Synchronization of Traffic Signals for Reduction of Pollution

Nidhi Malhotra
Department of Electronics and Communication Engineering
Faculty of Engineering, Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, India

ABSTRACT: The purpose of this study was to determine if traffic signals synchronized along a route are associated with fewer red-light violations than non-synchronized traffic signals. A total of 3700 traffic signal cycles were observed at 12 intersections along 2 major urban arteries. Synchronized intersections have been successful in decreasing the risk of red-light running (RLR) by (a) offering less opportunities than non-synchronized RLR intersections and (b) having a lower RLR rate compared to the number of chances. The odds of reaching the intersections in red in synchronized intersections were approximately 1/8 the odds of RLR in non-synchronized intersections after adjustment for the number of opportunities. Congestion decreased synchronized intersection efficiency compared to non-synchronized intersections. Male drivers were marginally more likely to run red lights than female drivers, and the effects of correlation through age, gender and the presence or absence of passengers were relatively constant. Actual or potential applications of this work include synchronization of signals in order to minimize violent driving in general and RLR particularly.

KEYWORDS: Distributed Systems, intersection, red-light running rate, Traffic Signal Synchronization.

INTRODUCTION

Regulation of traffic signals will dramatically reduce traffic congestion, leading to better conditions for both drivers and the environment (reduced air pollution, and energy consumption). Urban signal timing is a non-convex problem, so it may take a long time, wherever possible, to find an optimal solution for not very small and simple networks. In addition, recent advances in electronics, sensing, and ICT (information and communication technology) [1] allow the collection and processing of traffic data in real time, as well as the deployment of intelligent controllers for the efficient operation of a transport system. Nonetheless, managing a transport network's traffic signals presents a major challenge due to the broad nature and complexity of the problem, the network's unpredictable and dynamic actions (e.g., weather, incidents, events), and the patterns of different driver behaviors. Several different methods have been suggested for this reason; several strategies apply to single intersections, others use historical data to evaluate fixed plans, while a family of strategies attempts to dynamically decide on the timing plans for traffic signals in a distributed and online way. Usually regulated traffic signal variables are the length of the loop, the dividing plan and the offset [2].

Cycle length is the time needed to complete the signal indication sequence. The split schedule refers to the time allocated during a signal process for various phases. Finally, the offset is used to coordinate adjacent intersection phases to reduce traffic stoppages. Most techniques consider the single traffic signal control issue at the intersection, neglecting the consequences of interrelation with other intersections [3]. Nonetheless, the offset between intersections is not optimized by considering intersections atomically, leading to regular vehicle stops. Parameters of interest are often tailored locally rather than internationally, which may result in low global output [4].

Most techniques consider the issue of regulation of traffic signals at multiple intersections. Set or pre-timed signal control techniques refine the signal timing plans offline based on historical data to allow the implementation of set signal programs for different periods of the day. Fixed- Time for multiple intersection approaches either aim to change the offset between neighboring intersections to maximize the progression along multiple corridors using MILP approaches, e.g. in MULTIBAND, or optimize split plans and cycles according to some measure of effectiveness that incorporates various traffic metrics such as delay, minimum number of stops and throughput. Several online adaptive traffic signal control (ATSC) systems [5] have been developed to compensate for the stochastic fluctuations in traffic flows. Such methods gather on-demand information from different sources, and use it to optimize traffic signal schedule parameters such as breaks, offsets, and loop [6].

The centralized TSS problem solution can provide better results if it can be extracted but as a solution strategy it has many drawbacks. First, solving this problem is typically intractable and therefore not suitable for online decision-making, since the problem is complex (NP-hard) and large (especially when the problem involves a long time horizon and many intersections). Second, centralized solutions require global information about the network's status and may therefore be prone to communication related failures. Third, it is not reliable to solve the problem centrally, as failure of the central unit would result in the device failing entirely. Distributed methods, on the other hand, may be more resilient for failures. A new distributed method for obtaining a spatial decomposition to reduce the complexity of the problem is described. A surrogate method is applied to solve the problem of traffic signal synchronization given the subnetwork [7].

Traffic Signal Problem

Delay is one of the most critical performance steps at a signalized intersection as "it affects the amount of wasted travel time, fuel consumption and driver irritation and discomfort." Delay can also be used as an efficient way to assess and compare various control schemes. However, the calculation of such a parameter usually affects many, frequently uncontrollable factors: the presence of random traffic flows among others[8]. Note that a typical estimate of total user travel time is the sum of the un-signalized network free flow travel time, which is always believed to be constant, and a delay due to traffic signals, congestion, etc. As a result of this choice, minimizing total delay would imply minimizing total travel time. As for urban networks, it is safe to say that a small fraction of the overall delay time is spent on main arterial roads, since these roads have greater flows and greater congestion [9].

Therefore, one possible control strategy is to prioritize a high flow along these corridors. To do this a problem of optimization must be solved, but in many situations there may not be a closed-form objective function or it may be difficult to identify: a potential solution is to return to simulation. Approaches to simulation can be implemented to estimate the value of the objective function, and can be paired with algorithms to find the best solution [10].

