9-25-2024

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Vadhul Krishnan Veerakumar
University of Windsor

Recommended Citation

Veerakumar, Vadhul Krishnan, "Influence of Traffic Signal Countdown Timers on Safety and Efficiency at Signalized Intersections" (2024). *Electronic Theses and Dissertations*. 9547.
https://scholar.uwindsor.ca/etd/9547

Influence of Traffic Signal Countdown Timers on Safety and Efficiency at Signalized Intersections

By

Vadhul Krishnan Veerakumar

A Thesis
Submitted to the Faculty of Graduate Studies
through the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements for
the Degree of Master of Applied Science
at the University of Windsor

Windsor, Ontario, Canada

2024

Influence of Traffic Signal Countdown Timers on Safety and Efficiency at Signalized Intersections

by

Vadhul Krishnan Veerakumar

APPROVED BY:

E. Kim
Department of Mechanical, Automotive, Materials Engineering

Y. H. Kim
Department of Civil and Environmental Engineering

C. Lee, Advisor
Department of Civil and Environmental Engineering

August 29, 2024

DECLARATION OF CO-AUTHORSHIP / PREVIOUS PUBLICATION

I. Co-Authorship

I hereby declare that this thesis incorporates material that is result of joint research, as follows:

Chapter 4 of the thesis is based on a paper that was co-authored by Dr. Chris Lee. This paper was submitted to *Transportation Research Record: Journal of the Transportation Research Board*, but there has been no decision yet.

In the above case, the primary data analysis and writing were performed by the author. The co-author, namely Dr. Chris Lee, provided frequent supervisory input on the overall direction of the paper and provided editing support for the text and revisions before submission for publication.

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Thesis Chapter	Publication title/full citation	Publication status
Chapter 4	*Veerakumar. V. K., Lee, C., 2024. Assessing Impacts of Traffic Signal Countdown Timers on Safety and Efficiency of Car-Truck Mixed Traffic. Submitted for presentation at 104th Transportation Research Board Annual Meeting and publication in Transportation Research Record: Journal of the Transportation Research Board.*	*under review*

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ABSTRACT

Traffic Signal Countdown Timer (TSCT) displays the remaining times of green, yellow, and red intervals at a traffic signal. While TSCT has widely been implemented in various countries, the effects of TSCT on traffic involving passenger cars and trucks remain unexplored. Thus, this study investigates the impacts of TSCT on traffic safety and efficiency at signalized intersections with high truck volume along the Huron Church Road in Windsor, Ontario, Canada. Driver behavior and traffic flow were predicted using Vissim traffic simulation for the four scenarios: no-timer, Green Signal Countdown Timer (GSCT), Red Signal Countdown Timer (RSCT), and a combination of GSCT and RSCT (GSCT+RSCT). Based on the observational data from previous field studies, changes in driver behaviours in the presence of TSCT were replicated by dynamically adjusting the simulation parameters in different signal phases using Vissim-COM interface. The result shows that the Crash Potential Index (CPI) decreased by 37% while the network-wide speed increased by 6% in the GSCT+RSCT scenario compared to the no-timer scenario. Although the RSCT reduced the speed but it increased the number of vehicles entering the intersection in the first 5 seconds of the green phase by 61% and reduced the CPI by 23%. The increase in speed near the intersection during the green phase was observed in the GSCT scenario whereas smoother deceleration rate of approach vehicles during the red phase was observed in the RSCT scenario. Moreover, the TSCT helped cars avoid rear-end conflicts and increased truck speed. This study demonstrates that TSCT can potentially improve safety and efficiency of car-truck mixed traffic at signalized intersections.

Keywords: Traffic signal countdown timers, Signalized intersection, Traffic conflicts, Traffic simulation, Car, Truck

DEDICATION

This work is dedicated to my parents, Veerakumar Krishnamoorthy and Karpagam Veerakumar, as well as to my brother, Shrivatsan Veerakumar.

ACKNOWLEDGEMENTS

I would like to express my deepest and most heartfelt gratitude to my supervisor, Dr. Chris Lee. His unwavering support, motivation, and exceptional guidance throughout my research have been invaluable. I am profoundly thankful for the numerous opportunities he has provided, which have significantly contributed to my intellectual growth and professional development. His mentorship has been instrumental in shaping the trajectory of my academic journey, and I will always remain indebted to him.

I would also like to extend my sincere appreciation to Dr. Yong Hoon Kim and Dr. Eunsik Kim, who graciously served on my thesis committee. Their willingness to invest their time in reviewing my thesis, coupled with their insightful and constructive feedback, greatly enhanced the quality of my work. Their expertise and thoughtful critique were crucial in refining my research, and I am truly grateful for their contributions.

Moreover, I want to acknowledge and thank my colleague, Umair Durrani, whose assistance was always available whenever I needed advice or technical support. His collaboration and readiness to help were vital in overcoming various challenges during my research, and I deeply value his contributions.

I would like to extend my heartfelt thanks to all my past and present colleagues—Dhwani Shah, Haesung Ahn, Ayobami Adewale, Nada Alnaser, Saba Ikhlaq, and Larissa Dushime. Their ideas and support have been immensely helpful to me, and I am deeply grateful for their contributions.

I would like to thank the research sponsors: Natural Sciences and Engineering Research Council of Canada, Ministry of Transportation Ontario (MTO), and the University of Windsor.

Lastly, I would like to extend my heartfelt thanks to my family and friends. Their unwavering support, encouragement, and steadfast presence throughout this journey have been a source of immense strength for me. They stood by me through all the ups and downs, and for that, I am eternally grateful. Their belief in me has been a driving force, and I cannot thank them enough for their love and support during this significant chapter of my life

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1. INTRODUCTION

Traffic Signal Countdown Timers (TSCT) indicate the remaining time for green, yellow, and red signal phases before transitioning to the next phase at a traffic light. TSCTs assist drivers in making informed decisions about whether to stop or proceed through an intersection. These timers are categorized into three types based on the signal phase they represent: Red Signal Countdown Timer (RSCT), Green Signal Countdown Timer (GSCT), and Yellow Signal Countdown Timer (YSCT). Previous studies have shown that RSCTs and GSCTs can have both positive and negative impacts on traffic safety and efficiency, as evidenced by field observations and simulation experiments (Jatoth et al., 2020; Paul et al., 2022; Chiou and Chang, 2010; Long et al., 2011). The YSCT, however, is less commonly used due to the brief duration of the yellow phase, during which driver behavior is more influenced by factors such as the distance to the stop line and vehicle speed rather than the presence of a timer.

Despite extensive research on the impact of TSCTs on traffic safety and efficiency in countries such as the U.S., India, Vietnam, Singapore, Korea and China, similar studies have yet to be conducted in Canada. Over the past 20 years, Canada, particularly Ontario, has made significant strides in improving road safety. According to the Ontario Road Safety Annual Report 2020 (Ministry of Transportation of Ontario, 2024a), total collisions and fatal collisions in Ontario decreased by 39% and 32%, respectively, since the year 2000. Among these collisions, many collisions attributed to distracted driving, impaired driving, speeding, and red-light violations (RLV). However, a preliminary report from 2022 (MTO, 2024b) highlights that collisions involving large trucks remain particularly dangerous, accounting for 18.6% of total fatalities. TSCTs have the potential to reduce RLV-related collisions and those involving trucks at intersections with high truck volumes.

While TSCTs have been widely studied, their effects on traffic performance and safety in mixed car-truck traffic have not been fully explored. In this study, a simulation-based approach was adopted because TSCTs have not implemented in Canada at present and therefore, the field data are not available. Also, the previous field studies evaluated the effect of TSCT at a particular signalized intersection but they did not evaluate the effects of TSCT on a road network. In this regard, the simulation-based approach can evaluate network-wide effects more effectively. Moreover, the simulation-based approach can control for the effects of external factors such as weather and identify the independent effect of TSCT on the traffic flow.

Although some previous studies used simulation, they have not realistically modeled changes in driver reactions to different signal phases (e.g., green and red) in the presence of TSCTs. Additionally, the behavioral factors underlying observed changes in traffic flow due to TSCTs have not been thoroughly examined in prior research.

Therefore, this study aims to investigate the effects of TSCTs on traffic safety and efficiency at signalized intersections with mixed car-truck traffic in Canada using a simulation-based approach. Based on the observed influence of TSCTs, potential interventions will be proposed to enhance the functionality of signalized intersections where TSCTs are present.

2. LITERATURE REVIEW

2.1. Impacts of Red-light Cameras and TSCT on Collisions

As red-light cameras aim at reducing red-light violation, they have similar effect on safety as GSCT. Several researchers have assessed the safety impacts of red-light cameras using collision data. For instance, Ahmed and Abdel-Aty (2015) found that red-light cameras reduced angle and left-turn crashes by 24% (26% fatal and injury crashes) but increased rear-end crashes by 32% (41% fatal and injury crashes) at the signalized intersections in Florida using 2006-2008 (before period) and 2010-2012 (after period) crash data. They also found similar effects at the nearby intersections without red-light cameras. This is mainly because drivers are more cautious to avoid red-light violation. Persaud et al. (2005) also concluded that right-angle crashes decreased with an increase in the rear-end crashes by installing red-light cameras. Similarly, Lee et al. (2014) found that red-light cameras reduced fatal crashes by 4-48% but slightly increased no-injury angle and rear-end crashes using 2004-2010 crash data in Chicago.

On the other hand, Pulugurtha and Otturu (2014) found that red-light cameras increased sideswipe and rear-end crashes at more than 50% of the signalized intersections but reduced total crashes at 50% of the intersections after the installation. They suggested that red-light cameras were effective at signalized intersections with less than 40,000 entering vehicles per day, less than 20 rear-end crashes per year, or less than 5 sideswipe crashes per year. In contrast, Erke (2008) suggested that the installation of red-light cameras increased total number of crashes by 15%. Although red-light cameras decreased right-angle collisions by 10%, they increased rear-end collisions by 40%. In summary, red-light cameras are expected to reduce right-angle crashes but increase rear-end crashes as the drivers tend to abruptly stop at the intersection to avoid red-light violation.

Some studies investigated the impacts of TSCT on collisions using crash records. For instance, Spigolon et al. (2015) found that the number of collisions decreased after installation of TSCT which shows the remaining times of green and red phases at the traffic lights in 3 Brazilian cities as shown in Figure 2-1. In the model 1 (Figure 2-1a), the initial lamp on the upper left side is lit at the beginning of a phase, and the following lamp is illuminated sequentially after a set time interval with the initial lamp going to the off-condition at the same instance. The same event is followed for all the lamps until the last lamp is reached during a traffic phase. Whereas in the model 2 (Figure 2-1b), all lamps are illuminated at the start of a phase and decreases from the top as the remaining time of green or red phase decreases. Similarly, Anjana and Anjaneyulu (2015) inferred that the crashes occurred less frequently at the signalized intersections with the TSCT based on the analysis of 3 years of crash data from 32 intersections in India. In contrast, Chen et al. (2007) found that GSCT caused a twofold rise in reported crashes and a 33% upsurge in the number of injuries at 187 signalized intersections in Taiwan. In addition, crashes increased by 19% at the signalized intersections with both GSCT and RSCT. Thus, the effects of TSCT on collisions were inconsistent. with each lamp turning off within the phase until the final lamp is reached.

