3. Schematic of the West part of the experimental intersection

4.1 Downstream flow conditions

The decision to stop or to proceed can be influenced by the dowstream conditions perceived by a driver approaching the line during the switchover phase. If he can anticipate some benefits for the next steps in the intersection clearing, he would probably be more likely to clear the red line. One can assume that this would be the case if the next steps look free for crossing: no red signal neither traffic congestioned area. This would also happen if this free-for-crossing status is just about to change.

The approaching signal line A_a represents an interesting case to analyse from that point of view. Drivers that clear the A_a signal line face the second line B_i a few meters downstream; mean speed on this axe is quite high. For safety reasons all the control strategies impose to close the green phase of the Bi signal after having closed the green phase of the A_a signal. In all cases downstream flow conditions perceived by drivers approaching A_a when it turns to amber is free for crossing. However the offset between the two swhichovers is not fixed. One control strategy uses variable offset and produces frequent occurrences with a short offset of 2 seconds. In that case the B_i line turns to amber during the switchover phase of the A_a signal, and the drivers approaching A_a can see the B_i signal turning to amber.

On the other hand another set of A_a switchovers occur with a large offset (around 10 seconds): it postpones the B_i switchover outside the driver's decision window concerning the clearing of the A_a line. Comparing these 2 sets of switchover for A_a, our preliminary results show that the first class of downstream conditions could lead to higher LCS rates that the second class for S1 type of exposure; there is no significant difference for the S0 exposure and too little cases for the S2 exposure. It seems that such a short offset between switchovers of successive lines leads drivers to favour the red-clearing choice, and to clear also the second line. The East part of the intersection has not been analysed yet, but we will look for another signal configuration that enables us to check this hypothesis on another signal lane.

A second interesting situation has been identified and concerns the A_i line. In peak-hour conditions, the A_i line sometimes turns to amber while the B_i line signal is red with its storage zone occupied by waiting vehicle at full capacity. When such a situation occurs, driver approaching the A_i line cannot enter the next zone neither during the end of the green phase neither during the switchover phase. We have observed in this case that some drivers clear the A_i red signal when the next zone began to flow.

4.2 Upstream past clearing conditions

While approaching an inner signal line, drivers have already clear at least one other line. The way they have crossed the first steps may influence as well their compliance with the following signals. We have identified several configurations in our data base for analysing some aspects of such an impact.

The inner signal line B_i turns to amber while interrupting either a straight movement flow either a turning movement flow. These two types of upstream conditions induce different gravity in case of red-running, because the involved speeds are different. They could also induce differences in LCS rates; we will check if this is the case for all the inner signal lines of the junction.

For a given type of flow that is being interrupted, some specific conditions could lead to higher LCS rates too. This is the case when a flow just starts to approach the signal line that turns amber since the upstream line has turned green few second sooner ; the last drivers to start are not given time enough to proceed the line before the red onset. One control strategy produces such condition when the signal line B_i turns amber with a turning movement flow coming from the A_i line, while the other strategy always give a larger time window after A_i turning green. These two sets of samples give the opportunity to compare the impact of these two upstream conditions at least for one signal line.

4.3 Opposing stream conditions

When a signal line turns to amber, its opposing line reaches the end of the red phase and there are usually some vehicles waiting to move off. However, the case of an opposite zone without any vehicles occurs as well, especially in off-peak period; it depends on the line and on the control strategy. For instance it represents four switchovers out of ten for the A_a signal line. In configurations where drivers approaching the line see the opposing zone, situations where there is no waiting vehicle on it are perceived as less risky and could favour their decision to proceed.

The LCS rates given by our system for A_a are in line with this hypothesis. Considering cases where downstream conditions do not interfere (long offset before the B_i switchover) the LCS rate is higher for cases with an empty opposing zone than for cases with vehicles waiting, for S1 type of exposure. However this result needs additional validation work, because of the bias that might be introduced by this feature in the automatic red-running detection system.

5 Conclusion

The data base of traffic scenes collected under two types of control strategies enables us to analyse occurrences of switchovers for different signal line and to reveal specific contextual features during phase change intervals for each of them. Different elements of the environment of drivers approaching a signal line that turns to amber can then be analysed thanks to sets of switchover occurrences with discerning features.

The next step of this study is first to quantify the impact of the various contextual features for the four signal lines of the West part of the intersection. Then the four lines of the East part will be analysed to check if some trends apply to other lines.

Our goal is to find out new parameters that impact on red-running phenomena and that are directly or indirectly affected by the control strategy. As the control strategy takes part in the structuring of drivers activity by changing its surrounding conditions during the switchover phase [3], it becomes crucial to identify the interrelations between contextual factors and red-running occurrences. The stake is to discover new knowledge and rules that could be used for the design of innovative control strategies like real-time adaptive strategies, in order to improve the impact on traffic signal compliance.

References

1. Boillot, F., Blosseville, J.M., Lesort, J.B., Motyka, V., Papageorgiou, M., Sellam, S.: Optimal signal control of urban traffic networks. 6^{th} IEE International Conference on Road Traffic Monitoring and Control, London. (1992) 75-79
2. Boillot, F., Midenet, S., Pierrelée, J.C.: Real-life Cronos evaluation. 10^{th} IEE International Conference on Road Traffic Information and Control, London. (2000) 182-186
3. Fleury, D., Saad, F.: Driver behaviour and accidents at controlled traffic junctions., Proceeding of the International Conference of Road Safety in Europe, Berlin. (1992)
4. Hulscher, F.R.: The problem of stopping drivers after the termination of green signal at traffic lights. Traffic Engineering and Control, Vol. 25 (3). (1984) 75-78
5. Kokkalis, A.G., Papaioannou, P.I., Basbas, S.I.R.: A study of traffic signal violations at highway intersections. Proceeding IFAC Transportation Systems, Chania. (1997) 1391-1397
6. Koll, H., Bader, M., Axhausen, K.W.: Driver behavior during flashing green before amber: a comparative study. Accident Analysis and Prevention, Vol. 36. (2004) 273-280
7. Lum, K.M., Wong, Y.D.: A before-and-after study stopping propensity at red light camera intersections. Accident Analysis and Prevention, Vol. 35. (2004) 111-120
8. Mahalel, D., Zaidel, D.M.: Safety evaluation of a flashing green light in a traffic signal. Traffic Engineering and Control, Vol. 26 (2). (1985) 79-81
9. Midenet, S., Boillot, F., Pierrelée, J.C.: Signalized intersection with real-time adaptive control: on-field assessment of CO_2 and pollutant emission reduction. Transportation Research Part D, Vol. 9 (1). (2004) 29-47
10. Perkins, S.R., Harris, J.L.: Traffic conflict characteristics-Accident Potential at Intersections. Highway Research Record, TRB, Vol. 225. (1968) 35-44
11. Porter, B.E., England, K.E.: Predicting Red-Light Running Behavior: A Traffic Safety Study in Three Urban Settings. Journal of Safety Research, Vol. 31 (1). (2000) 1-8

12. Retting, R.A., Greene, M.A.: Influence of traffic signal timing on Red-Light Running and Potential vehicle conflicts at Urban Intersections. Transportation Research Record 1595. (1995) 1-7
13. Van Der Horst, R.: Driver decision making at traffic signals. Transportation Research Record 1172. (1988) 93-97
14. Wortman, R.H., Witkowski, J.M., Fox, T.C.: Traffic characteristics during signal change intervals. Transportation Research Record 1027. (1985) 4-6
15. Zegeer, C.V., Deen, R.C.: Green extension systems at high-speed intersections. ITE Journal. November. (1978) 19-24