METHOD

Participants

The study participants were regular drivers who were driving through the selected signalized intersections during observation times. Drivers were seen passing 3700 signal cycles.

Observation site

Following many consultations with the City traffic engineer, and selected 12 intersections. The goal was to balance the synchronized and non-synchronized intersections in terms of traffic flow, location and general purpose as much as possible. Therefore, all intersections were along two main north-south urban thoroughfares with two in each direction through lanes and separate drop-off lanes for right and left turns. Eight of the intersections were with synchronized signals in the main portions of major highways, and four were with non-synchronized signals. On the daylight hours of the dry summer months, when the sky is clear, data were recorded for the two through lanes. No data was obtained in serious or unusual circumstances, such as when a police officer was present or when traffic was halted due to an incident in one of the lanes. Rush hours (Sunday – Thursday, 8:00–10:30 and 17:30–20:00; Sunday is a daily working day in Israel), non-rush hours (weekdays, 11:00–16:00) and weekend hours (Saturday, 10:00–20:00) were the times for observation.

At each of the 12 inter-sections, detected 120 signal cycles on each of the three observation days, yielding a total of 3700 traffic signal cycles. The key independent measure was intersectional nature: synchronized versus non-synchronized. The following data were observed or estimated for drivers going through a red light, as well as for a representative sample of all drivers going through the intersections: driver gender, perceived age and presence or absence of other occupants in the vehicle.

Procedure

All observations were performed by two trained observers. At each intersection they observed the traffic moving across lanes in one direction on the two. The observers stood them-self in such a way as to hide them from the forward field of view of the drivers. They made different counts for each cycle of (a) the number of vehicles entering the intersection after the light turned yellow, but cleared it after the light turned red, and (b) the number of vehicles entering the intersection after the light turned red. The front of the car was the reference point for entering and clearing the intersection end crossing the beginning and end of the intersection, as defined by the imaginary line which is tangential to the edges of the curbs. Only when both observers decided was a car considered RLR. The gender of the driver, approximate age, and presence or absence of passengers were also noted for each such vehicle. Additionally, these data were noted for the first 100 cars passing through the intersection at each observation period to obtain exposure data on driver gender, approximate age, and the presence or absence of passengers. They are meant to be a representative sample of the drivers who ride the intersection at the time.

RESULT AND DISCUSSION

RLR and Synchronization

The key hypothesis relates to the effect of synchronization on RLR. 190 vehicles were observed approaching the intersection in all 3700 cycles of observations, after the light had shifted to red. Of these, 145 were in the four non-synchronized intersections and 40 were in the eight intersections synchronized.

This discrepancy alone is insufficient to suggest that RLR is more common in non-synchronized intersections, as in those intersections, the potential for RLR is smaller. This distinction alone is insufficient to indicate that RLR is more widespread in non-synchronized intersections, because in those intersections the potential for RLR is less. An opportunity for RLR was described as a situation where one or more cars entered the signaled intersection just as the light turned yellow, thus giving the driver the chance to cross the intersection on red. If two cars, one behind the other, enter an intersection after the light turns yellow or red and the lead driver stops for the signal, RLR has only one chance as the second driver does not have the opportunity to cross the intersection

The reason for RLR in synchronized intersections to have less incentives than in non-synchronized intersections is that synchronization causes traffic to travel in "platoons," with most cars going through the synchronized green process. Thus, with good coordination, traffic waiting at red light consists mostly of cars that had just entered the road from another road. The findings, summarized in Table 1, show that in the synchronized intersections the number of incentives for RLR has been much lower than in the non-synchronized intersections. To account for the variations in opportunities for RLR, and then carried out a chi-square study of the frequencies of entry into the intersection after the light had turned red in the synchronized and non-synchronized intersections, compared to the number of opportunities observed in these two types of intersections. The difference was highly important, yielding a 7 odds ratio = 150.06, p<.0001. Thus RLR chances in the non-synchronized intersections were nearly seven times higher than in the synchronized intersections.

There were also 1200 car reports reaching the intersection after light had changed to yellow and the intersection was cleared only after light had changed to red. Such vehicles were paired with the 190 vehicles that approached the intersection during the red process for the remaining tests, yielding a total of 14500 RLR observations. It was done on two levels. The first is the fairly small number of cars approaching the intersection after the light turned red. The second, a behavioral one, is that all these drivers had ample time to stop before reaching the intersection in response to the yellow signal but chose not to do so. They avoided entering the intersection against the light instead: some crossed the intersection under a red signal and others approached it under a red signal.

Signal Type	Rush Hours	Nonrush Hours	Weekends	Total
Synchronized	80	55	42	177
Non-synchronized	91	69	55	215

Table 1: Number Of Opportunities Per Intersection to Run Red Lights

However, it should be noted that although all these drivers actually blocked the intersection during the red phase, only those who entered the intersection after the light had turned red would be legally considered as RLRs. When the two types of behaviors were combined, the chi-square analysis of the number of RLRs in the two types of intersections in relation to the number of opportunities produced a highly significant effect, as well as a 2.1 odds ratio.