(a) (b)

Figure 2-1. Traffic signal countdown timer installed at traffic signals in Brazil. (Source: Spigolon et al., 2015)

Chen et al (2009) quoted from previous studies that GSCT can lead to increased crash rate as people tend to cross the intersection at higher speeds. Also, the authors referred to a Taiwan study which inferred that the intersections with only GSCT and GSCT + RSCT increased the crash rates whereas intersections with only RCSD decreased the crash rates. The reason that GSCT was not beneficial was that the drivers tend to focus/ concentrate more on the timer than the intersection while on move whereas the situation is not comparatively dangerous in terms of RSCT as the vehicle is stationary.

Unlike TSCT, Pedestrian Countdown Signals (PCS) have been more widely installed and operated in many countries including Canada. Thus, relatively more studies have been conducted to examine safety effects of PCS on collisions using crash data. For instance, Camden et al. (2012) found that there was no significant difference in the rates of pedestrian-vehicle crashes before and after the installation of PCS in Toronto, Canada. Schattler et al. (2017) also found that PCS did not significantly decrease yellow light running and red-light violation based on both cross-sectional study and before-and-after study. However, they found that PCS reduced the pedestrian violations rate, i.e., the number of pedestrians who crossed the intersection at the steady

“Don’t Walk” interval, from 35.3% to 18.8%. On the other hand, Do et al. (2023) assessed safety impacts of PCS at a traffic signal which helps drivers anticipate the remaining time of green light as shown in Figure 2-2. They found that PCS at a traffic signal led more vehicles to enter an intersection during yellow and red intervals. However, it increased the number of yellow light violations more than the number of red-light violations. In addition, PCS at a traffic signal generally increased approach speeds by more than 11.5 km/h, which in turn increased the frequency of severe conflicts.

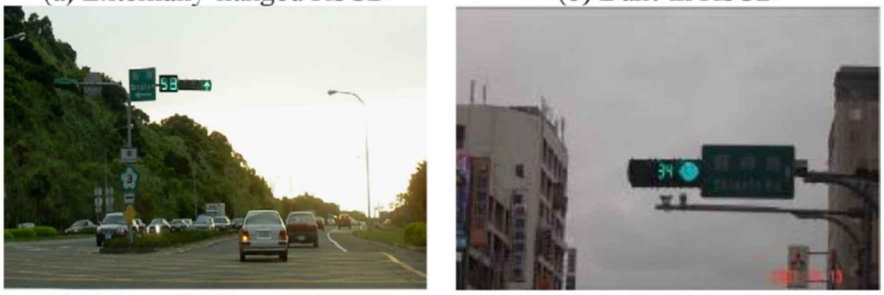
Figure 2-2. Traffic signal with pedestrian countdown signal (Source: Do et al., 2023)

2.2. Impacts of TSCT on Driver Behavior

Several studies evaluated the impacts of TSCT on driver behavior using the traffic flow data collected from video. Driver behavior was observed in terms of red-light violations, approach speed of vehicles, and decision to stop at intersections. Some studies found that the GSCT reduced red-light violation. Chiou and Chang (2010) suggested that the GSCT in Taiwan (Figure 2-3) discouraged drivers from crossing the intersection before the onset of red light and thereby it decreased the number of red-light violation. Jatoth et al. (2020) also observed a reduction in the red-light violations due to the GSCT in

India (Figure 2-4). Other field studies (Papaioannou and Politis, 2014; Huang et al., 2014; Kidwai et al., 2005; Klos et al., 2020; Devalla et al., 2015) and a driving simulator study (Raveendran et al., 2024) observed similar results. In particular, Limanond et al. (2010) and Biswas et al. (2017) found that GSCT significantly reduced red-light violation during the initial red phase (10 s) based on cross-sectional analysis and before-and-after analysis. An example of TSCT in Thailand presented in Limanond et al. (2010) is shown in Figure 2-5.

(a) Externally-hanged RSCD (b) Built-in RSCD



(c) Externally-hanged GSCD (d) Built-in GSCD

Figure 2-3. TSCT installed at traffic signals in Taiwan.
(Source: Chiou and Chang., 2010)

Figure 2-4. TSCT installed at traffic signals in India.
(Source: Jatoth et al., 2020)

Figure 2-5. TSCT installed at traffic signals in Thailand.
(Source: Limanond et al., 2010)

Paul and Ghosh (2020) found that GSCT also reduced crossing conflicts using Post Encroachment Time (PET) as a measure of conflicts. Kashani et al. (2020) compared four types of TSCT - 1) both GSCT and RSCT enabled, 2) both GSCT and RSCT disabled, 3) only RSCT enabled and 4) only GSCT enabled at an intersection in Iran as shown in Figure 2-6. They found that GSCT decreased the red light and yellow light violations, and stop-after-stop-line, and concluded that the scenario with only GSCT was the most effective type of TSCT for reducing red light and yellow light violations.

Figure 2-6. TSCT installed at traffic signals in Iran.
(Source: Kashani et al., 2020)

Some studies found that GSCT induced safe stopping action at the intersection before the onset of red phase. Field studies by Yu and Shi (2015) inferred that the GSCT with the final 9 seconds before the start of red phase (see Figure 2-7) decreased red-light violation since the drivers could make an advanced decision on stopping/crossing the intersection. Another study by Huang et al. (2017) observed that the average maximum deceleration rate was reduced by 1 to 1.8 m/s^2 in the presence of GSCT due to earlier decision to stop at the intersection. Moreover, a driving simulator study by Islam et al. (2017) revealed that the probability of stopping at the intersection increased by 25% and the deceleration decreased in the presence of GSCT (see Figure 2-8) during the last 10 seconds of the phase. Another driving simulator study by Haperen et al. (2016) in Belgium found that the drivers used lower deceleration rates to stop at the intersection and applied brakes in a longer stretch in the presence of GSCT as shown in Figure 2-9. Similarly, Fujita et al. (2007) found that the GSCT reduced rushing into intersection during the inter green period and suggested that the GSCT can improve the intersection safety when the travel delay is controlled accordingly. But the authors also found that the GSCT delayed the drivers' decision to stop or go and therefore, it can lead to risky driving behaviours such as higher acceleration or deceleration near the intersection when moving in high speed. Milaszewicz (2018) also argued that high acceleration near the end of green phase can increase the risk of collision. Also, Yan et al (2022) suggested that the variation in acceleration while crossing and deceleration during stopping in the presence of GSCT was higher than the no timer situation due to which rear end collision can increase.

Figure 2-7. TSCT installed at traffic signals in China.
(Source: Yu and Shi, 2015)

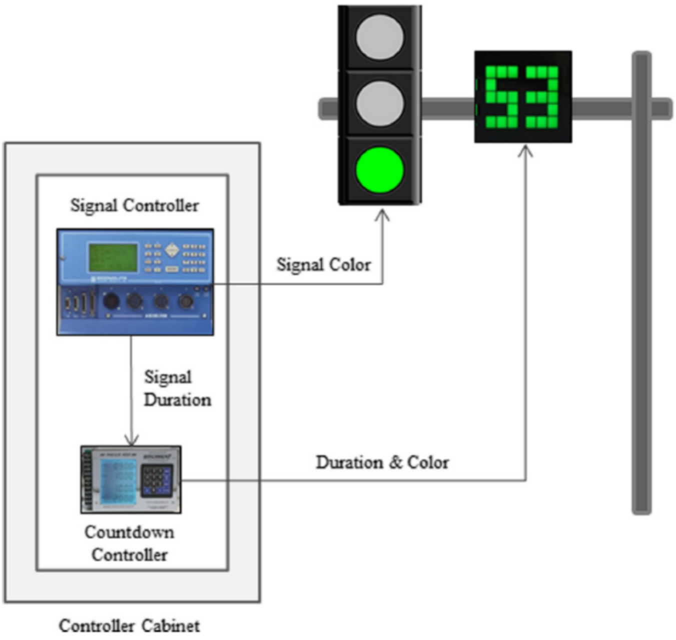


Figure 2-8. Traffic signal controller and countdown controller.
(Source: Islam et al., 2017)

Figure 2-9. TSCT at traffic signals in driving simulator experiment. (Source: Haperen et al., 2016)

Few studies also discussed the impact of GSCT on dilemma zone. Dilemma zone (DZ) is defined as the area upstream of traffic signals where drivers unable are to safely stop at the intersection or legally cross the intersection. They are classified into 2 types based on the causal factor of the driver’s dilemma to safely cross or stop at the intersections. The Type I DZ emerges due to inadequate time left in the signal phase to make a safe decision whereas the Type II DZ (also known as option zone) is caused due to driver’s behaviour and inability to make a clear decision.

Ma et al. (2010) found that the GSCT eliminated Type I DZ and reduced variation in speed when approaching intersections as the counter helped drivers make an advanced decision when approaching intersections. Similarly, Biswas et al. (2017) suggested that the size of dilemma zone Types I and II for small passenger cars was reduced and shifted the Type II DZ away from the intersection when compared to the intersection without GSCT. Also, a study by Ni and Li (2014) which only focused on the effects of GSCT on Type II DZ, inferred that the size of zone was reduced and shifted away from the intersection when compared to the non-GSCT intersection. Another study by Huang et al (2014) compared the effects of Common Signal display

(CSD), Green Signal Flashing Display (GSFD) and GSCT, on the DZ through a field study conducted at six signalized intersections in Changsha, China and observed that the probability of being in a dilemma zone is reduced in presence of the timers. Also, it was inferred that RLR violations is positively corelated to the range of DZ and therefore, the possibilities of the same is expected to reduce under GSCT conditions.

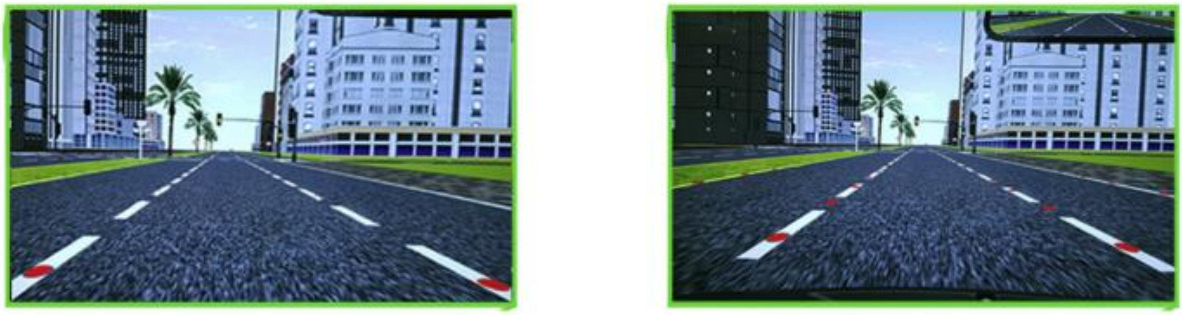
In contrast, Chiou and Chang (2010) observed that GSCT increased the size of Type II DZ from 30 m to 58 m implying that there was a high deviation in decision to stop. They suggested that the conservative drivers stopped well before the stop line whereas the aggressive drivers stopped closer to the stop line. But in the authors' view, increased DZ can have a positive impact on the safety as drivers' decision to stop or cross the intersection can be less impulsive. Almutairi and Wei (2021) observed that speed/red-light cameras and TSCT shifted Types I and II DZ towards the intersection and reduced the maximum passing distance. This showed that the stopping action increased in DZs when strict enforcement measures were established. They also found that Type II DZ was a better representative than Type I as it can capture the stopping and yellow light running more accurately. Moreover, when distance and speed increased, Type II DZ decreased whereas Type I DZ increased. Furthermore, Paul et al. (2022) observed from the PTV Vissim traffic simulation that GSCT with additional 1-s yellow and all red phase decreased Types I and II DZ, and this resulted in the decrease in red-light violation and abrupt stopping and the number of conflicts. Yan et al. (2024) observed that drivers' hesitation to cross the intersection during the yellow phase decreased when the GSCT displayed longer countdown. However, 5-10 s countdown of the GSCT decreased vehicle speeds and better mitigated the dilemma zone than shorter or longer countdowns.

Some studies found that GSCT rather increased or did not significantly change red-light violation. Ibrahim et al (2008) conducted a with and without analysis on 6 intersections in Malaysia that the red-light violation increased in its presence when compared to the no countdown timer intersections. Long et al. (2011) concluded that the probability of red-light violations and drivers' crossing the intersection increased in the presence of green and yellow light counters. Also, the vehicle's entry into the intersection extended up to the first 4 s of red phase in the presence of the counters whereas vehicle entered the intersection only until the first second of red phase without the counters. Similarly, Lum and Halim (2006) concluded that the GSCT with countdown starting from 9 seconds (see Figure 2-10) did not have any impact on red-light violations in the longer term. They found that the red running violations decreased by 65% after 1.5 months of installation but continued to rise to the pre-installation phase count after 7.5 months. But during off-peak hours or lower traffic volume conditions, GSCT significantly decreased red-light violations in all stages of post-installation and it was also effective in encouraging drivers to stop at red under heavy traffic flow for longer terms.

Figure 2-10. GSCT at traffic signals in Singapore.
(Source: Lum and Halim, 2006)

Some studies found that GSCT increased approach speed and decreased headway. Felicio et al (2015) examined driver behaviour towards 3 types of traffic light warning schemes currently in use across Metro Manila, Philippines: traffic lights, countdown timers, blinking light and inferred that the timers increased the proportion of cars that sped up at yellow lights. The authors suggested that the timers created a sense of urgency for drivers in the last 5 secs of green timer, increasing the tendency to speed up. A literature review study by Krukowicz et al (2021) suggested that approach speed of vehicles increased with the presence of GSCT. Ma et al (2010) also found that the GSCT increased the approach speed of vehicles at the intersections which can increase the probability of collision with pedestrians and bicyclists. For the drivers to pass the intersection without any violation when encountering yellow light, the authors concluded that they tend to increase their speed. Devalla et al. (2015) also suggested that the presence of the GSCT encouraged the drivers to travel at higher speeds which can lead to accidents. Ni and Li (2013) observed that the probability of rear-end collisions during the flashing green light phase, which indicates the last 3s of the green phase before the yellow phase, increased between the zone of 5 m to 70 m from the stop line as the vehicles tend to maintain a smaller headway with the presence of GSCT.

Hussain et al. (2020) proposed 5 different countermeasures such as default traffic signal setting (control condition), flashing green signal setting (F-green), red LED ground lights integrated with a traffic signal (R-LED), yellow light counter variable message sign (C-VMS), and red-light running detection camera warning gantry (RW-gantry) at signalized intersections using a driving simulator in Saudi Arabia with 62 driving samples as shown in Figure 2-11.



Simulation view of V_{S1} Simulation view of V_{S2}

(a) Red LED ground lights integrated with a traffic signal

(b) C-VMS (Yellow light countdown timer)

(c) Warning for red-light camera

Figure 2-11. Application of countermeasures at signalized intersections in Saudi Arabia.
(Source: Hussain et al., 2020)

The R-LED consists of 2 series of LED lights - i.e., dynamic lights are located on lane edges at the stopping zone from the stop line to 75 m upstream of the intersection and static lights are located at the zone from 70 m upstream of the stopping zone. The dynamic lights turn to red one by one sequentially towards the intersection whereas all the static lights turn to red at once after the onset of yellow phase until the start of red phase. As the R-LED indirectly indicates the remaining time for passing the intersection, it is similar to the GSCT. The R-LED can help the drivers make their decision to stop or cross the intersection based on their relative position to the red light (refer Figure 2-11(a)). It was inferred that the R-LED reduced red-light violations compared to the no R-LED case. Also, the variations in vehicle speed were lower for the R-LED than C-VMS and RW-gantry.

Some studies found that RSCT can increase red-light violations, especially during its final seconds. Kashani et al. (2020) found that the RSCT increased red-light violations during the end of the red phase in Iran and similarly, Papaioannou and Politis, (2014) concluded that RSCT increased red-light violations due to early start at the end of red phase in a field study conducted at Greece. Similar results were found in Biswas et al. (2017) and Jatoth et al. (2020) through before-and-after analysis and cross-sectional analysis, respectively. This is because the drivers tend to start before the red phase ends when they can estimate the end time of red phase with the aid of the RSCT. However, Chiou and Chang (2010) found that the RSCT did not have a significant effect on crashes in the long term. They found that the number of crashes did not significantly change after 4.5 months of installation of RSCT. However, Klos et al. (2020) suggested that the RSCT without showing countdown in the last 3 seconds of red phase was effective in reducing red-light violations. Kim and Kim (2020) also suggested that the RSCT can help drivers control vehicle idling and reduce greenhouse gas emissions from idling vehicles by 56.8%.

Some studies found that yellow signal countdown timer (YSCT) had a negative influence on the safety at intersections. Almutairi and Wei (2021) studied the driver's stopping decision after the onset of yellow light through cross-sectional analysis at 2 intersections of Saudi Arabia. They found that YSCT of the TSCT increased the approach speeds (85th percentile) especially in yellow light. Fu et al. (2016) identified that the mean Brake Perception Reaction Time (BPRT) to yellow light with YSCT was significantly longer than the mean BPRT to yellow light without YSCT. This increase in BPRT due to YSCT can induce risky driver behaviours. In addition, the likelihood of failing to brake increased with red-light violation, which indicates that YSCT may increase yellow light running and furthermore red-light violations.

In addition, Almutairi and Wei (2021) found that the combination of TSCT and red-light cameras (see Figure 2-12) had positive effect on safety. It was observed that the effect of speed/red-light camera (SRLC) on driver behavior was higher than the effect of TSCT. Intersections with only TSCT increased the approach speed of vehicles by 10 km/h and exhibited similar patterns of driving behavior in terms of traffic violations and stopping action. The combination of SRLC and TSCT reduced yellow light running and red-light violation violations and increased the stopping behavior of drivers but lesser than only SRLC. However, the presence of SRLC shifted the dilemma zone at least 15 m towards the intersection and increased the chances of rear-end crashes. Thus, the study suggested a hidden and mobile SRLC.

Figure 2-12. TSCT at traffics signals in Saudi Arabia.
(Source: Almutairi and Wei, 2021)

2.3. Impacts of TSCT on Traffic Efficiency

The findings from the literature suggested that the TSCT had impacts on the traffic flow efficiency. Sharma et al. (2009) studied the pattern of discharge headway in heterogeneous traffic condition through a cross-sectional analysis for 2 intersections in the city of Chennai, India. They found that the discharge gap time continuously decreased towards the end of green with the presence of the GSCT. Similarly, Wenbo et al. (2013) observed that the RSCT reduced the saturation headway of discharge vehicles and the capacity of through movement increased by about 5 to 10%. They explained that this was because more drivers tried to start earlier at the end of red.

In contrast, some studies found that the GSCT reduced the traffic flow efficiency. Limanond et al. (2010) found that the GSCT reduced the saturation flow rate because the drivers generally increased the discharge headway. A driving simulator study by Haperen et al. (2016) also suggested that the GSCT decreased the traffic flow efficiency as more vehicles decided to stop in the presence of counter. In particular, higher number of vehicles stopped at the intersection when displaying the countdown for the final 3 s of green and red phases compared to displaying the countdown for the entire phases. However, Biswas et al. (2017) found that the GSCT was not effective in improving efficiency as the saturation flow rate remained unaffected.

Some studies suggested that the RSCT reduced the Start-Up Lost Time (SULT). A field study by Chiou and Chang (2010) inferred that the SULT and the saturated headway reduced with RSCT and concluded that it was more beneficial than GSCT in terms of traffic efficiency through a time series comparison of a signalized intersection. Similarly, field studies by Biswas et al. (2017), Raksuntorn (2012), and Jatoth et al. (2020), a driving simulator study by Haperen et al. (2016), and a literature review study by Krukowicz et al. (2021) also inferred that the RSCT was effective in decreasing the SULT and increasing the traffic efficiency. Also, a field study by Li et al. (2014) inferred that the RSCT decreased the perception-reaction time from 2.12 s to 1.48 s and the variation in perception-reaction time. On the other hand, a few studies found negative effects of the RSCT on traffic efficiency. Liu et al. (2012) stated that although the RSCT shown in Figure 2-13 significantly reduced the driver’s start response time and start-up lost time for both the through and protected left-turn lanes. However, the RSCT increased the saturation headway which resulted in minimum gains of intersection capacity. Limanond et al. (2010) also found similar results. On the other hand, Islam et al. (2016) observed that the RSCT reduced the headway of the first queued vehicle by 0.82 s and improved the traffic efficiency at signalized intersections.

Figure 2-13. RSCT at traffics signal in China.
(Source: Liu et al., 2012)

2.4. Driver Satisfaction and Comfort

Some studies investigated drivers’ satisfaction with the TSCT using survey. Chang and Jung (2017) observed that the TSCT generally had higher satisfaction score than the standard signals. They also found that the drivers showed higher satisfaction score for the countdown-overlaid signal than the countdown-separated signal as shown in Figure 2-14. Fujita et al. (2007) studied the effect of green and RSCT on driver behaviour and satisfaction through an in-person questionnaire survey involving 201 random participants at the city centre of Kayseri city in Turkey. They found that the TSCT had positive effect on user comfort during their wait time and crossing time at the intersection. More importantly, the TSCT also had positive impact on the driver’s state of mind and reduced driver aggression.

(a) Countdown-separated signal (b) Countdown-overlaid signal

Figure 2-14. Types of TSCT
(Source: Chang and Jung, 2017)

Similarly, Rijavec et al. (2013) conducted a survey for 411 participants in Slovenia and inferred that 84% of the respondents deemed the TSCT to be a positive impact on safety. Driver’s ability to prepare for starting and stopping, and the information on duration of individual phases were found to be the major reasons for the response. Limanond et al. (2010) also conducted a public survey in Bangkok and found that 64% of the car drivers and 52% of the motorcycle riders agreed that the TSCT reduced their frustration level. A survey-based study by Pan et al. (2017) also highlighted that the red-light violation at the intersections with GSCT was expected to decrease.