Congestion effect on RLR

The levels of RLRs (number of RLRs / signal / observation period) were significantly lower in the synchronized intersections at all three observational periods, as illustrated in Table 2. These findings represent 40 per cent fewer RLRs in synchronized intersections than in intersections with non-synchronizes. Moreover, although the absolute number of RLRs in rush hours was greater than in non-rush hours and weekends, the relative difference between synchronized and non-synchronized intersections increased from rush hours to non-rush hours and weekends;

< .0001, = 49.29, p < .0001, = pattern 2 (1)= 9.02, p <.0001.

Thus at non-synchronized intersections there were 83 percent more RLRs than at synchronized intersections during rush hours, 303 percent more at nonrush hours, and 386 percent more at weekends. As already mentioned, one potential explanation for the effect of synchronization may be simply that synchronization provides less opportunities for RLR, due to the nature of signal synchronization. Table 1 shows the number of RLR chances in each case. As can be seen from Table 1, the number of opportunities for RLR in each of the three observation periods was generally greater in the non-synchronized intersections than in the synchronized ones, and in both cases the number of opportunities increased with congestion. However, there was no major differential effect of the measurement duration on the RLR frequency = 1.88, p = 0.40.

The number of RLRs as a function of the average number of cars queued in each lane at the end of the red-light process for a more detailed study of the source of variations between the different observation periods. This provides a measure of congestion quantitatively, directly and continuously (unlike the indirect assessment through observation period). Figure 1 presents the results with the best-fitting functions Best-fitting quadratic equations for synchronized intersections yielded R2 = 0.90 and R2 = 0.70 for non-synchronized intersections. For both synchronized and non-synchronized intersections, a linear fit to the two data point sets yielded R2 =0.78. Such findings are consistent with those of Table 2, but show more specifically that the total number of RLR increases in both types of intersections as con- management increases, while the gap in RLR between the synchronized and non-synchronized intersections decreases until it eventually disappears entirely. Therefore, as congestion increases, synchronization effectiveness decreases until it becomes totally meaningless at the intersections to driver actions.

Signal Type	Rush Hours	Nonrush Hours	Weekends	Total
Synchronized	55	15	07	77
Non-synchronized	110	50	35	185

Table 2: Number of RLRs Per Intersection.

Individual Difference in RLR

Gender: The percentage of men in the RLRs (82 percent) at the same intersections (72 percent) was marginally (but significantly, p =0.0005) higher than their percentage in driving population. The gender-synchronization relationship (see Table 3) was not statistically significant = 2.75, p = .10, suggesting that synchronization did not influence the slight difference between male and female drivers.

Age: The number of older drivers (50 + years) in the RLRs (25%) was marginally higher than their number in the driving population at the same intersections (20%) (but substantially higher than their percentage). By comparison, the percentage of young drivers in the RLRs (< 25 years) (8%) was significantly lower than their percentage in the driving population at the same intersections (10%), although this gap was not important. It seems overall that age at least as measured – was unrelated to the propensity to run a red light. The age-to-synchronization relationship (see Table 4) was not statistically important, suggesting that synchronization had no differential impact on younger and older drivers = 0.39, p = 0.70. Passenger Presence. The percentage of drivers without passengers in the RLRs at the same intersections (63 percent) was almost identical to their percentage in the driving population. The relationship between passenger presence or absence and synchronization (see Table 5) was not statistically relevant, indicating that the impact of synchronization on passenger-free drivers was not different from that on passenger drivers.

Signal Type	Men	Women	Total
Synchronized	50	20	70
Non-synchronized	155	36	191

Table 3: Number Of RLRs Made By Male And Female Drivers Per Intersection.

Signal Type	Young	Mature	Older	Total
Synchronized	8	50	20	78
Non-synchronized	20	150	30	200

Table 4: Number Of RLRs Per Intersection for Each Estimated Age Group.

Signal Type	Without Passengers	With Passengers	Total
Synchronized	55	16	71
Non-synchronized	136	55	196

Table 5: Number Of RLRs Per Intersection For Intersection For Drivers With And Without Passengers

CONCLUSION

The findings of this analysis demonstrate the efficacy of signal synchronization beyond the usual advantages of engineering. As vehicles travel down a path with synchronized signals, the red lights are much less likely to run (either enter the red intersection or enter it on yellow and clear it on red) than when the signals are not synchronized at consecutive intersections. Additionally, synchronization effectiveness exceeded individual variations in driver gender, driver age, and passenger presence or absence. Thus, unlike some previous research , this study did not achieve higher (or practically significant) RLR levels among people, younger drivers or drivers without passengers, and synchronization appears to have the same impact on all drivers, less of these individual differences.

The Synchronization benefits are strongest when traffic is lightest and decreases as congestion increases, the driver behavior at synchronized and non-synchronized intersections is the same. Such results demonstrate how important engineering and design are in alleviating one form of violent driving. If the traffic network is built to handle traffic more effectively, it not only decreases the amount of chances for RLR, but also diminishes the tendency of individual drivers to commit RLRs if they experience the irritating red light. It thus demonstrates a basic principle ergonomics: Changing the environment can be more active as changing users.

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