3. METHODOLOGY

3.1. Description of Data

This study examined the effects of Traffic Signal Countdown Timers (TSCT) on traffic safety and efficiency at signalized intersections along a section of Huron Church Road, between Totten Street and Dorchester Road in Windsor, Ontario, as depicted in Figure 3-1. This specific stretch was chosen due to its higher incidence of red-light violations compared to other intersections within the city. The road experiences a significant proportion of heavy vehicle traffic due to its proximity to the Windsor-Detroit international border crossing, leading to frequent interactions between passenger cars and heavy vehicles at signalized intersections. This unique traffic characteristic is notable on urban streets in Canada.

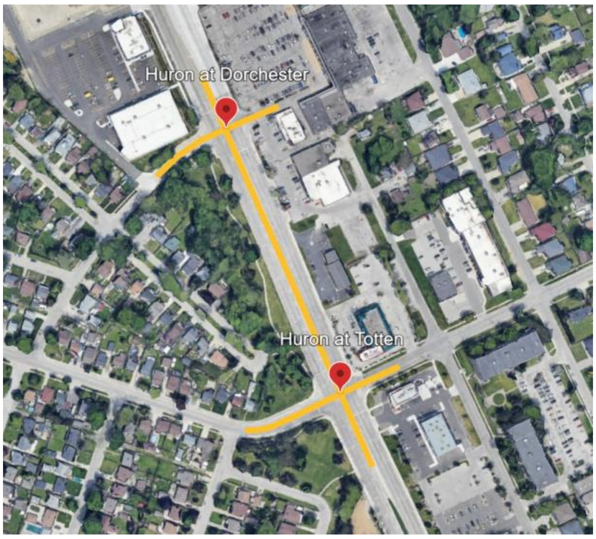


Figure 3-1. Aerial view of signalized intersections on Huron Church Road. (Source: Google, 2024)

Traffic data, including hourly traffic volume for each road in the network, vehicle composition by type (passenger cars and commercial trucks), signal timing plans (cycle length, signal phases, and duration of individual phases) during the afternoon peak hours from 4 to 5 PM, and road geometry (such as the number of lanes and lane width), were obtained from the City of Windsor.

Huron Church Road features six through lanes (three lanes in each direction) with dedicated left-turn lanes as shown in Figure 3-2. The intersections at Totten Street and Dorchester Road are both four-legged, signalized intersections. The signal cycle time is 120 seconds, with yellow phases of 4 seconds and 3 seconds following green phases for through movements and left-turn movements, respectively. The posted speed limits for Huron Church Road and the two side roads are 60 km/h and 50 km/h, respectively. Left turns from Huron Church Road are protected, while left turns from side roads (Totten Street and Dorchester Road) are unprotected, allowing vehicles to turn left during the green phase if no oncoming traffic is present.

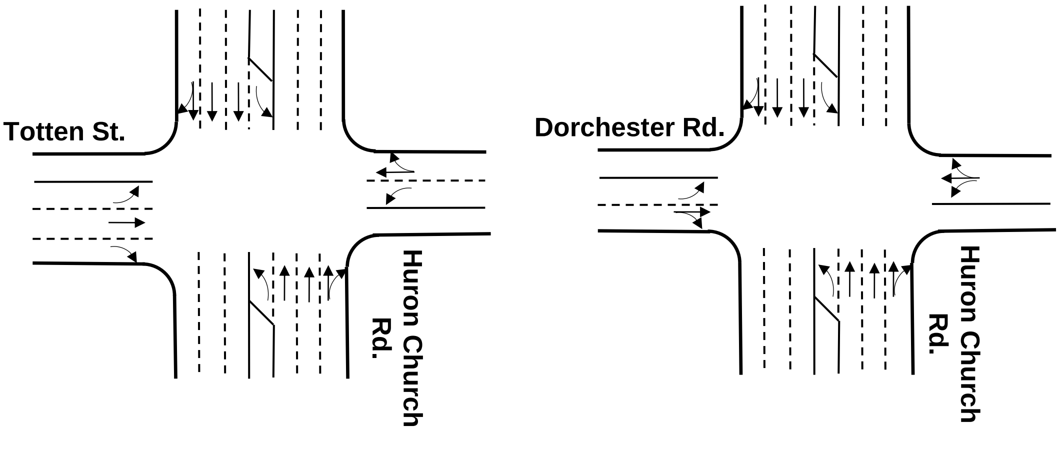


Figure 3-2. Geometric design of signalized intersections on Huron Church Road.

3.2. Vissim Traffic Simulation

Since the TSCT has not yet been implemented on Canadian roads, no field data for TSCT are available for the study site. Consequently, the impacts of TSCT on traffic safety and efficiency were assessed based on the predicted changes in driver behavior in the presence of TSCT using the PTV Vissim traffic simulation software (PTV AG, 2022). The traffic flow was simulated under three TSCT scenarios - GSCT-only, RSCT-only, and a combination of GSCT and RSCT (GSCT+RSCT) - as well as a no-timer scenario, with the timers placed only on the through lanes of the Northbound (NB) and Southbound (SB) Huron Church Road corridor. The GSCT+RSCT scenario was considered in this study because GSCT and RSCT have not always been implemented at the same intersection in the past studies. Also, the implementation of both GSCT and RSCT does not necessarily result in the sum of the independent effects of the GSCT-only and RSCT-only scenarios. Note that traffic patterns change as the GSCT and RSCT sequentially affect driver behavior during successive green and red phases.

Due to lower total traffic volume and truck traffic volume on the side roads compared to Huron Church Road, it was assumed that the TSCT was not implemented on the side roads. Additionally, due to the absence of right-turn signal and the shorter duration of exclusive left turns, the TSCT was not considered for right-turn and left-turn traffic in this study.

A review of the literature indicated that the Region of Influence (ROI) of the TSCT at intersections where drivers can view and respond to the TSCT is determined based on visibility, intersection type, road geometry, and land use. Based on a survey conducted for a similar signalized intersection in Windsor, a road section within 100 m upstream of the stop line on the approaching NB/SB Huron Church Road was selected as the ROI for timers at both intersections.

This simulation-based approach allows for the observation of network-wide traffic efficiency under different TSCT scenarios, which has not been explored in previous studies. Data collected from Vissim were used to conduct a spatiotemporal analysis of approach speeds and acceleration/deceleration at the intersections for each scenario. This analysis provides valuable insights into driver behaviors that influence the impact of TSCT on traffic flow.

To measure potential crashes at the intersection, traffic conflicts were assessed using the Surrogate Safety Assessment Model (SSAM) and Crash Potential Index (CPI), utilizing the vehicle trajectory dataset obtained from Vissim. The methods for Vissim simulation and conflict analysis are detailed in the following sections. Also, the dilemma zone (DZ) has been a crucial factor in understanding driver behavior when approaching during the green phase and in analyzing conflicts at signalized intersections. Therefore, the length and position of the DZ were compared between the GSCT and no-timer scenarios to understand the effect of GSCT on collision probability.

3.3. Road Network and Driver Behaviour Parameters

The studied road network was built and the respective traffic and signal timing data were imported into PTV Vissim. The simulation utilized the Wiedemann 74 car-following model, which is suited for interrupted traffic flow on urban streets and incorporated lane-changing behavior based on free lane selection. To accurately replicate real-world traffic conditions, various Vissim parameter values for each type of TSCT, signal phase and vehicle type were determined based on the observed driver behaviour in the literature as shown in Table 3-1.

The traffic flow parameters remained constant in the no-timer scenario irrespective of the signal phases. In the remaining timer scenarios, the driver behavior parameter values were changed to replicate the effects of GSCT and RSCT only on green and red signal phases, respectively, owing to the effect of TSCT only on its respective signal phase. Also, this study considers the effect of GSCT on both the green and yellow intervals based on the stopping and passing action of the vehicles at the intersections.

Table 3-1. Calibrated Parameters of Vissim Simulation

Parameters for Calibration	No timer	GSCT-only			RSCT-only		
		Green phase	Yellow phase	Red phase	Green phase	Yellow phase	Red phase
Compliance rate	99.95%	99.96% (only applies to red phase)			99.95% (only applies to red phase)		
Approach speed distribution*							
Huron Church Road	50-60-70 km/h	50-66-70 km/h	50-66-70 km/h	50-60-70 km/h	50-60-70 km/h	50-60-70 km/h	50-60-70 km/h
Desired acceleration distribution							
Car	0 – 3.5 m/s^2	0 – 5.37 m/s^2	0 – 5.37 m/s^2	0 – 3.5 m/s^2	0 – 3.5 m/s^2	0 – 3.5 m/s^2	0 – 3.5 m/s^2
Truck	0 – 2.5 m/s^2	0 – 3.83 m/s^2	0 – 3.83 m/s^2	0 – 2.5 m/s^2	0 – 2.5 m/s^2	0 – 2.5 m/s^2	0 – 2.5 m/s^2
Desired deceleration distribution							
Car	2.55 – 3 m/s^2	2.09 – 2.45 m/s^2	2.09 – 2.45 m/s^2	2.55 – 3 m/s^2	2.55 – 3 m/s^2	2.55 – 3 m/s^2	2.09 – 2.45 m/s^2
Truck	1.05 – 1.5 m/s^2	0.86 – 1.23 m/s^2	0.86 – 1.23 m/s^2	1.05 – 1.5 m/s^2	1.05 – 1.5 m/s^2	1.05 – 1.5 m/s^2	0.86 – 1.23 m/s^2
Reaction time to onset of red signal	2 s	2 s	2 s	2 s	2 s	2 s	0.5 s

*The values represent the minimum, 85th percentile speed and maximum speed, respectively.

First, the compliance rate in Vissim was modified to reflect the effect of TSCT on Red Light Violations (RLV). Lower compliance rate increases the proportion of vehicles which violate the traffic signal. According to the report from CTV News Windsor (2023), 0.05% of vehicles violated red light at the Huron Church Road corridor, which is one of the corridors with high RLV in Windsor. Based on this data, the compliance rate (100 – 0.05 (percentage of RLV) = 99.95%) was used for the no-timer scenario. The compliance rate in the presence of GSCT was calculated based on the findings in previous field studies (Paul et al., 2022; Paul and Ghosh, 2020). Since the RLV was reduced by 20% as observed in these field studies, the compliance rate in the presence of GSCT was calculated as 99.96% (100 – 0.05 * (1 - 0.2)). The signal violations are applicable only for the red signal phase because drivers do not violate the green signal (i.e., stop) during the green phase and they are allowed to either pass or stop at the yellow phase.

Similar to the GSCT, the RSCT can increase RLVs (i.e., early start before the onset of the red phase). However, Biswas et al. (2017) found that RLV by passenger cars and commercial trucks did not significantly increase after the RSCT was installed. Thus, the same compliance rate as the no-timer scenario was adopted for the RSCT scenario.

The speed distribution, desired acceleration, and desired deceleration distributions were also modified during the green phase in the GSCT scenario based on the literature review. In general, the past studies suggested that the GSCT tended to increase the speed and acceleration rate of approaching vehicles at the intersection as the drivers attempted to cross the intersection before the onset of red. In addition, the GSCT induced a smoother deceleration rate for the vehicles due to the drivers' advanced decision-making and therefore reduced RLV.

Similarly, the RSCT induced a smoother deceleration rate for vehicles approaching an intersection during the red phase due to earlier decision-making. With knowledge of the remaining time, drivers either decelerated gradually to stop at the intersection or maintained their speed to cross it. For acceleration and deceleration in the no-timer scenario, the default Vissim distributions for cars and trucks were used. However, the distributions for maximum and desired deceleration were reduced by 18.2%, while those for maximum and desired acceleration were increased by 53.4%.

For the approach speed, the 85th percentile speed was assumed to be the posted speed limit for a given road (60 or 50 km/h) in the no-timer scenario and it was increased by 9% in the presence of GSCT as observed in the previous field studies (Paul et al., 2022; Paul and Ghosh, 2020) during the green and yellow signal phases.

Driver’s reaction time was also adjusted as the past studies found that the RSCT significantly reduced the start-up lost time (from 1-3 s to 0-2 s). In Vissim, the reaction time is defined as the time delay between the onset of green phase and the start time of first vehicle movement in the stop line. Thus, a change in the reaction time does not apply to the GSCT scenario. The default drivers’ reaction time of 2 s was used for the no timer and GSCT scenario, and it was reduced to 0.5 seconds (i.e., the lowest value in Vissim) only in the RSCT scenario during the red signal phase. The reaction time represents the difference between the onset of green phase and the time when the first vehicle in a queue which forms during the red phase crosses the stop line. The subsequent vehicles in the queue follow the lead vehicles according to the Wiedemann 74 car-following model. Thus, the reduced reaction time is only applicable to the first vehicle in the queue and it does not imply that the reaction time for subsequent vehicles is also reduced with the anticipation of early start of the first vehicle.

3.4. Vissim Component Object Model (COM) Interface

To implement changes in driver behavior parameter values during different signal phases in the Vissim simulation, dynamic adjustments of these parameters are required. For this purpose, the Component Object Model (COM) interface was employed to modify Vissim functions and parameters. The Vissim-COM interface allows users to control and manipulate Vissim objects through external applications using programming languages like Python, Visual Basic, and C# (PTV AG, 2024). In this study, Python was utilized to adjust parameter values for the respective signal phases throughout the simulation, with the code accessed through the Visual Studio Code platform.

The Vissim-COM interface can be employed through two main approaches: event-based scripts and external scripts. Event-based scripts, which are integrated within the simulation environment, allow for dynamic changes in driver behavior parameter values during specific events, such as the start and end times of the simulation or predefined time intervals. These scripts enable changes in driver behavior at traffic signals to occur when events like signal phase changes take place. They are typically written in Vissim's internal scripting language, Visual Basic for Applications (VBA), or other programming languages such as Python, MATLAB, and VBScript. Event-based scripts are suitable for simpler, predefined tasks within the simulation environment. However, for frequent events or complex scripts, they may be limited in functionality and could impact performance.

In contrast, external scripts are developed and executed outside of Vissim, interacting with it through the COM interface using one of the aforementioned programming languages. External scripts offer greater flexibility and independence, enabling more complex logic and extensive data processing. They are ideal for advanced simulation control, real-time traffic management applications, and integration with other systems. While external scripts avoid some performance issues associated with event-based scripts, they require careful setup, detailed calibration of parameters, and extensive programming. In this study, event-based scripts were chosen for the Vissim COM interface as they were designed to run during predefined signal phases.

Events corresponding to the specific start and end times of each signal phase in each cycle were created in Vissim. Event-based scripts, which included Python code snippets written in Visual Studio Code, were executed during these events. This required synchronizing the signal times of both intersections with the simulation time across all signal cycles to accurately identify red and green intervals in simulation seconds. This synchronization was manually performed using signal controller data obtained from Vissim. Due to a 5-second signal offset and differences in the length of signal phases between the two intersections, the start and end times of red and green phases differed between them. After determining these start and end times in simulation seconds, the corresponding driver behavior parameters were modified by executing the event-based scripts. The script executed during a particular event remains consistent across all signal cycles. The flowchart illustrating the script execution sequence is shown in Figure 3-3.

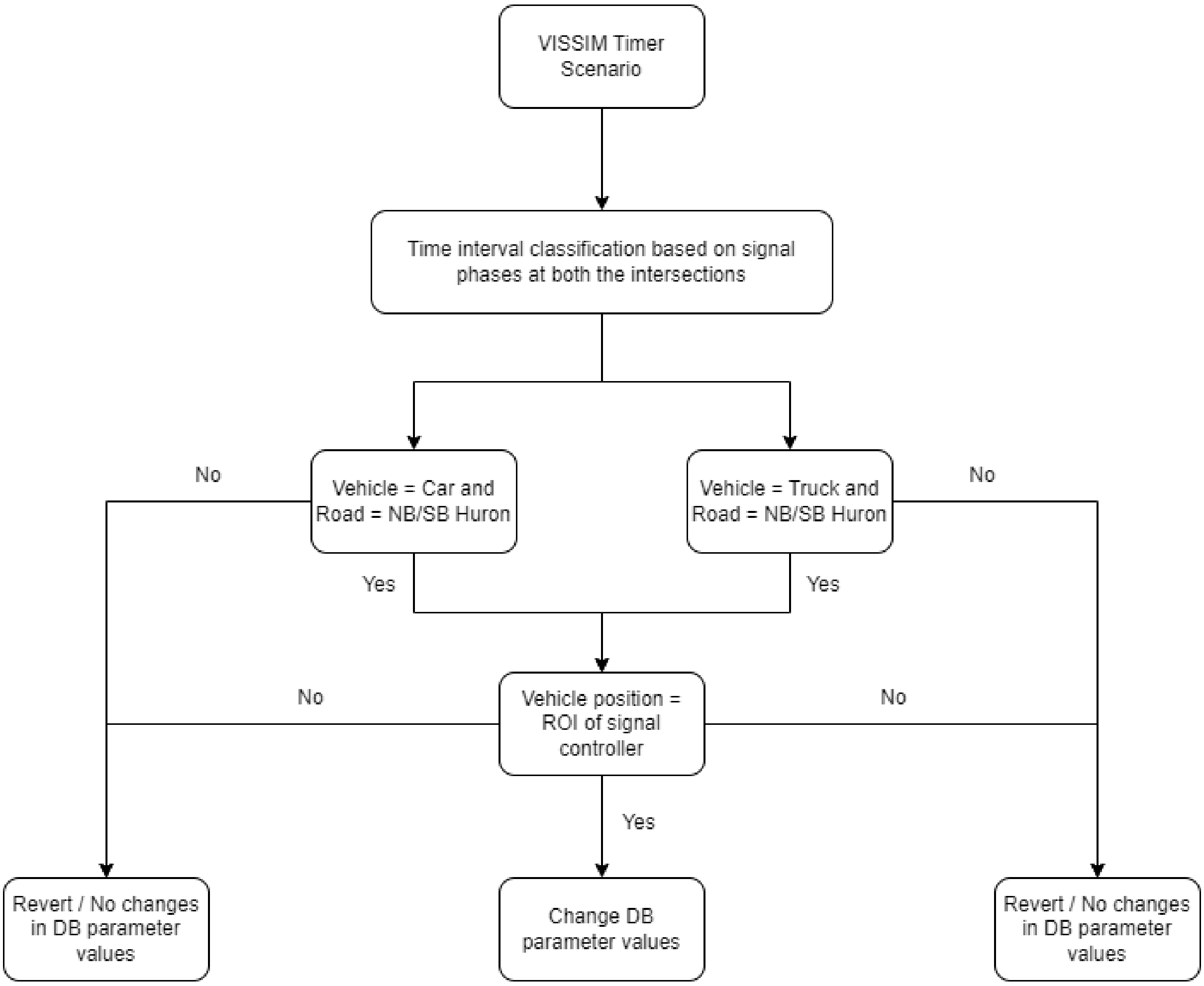


Figure 3-3. Flow chart of an event-based script for the traffic signal countdown timer.

Due to the signal offset between the controllers at both intersections, the event or signal phase duration was initially divided into three time intervals: 1) Interval 1: Only the Totten intersection had a red (or green) phase, 2) Interval 2: Both intersections had a red (or green) phase, and 3) Interval 3: Only the Dorchester intersection had a red (or green) phase. Classification was then performed based on vehicle types (cars and trucks), the road link they were on (NB Huron Church Road, SB Huron Church Road), and their position on the link within each timer interval. Since the Region of Influence (ROI) of the timers varied in each time interval, the code was scripted so that when a vehicle entered the ROI while approaching a signal, the driver behavior parameter values were adjusted accordingly. Once the vehicle exited the ROI, the parameter values reverted to their original settings.

As noted in previous studies, the Red Signal Countdown Timer (RSCT) reduced the deceleration rate of approaching vehicles and shortened their reaction time to the onset of the green signal. This effect was achieved by creating events during the red signal phase of each signal cycle and accessing the "IndivDesDecelFunc" and "ReactTmDistr" attributes in the vehicle class and driver behavior class, respectively, when the vehicle met specific conditions and was within the Region of Influence (ROI) of the approaching signal controller.

In the presence of the Green Signal Countdown Timer (GSCT), traffic compliance rate, acceleration rate, and vehicle speeds increased, while the deceleration rate decreased. The compliance rate remained constant regardless of the signal phases and was set to its respective value based on the timer scenario before the simulation began. The acceleration rate, deceleration rate, and speed of vehicles were modified using events that occurred during the green signal phase, through attributes such as "IndivDesAccelFunc," "IndivDesDecelFunc," and "DesSpeed," respectively, in the vehicle class, similar to the RSCT scenario.

In the GSCT+RSCT scenario, the scripts for GSCT and RSCT were integrated. Consequently, during the red and green phases, the parameter values were adjusted accordingly in each phase throughout the simulation. The logic of this even-based script in the Vissim-COM interface was explained in detail in Appendix A.

3.5. Dilemma Zone

There are two types of DZ - Type I (Dilemma Zone) and Type II (Option Zone) which arise due to improper signal timings and driver's indecisiveness, respectively. In this study, Type I DZ which occurs due to poor intersection design and signal timing was used to assess the impact of GSCT. The length and position of Type I DZ are calculated by comparing the minimum stopping distance (X_s) and the maximum passing distance (X_p) as shown in Figure 3-4. X_s is the minimum distance from the stop line at which a vehicle can stop before entering the intersection and X_p is the maximum distance from the stop line at which a vehicle can legally clear the intersection. Type I DZ exists only when X_s is greater than X_p – i.e., drivers can neither safely stop at the intersection nor legally clear the intersection in the zone.

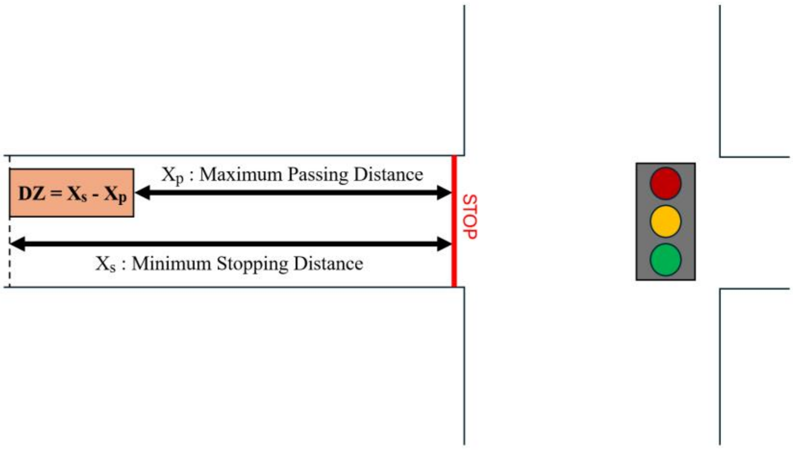


Figure 3-4. Dilemma Zone Type I at a signalized intersection.

As per the Gazis, Herman, and Maradudin (GHM) model (Gazis et al., 1960), X_s, X_p and the length of DZ were calculated using the equations as follows:

Minimum Stopping Distance, $X_s = V_0 t + {V_0}^2/2a_1$

Maximum Passing Distance, $X_p = V_0 Y + 0.5a_2(Y - t)^2 - W - L$

Length of Dilemma Zone $= X_s - X_p$ if $X_s > X_p$

where V_0 = 85th percentile speed of vehicles while approaching an intersection (m/s), t = perception reaction time to apply brakes (s), a_1, a_2 = maximum deceleration and acceleration rates (m/s^2), respectively, Y = yellow phase (s), L = length of vehicle (m), and W = width of intersection (m). The length and position of DZ are separately calculated for the no timer and GSCT scenarios using their respective parameter values in Table 1. As the drivers can react faster to the onset of yellow signal, the shorter braking perception reaction time (t) was assumed for the GSCT scenario (= 0.896 s) than the no-timer scenario (1.184 s) as per the field study by Paul et al. (2022).

3.6. Surrogate Safety Assessment Model

In this study, vehicle conflicts were estimated using in the Surrogate Safety Assessment Model (SSAM) developed by the U.S. Federal Highway Administration (FHWA) (2008). Conflict events are defined as the events when the surrogate safety measures such as Post Encroachment Time (PET) and Time-to-Collision (TTC) exceed the threshold values of 5 s and 1.5 s, respectively. The model classifies conflict events into crossing (85–180 degrees), lane change (30–85 degrees), and rear-end conflicts (0–30 degrees) based on the collision angle between vehicles as shown in Figure 3-5. In this study, the numbers of conflicts by type were compared among the scenarios.

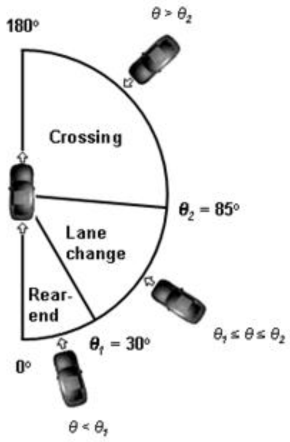


Figure 3-5. Classification of conflict based on the angle of collision as per the SSAM software. (Source: FHWA, 2008)

3.7. Spatiotemporal Analysis of Traffic Flow Parameters

The literature review revealed that the TSCT has shown inconsistent effects on traffic safety and efficiency across different study areas. Rear-end conflicts and speeding at intersections emerged as major concerns related to the installation of TSCT. However, past studies have not analyzed how the TSCT changes the patterns of traffic flow parameters during different signal phases and at different locations, which are closely related to traffic safety and efficiency. To address this limitation, a spatiotemporal analysis of speed was conducted to understand how different types of TSCT influence variations in speed over time and distance from the stop line for the vehicles approaching the intersection.

Traffic flow parameters, including average speed, acceleration/deceleration, and the number of vehicles crossing, were collected for cars, trucks, and all vehicles at 10 locations before the stop line, spanning up to 100 m in 10-m intervals using data collection points in Vissim. Although data were recorded for both intersections in both directions on Huron Church Road, the analysis focused on the Totten intersection in northbound through approach for demonstration purpose. It is expected to yield similar results to other approaches at both intersections. Patterns of speed change during the presence of TSCT were observed for each signal cycle and compared to the speed patterns observed in the no-timer scenario.

Data were collected every second throughout the simulation, excluding the initial 360 seconds of warm-up (equivalent to three signal cycles). The simulation was run 10 times for each scenario and the average values from 10 simulation runs were calculated. This will consider random variations in the simulation results due to different patterns of vehicles being released into the road network in different simulation runs.

The average traffic flow parameters per second were computed for each second of a signal cycle (0-120 seconds) across all 27 signal cycles in the simulation. These values were then plotted against time in each cycle (0-120 seconds) and distance from the stop line (locations of data collection points 10-100 meters from the stop line) to observe spatiotemporal patterns of speed and acceleration/deceleration under different scenarios. This spatiotemporal analysis provides insights into the effect of TSCT on traffic flow and efficiency.

3.8. Spatial Analysis of Rear-end Conflicts

Previous studies have identified rear-end conflicts as a significant contributor to overall conflict events and a key indicator of traffic safety in the presence of TSCT. Although the SSAM can estimate rear-end conflicts, the model neither considers different vehicle types and nor specifies the location and time of conflicts. However, the impacts of TSCT on conflicts are likely to be different between cars and trucks due to their differences in reaction time and vehicle performance characteristics (e.g., maximum deceleration). Also, the impacts of TSCT on conflicts are likely to vary over distance to the stop line (e.g., higher number of conflicts near the stop line).

Thus, spatial analysis of rear-end conflicts for different vehicle types was performed using vehicle trajectory extracted from the Vissim simulation. Using the trajectory data, the Crash Potential Index (CPI) was calculated separately for cars and trucks. The CPI represents the likelihood that the following vehicle's required deceleration rate to avoid a collision with the lead vehicle (DRAC) exceeds its maximum available deceleration rate (MADR) (Cunto and Saccomanno, 2008). The CPI accounts for differences in deceleration capabilities between cars and trucks, as well as their respective collision risks. According to Cunto and Saccomanno (2008), the average MADRs for cars and trucks were assumed to be 8.45 m/s^2 and 5.01 m/s^2, respectively. To account for delays in deceleration due to drivers' reaction time, the modified DRAC proposed by Zhao and Lee (2018) was employed in this study as follows:

$$\mathrm{DRAC}\ (\mathrm{t}) = \frac{(\mathrm{V_L(t)} - \mathrm{V_F(t)})^2}{2\mathrm{S(t)} - (\mathrm{V_F(t)} - \mathrm{V_L(t)} * \mathrm{t_r})}, \ \mathrm{V_F(t)} > \mathrm{V_L(t)} \qquad (3\text{-}1)$$

where $V_L(t)$ and $V_F(t)$ are the speeds of the lead and following vehicles at time t, respectively; $S(t)$ is the front-to-rear spacing between the lead and following vehicles at time t, and t_r is the driver's reaction time. Based on the study by Dozza (2013), the reaction times were set at 1.45 s for car drivers and 0.26 s for truck drivers.

DRAC values were calculated for all vehicle pairs traveling on the NB and SB Huron Church Roads. These values were then compared to the MADR values to identify the number of conflicts and calculate the CPI. The average CPI for each scenario was determined based on 10 simulation runs. Additionally, the position of the following vehicle during conflict events was recorded, and a spatial analysis of conflicts was conducted to examine the distribution of CPI in relation to the distance from the stop line. This method offers insights into how the impact of TSCT on rear-end conflicts changes at different locations as vehicles approach the signalized intersection.

4. RESULTS AND DISCUSSION

The effects of GSCT, RSCT, and GSCT+RSCT on traffic safety and efficiency were analyzed through the comparison with the no-timer scenario. This analysis also investigates how specific driver behavior parameters contribute to these effects using the data obtained from the Vissim simulation. The results of this comprehensive analysis, including detailed observations of how GSCT, RSCT, and GSCT+RSCT impact both traffic safety and efficiency, are presented and discussed in the following sections.

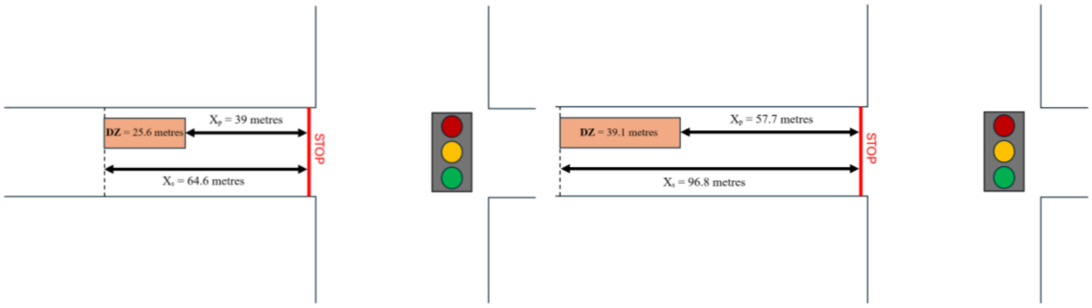
4.1. Impacts of TSCT on Traffic Safety

The impacts of TSCT on traffic safety were assessed based on the dilemma zone and vehicle conflicts. First, the dilemma zone (DZ) was calculated for the GSCT scenario and the no-timer scenario. Since the DZ only exists during the green phase, the DZ cannot be calculated for the RSCT scenario. It was found that the DZ was longer in the GSCT scenario (39.1 m) than the no-timer scenario (25.6 m). This indicates that the driver's dilemma exists for a longer distance of 13.5 m, and it can lead to increase in erratic driving behaviours. Although many studies found that longer DZ had a negative effect on the traffic flow, it can also lead to more gradual change in vehicle's motion or trajectory when deciding to stop or go and reduce large variations in a vehicle's behavior (Chiou and Chang, 2010).

The distance of DZ from the intersection was also determined to understand its overall effect on intersection safety through estimating X_s and X_p in both no timer and GSCT scenarios. For instance, if the DZ is closer to the intersection, drivers will have less time for decision to stop or go, which makes drivers more dangerous. It was found that the location of DZ was 57 m to 96 m from the intersection in the presence of GSCT whereas 39 m to 64 m from the intersection in the no-timer scenario as shown in Figure

4-1. Thus, the GSCT shifted the location of DZ further upstream of the intersection. This implies that the GSCT allowed drivers to make an earlier decision to stop or go and made them safer when approaching the intersection.

In the presence of GSCT, the approach speed and acceleration increased whereas the deceleration and breaking perception time decreased. As a result, X_s and X_p increased and the difference between these values also increased (i.e., increase in the length of DZ). As X_s increased, the zone's position was also shifted further away from the intersection.



(a) No-timer scenario (b) GSCT scenario

Figure 4-1. Comparison of dilemma zone between the GSCT and no-timer scenarios.

Vehicle conflicts were also estimated using the SSAM. As an input to the SSAM, the vehicle trajectory data were extracted from 10 simulation runs for each of the scenarios. The average number of conflicts were estimated using the SSAM and compared among different scenarios as shown in Table 4-1.

Table 4-1. Average Number of Conflicts Predicted using SSAM

Scenario	Crossing	Rear-end	Lane change	Total
No-timer	17.5	188.8	88.6	294.9
(%)	5.9	64.0	30.0	
GSCT	18.9	179.4	94.4	292.7
(%)	6.5	61.3	32.3	
RSCT	15.3	178.2	83.7	277.2
(%)	5.5	64.3	30.2	
GSCT+RSCT	14.8	169.2	89.8	273.8
(%)	5.4	61.8	32.8	

When PET and TTC were used as surrogate safety measures, the GSCT+RSCT scenario reduced the number of conflicts more effectively compared to the other timer scenarios. Statistical tests were performed to check if the numbers of conflicts are significantly different between the no-timer scenario and any TSCT scenarios. The number of conflicts obtained from the trajectory data of 10 simulation runs for each of the TSCT scenario were used for the test. Due to a small number of observations, statistical significance of the difference in the number of conflicts between the TSCT scenarios and the no-timer scenario was assessed using the Mann-Whitney U test, which is one of non-parametric statistical tests. Although the average number of conflicts was lower for the timer scenarios compared to the no-timer scenario, the difference was not statistically significant at a 95% confidence interval ($p\text{-value} > 0.05$).

Table 4-1 also shows that rear-end conflicts were the most common type of conflicts, which account for over 60% of total number of conflicts in all scenarios. This result is consistent with findings from previous studies.

To further analyze rear-end conflicts by vehicle type and location, rear-end conflicts were also estimated using the Crash Potential Index (CPI). The average number of conflicts which occurs when the DRAC exceeds the MADR and the average of CPIs (overall and for different types of following vehicles) in 10 simulation runs was calculated for each scenario as shown in Table 4-2.

Table 4-2. Comparison of Average Number of Rear-end Conflicts and Crash Potential Index among Scenarios

Timer Scenario	Cars		Trucks		Overall	
	Number of conflicts	CPI ($\times 10^{-4}$)	Number of conflicts	CPI ($\times 10^{-4}$)	Number of conflicts	CPI ($\times 10^{-4}$)
No-timer	31.9	9.8	1.1	1.1	33	7.8
GSCT	29.9	9.5	0.7	0.7	30.6	7.3
RSCT	24.7	7.4	0.8	0.8	25.5	6.0
GSCT+RSCT	19.6	6.3	0.5	0.5	20.1	4.9

The table shows that the overall CPI was lower for all TSCT scenarios than the no-timer scenario. This indicates that the TSCT has a positive impact on traffic safety by reducing rear-end collision risk. In particular, the percentage reduction in CPI compared to the no-timer scenario was highest for the GSCT+RSCT scenario (37%), followed by the RSCT scenario (23% reduction). Based on the Mann-Whitney U test, this reduction was statistically significant at a 95% confidence interval ($p\text{-value} < 0.05$). These findings suggest that vehicles adopted lower and safer deceleration rates in the presence of TSCT during car-following situations, compared to the no-timer scenario across the road network.

While the desired deceleration of vehicles was reduced in the TSCT scenarios, the actual deceleration during a conflict or unexpected situation was also influenced by surrounding vehicles and environmental factors. Additionally, the effect of TSCT was limited to specific regions and during a specific signal phase. Nevertheless, these results indicate that the presence of TSCT can significantly reduce rear-end conflicts at signalized intersections.

When comparing the different TSCT scenarios, it was found that the RSCT was more effective in enhancing overall safety than the GSCT. The greater the speed difference between the lead and following vehicles, the higher the probability of a rear-end collision at a given distance. In the presence of the GSCT, while vehicle deceleration for stopping at the intersection decreased, the acceleration and speed of vehicles passing through the intersection increased. In contrast, the RSCT promoted smoother deceleration for the vehicles approaching the stop line during the red phase. As a result, a higher deceleration rate was generally required under the influence of the GSCT to avoid collisions, compared to the RSCT.

Additionally, it was observed that the reduction in CPI was greater for cars than for trucks. Similar patterns of reduction in CPI were observed in different TSCT scenarios. This is because due to the lower speeds and acceleration/deceleration characteristics of trucks compared to cars, the number of conflicts involving trucks was also comparatively lower. However, the GSCT+RSCT scenario effectively halved the number of truck-involved conflicts. This indicates that the GSCT+RSCT scenario can more effectively decrease the risk of rear-end collision for trucks. This reduction in truck-involved conflicts can, in turn, lower the severity of rear-end collisions.

A spatial analysis of rear-end conflicts using the CPI was carried out to understand the spatial patterns of rear-end collision risk and the related driver behaviors when vehicles approached intersections under the influence of TSCT, as depicted in Figure 4-2. The analysis showed that the distributions of CPI within the ROI were different among different scenarios..

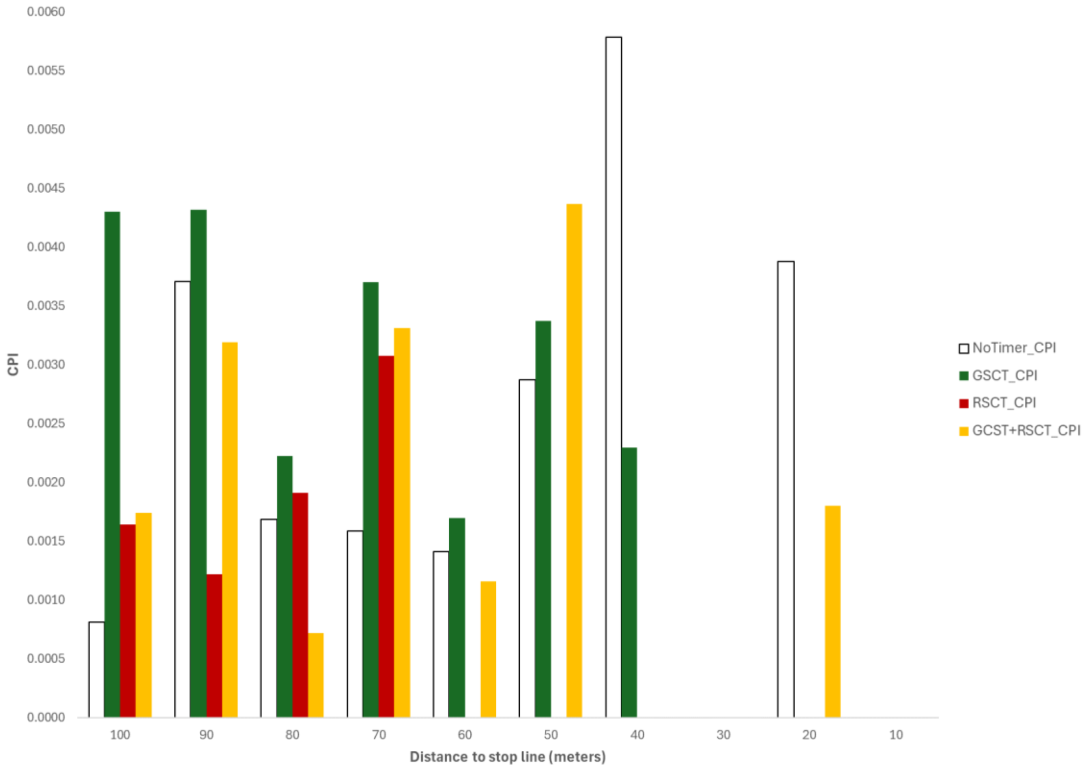


Figure 4-2. Crash Potential Index at different distances to the stop line

More specifically, non-zero CPI values were observed between 100 m and 40 m from the stop line with the GSCT, between 100 m and 70 m with the RSCT, and between 100 m and 20 m with the GSCT+RSCT. This suggests that each type of TSCT uniquely influenced vehicle maneuvering and decision-making as drivers approached the intersection.

The GSCT was particularly effective in reducing the CPI within 40 m of the stop line compared to the no-timer scenario, while the RSCT significantly reduced the CPI at a distance of 90 m from the stop line. This implies that the GSCT is more effective in reducing rear-end collision risk closer to the stop line whereas the RSCT is more effective at a longer distance from the stop line. This indicates that drivers were able to make clearer decisions of stopping or crossing the intersection when the GSCT was present. This is supported by the results from the Dilemma Zone analysis. Knowing the remaining time during the green signal phase allowed drivers to make early decisions, leading to more predictable vehicle maneuvers near the stop line and avoiding rear-end conflicts. After this point, the CPI for the GSCT scenario dropped to zero, indicating that rear-end collision risk is low after their decision to stop or cross.

Similarly, when vehicles approached the intersection during the red phase in the presence of the RSCT, drivers could make earlier decisions of adjusting their speed to either stop or maintain speed to cross the intersection immediately after the signal turns to green. Without the RSCT, vehicles would likely experience higher variation in speed, which results in higher rear-end collision risk. The GSCT+RSCT scenario was most effective in reducing the CPI within 20 m of the stop line compared to the no-timer scenario. These findings suggest that different TSCTs have varying impacts on rear-end conflicts as vehicles approach intersections.

4.2. Impacts of TSCT on Traffic Efficiency

To evaluate the impacts of TSCT on traffic efficiency, spatiotemporal patterns of speed were compared among different scenarios. Figure 4-3 shows average speed at each data collection point and each second in a cycle were calculated using the speeds for each cycle in 10 simulation runs. In the figure, the red phase occurs at 0 to 44 s and 117 to 120 s whereas the green phase starts at 45 s and ends at 116 s. The total length of one cycle is 120 s. Lighter yellow color represents higher speed and darker blue color represents lower speed and varied between 0 to 70 km/h.

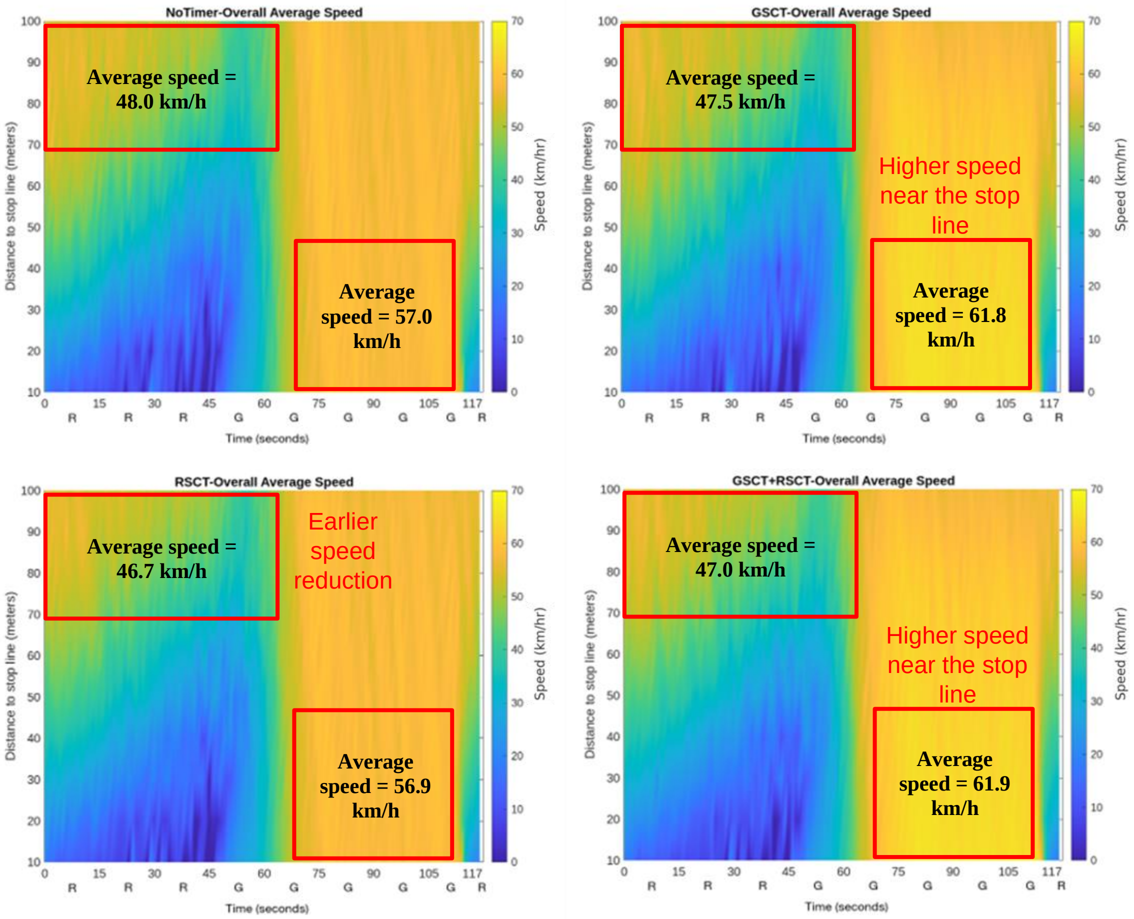


Figure 4-3. Spatiotemporal plots of speeds (km/h) for all the timer scenarios

Figure 4-3 shows that the speed was initially slower at the beginning of green phase (45 s) and it gradually increased until the end of green phase in all scenarios. However, the speed near the stop line during the green phase as indicated by the red box was generally higher for the GSCT and GSCT+RSCT scenarios (average speed of 61.8 and 61.9 km/h, respectively) than the no-timer and RSCT scenarios (average speed of 57.0 km and 56.9 km/h, respectively). This result is consistent with the results from previous studies that drivers tend to cross the intersection during the green phase in the presence of GSCT.

The figure also shows that the speed 70-100 m from the stop line while approaching the intersection during the red phase was lower in the RSCT scenario (average speed of 46.7 km/h) compared to the no-timer and GSCT scenarios (average speed of 48.0 km/h and 47.5 km/h, respectively) as indicated by darker blue color. Again, as seen in the CPI distribution, the drivers were able to make an earlier decision to reduce speed while approaching during the red phase in the presence of RSCT.

In summary, the reasons for reduction in the CPI in the GSCT and RSCT scenarios can be explained as follows. In the GSCT scenario, as more vehicles pass the intersection at higher speed than the no-timer scenario, they are less likely to reduce or stop at the intersection near the end of the green phase, which can increase rear-end conflicts. In the RSCT scenario, as vehicles start decelerating earlier during the red phase, they can reduce speed more gradually as they approach the intersection, and this results in the reduction in rear-end conflicts.

The spatiotemporal patterns of acceleration and deceleration were also compared among the scenarios as shown in Figure 4-4. It was found that the GSCT and GSCT+RSCT increased acceleration 80-100 m from the stop line during the green phase (average acceleration of 0.47 and 0.49 m/s^2, respectively) compared to the no-timer and RSCT scenarios (average acceleration of 0.15 m/s^2 for both scenarios). This indicates that the GSCT facilitated earlier decision-making and helped drivers cross the intersection by increasing speed as they approach the intersection during the green phase.

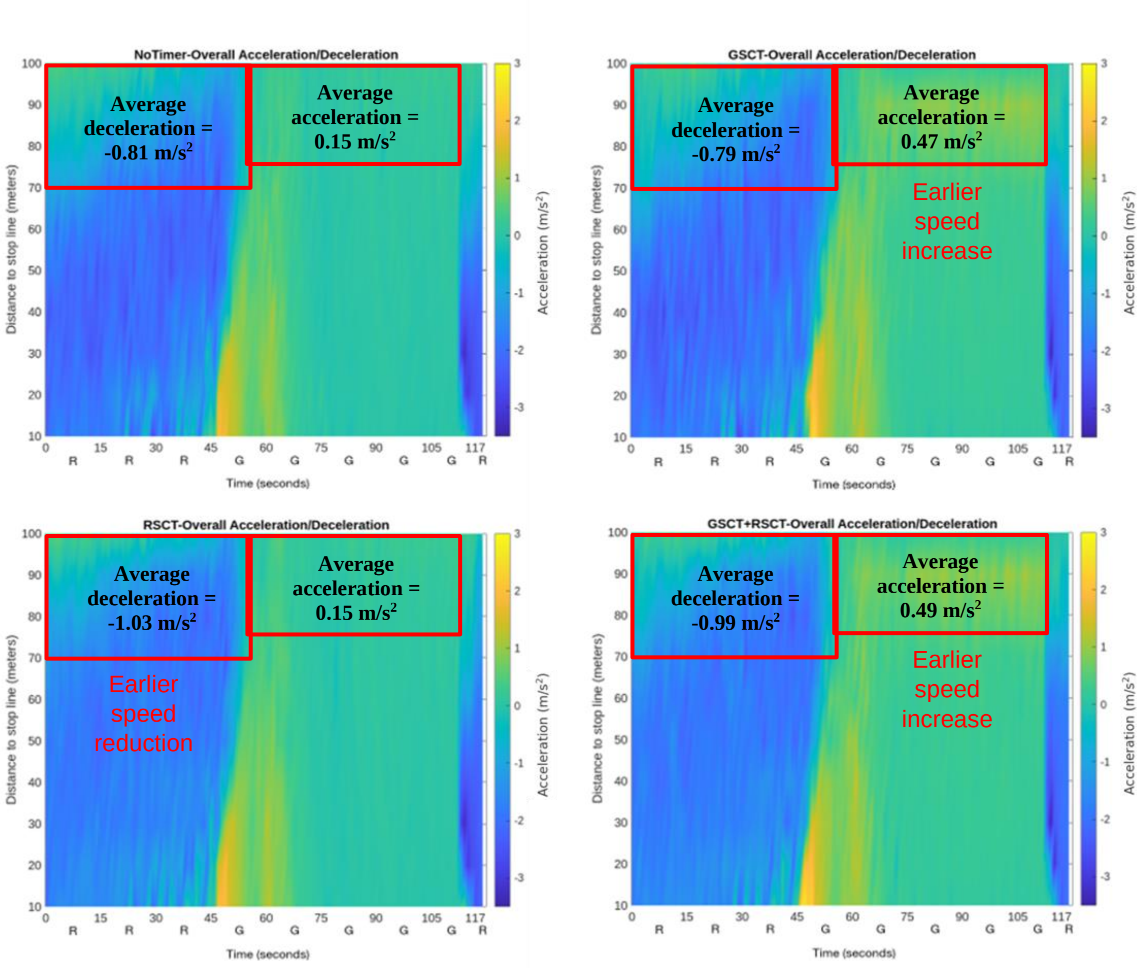


Figure 4-4. Spatiotemporal plots for acceleration/deceleration (m/s^2) of all the timer scenarios

Figure 4-4 also shows that the deceleration started 70-100 m from the stop sign during the red phase was higher for the RSCT scenario (average deceleration of -1.03 m/s^2) than the no-timer, GSCT and GSCT+RSCT scenarios (average deceleration of -0.81 m/s^2, -0.79 m/s^2, and -0.99 m/s^2, respectively). Also, there was no clear difference in the acceleration rates between the no-timer and RSCT scenarios at the start of the green phase. This shows that although the RSCT facilitated early start of vehicles at the beginning of green, it did not significantly affect the speed.

Overall average speed in the entire road network was also compared as traffic signal operations can have a chain effect on other roads connected to the intersection as shown in Table 4-3. The difference in average speed between the no-timer and TSCT scenarios was statistically significant at a 95% confidence interval based on the result of Mann-Whitney U test. The table shows that the GSCT+RSCT scenario had the highest increase in the speed (6.1%) compared to the no-timer scenario among the TSCT scenarios. The GSCT also increased the speed by 4.4 %. However, the RSCT rather slightly decreased the speed by 0.9%. This is because in spite of earlier start at the beginning of green phase, the deceleration also started earlier when approaching the intersection during the red phase in the presence of RSCT. It is worth noting that the increase in speed was higher for trucks than cars in the presence of GSCT and GSCT+RSCT. This shows that the GSCT can increase truck speed more effectively than car speed. The average speed of car is lower than the average speed of truck potentially because a majority (70-75%) of vehicles on Huron Church Road were cars which had to stop and go more frequently. Also, all vehicles on the cross streets (Totten St. and Dorchester Rd.) were assumed to be cars. In particular, these cars stopped for a long period of time during the red phase to yield to car and truck traffic on Huron Church Road. Thus, their low average speeds on the cross street decreased overall average car speed for the entire road network.

Table 4-3. Overall Average Speed (km/h) of Entire Road Network

	No-timer	**GSCT**	**RSCT**	**GSCT+RSCT**
Car	28.4	29.4	28.1	29.9
% Change	-	3.6	-1.0	5.2
Truck	30.9	33.0	30.7	33.7
% Change	-	7.1	-0.5	9.0
All	29.0	30.3	28.7	30.7
% Change	-	4.4	-0.9	6.1

Previous studies suggested that the RSCT had a positive impact on the traffic flow efficiency by enabling vehicles to start early at the start of the green phase and thereby increasing the number of vehicles entering the intersection. Although the spatiotemporal analysis did not observe any significant change in speed when starting at onset of the green phase in the RSCT scenario, the number of vehicles entering the intersection was observed at the stop line and compared among the scenarios. Table 4-4 shows the number of vehicles crossing the stop line during the first 5 s of the green signal phase was calculated using the data collection points at the stop line in Vissim.

Table 4-4. Average number of vehicles entering the intersection during the first 5 s of green phase in all cycles

	No-timer	**GSCT**	**RSCT**	**GSCT+RSCT**
Car	15.3	16.4*	26.9	31.2
% Change	-	7.2	75.8	103.9
Truck	11.6	11.50*	16.50	18.60
% Change	-	-0.9	42.2	60.3
All	26.9	27.90*	43.40	49.80
% Change	-	3.7	61.3	85.1

*The difference in numbers between the no-timer and GSCT scenarios are not statistically significant at a 95% confidence interval.

The table shows that the GSCT+RSCT scenario allowed highest number of vehicles entering the intersection with a total of around 50 vehicles throughout all the signal cycles and increased the vehicle entry by 85.1% compared to the no-timer scenario. It was followed by the RSCT scenario which increased the number by 61.3%. The number of vehicles entering the intersection for the RSCT and the GSCT+RSCT scenarios was significantly different from the number for the no-timer scenario at a 95% confidence interval (p-value < 0.05) according to the Mann-Whitney’s U Test. Since early start did not occur in the GSCT scenario, the difference in the number of vehicles entering the intersection between the GSCT scenario and the no-time scenario was not statistically significant. This result confirms that the reduced drivers' reaction time in the RSCT scenario resulted in earlier start at the beginning of the green phase and the increase in the number of vehicles entering the intersection. The table also shows that the percentage change was found to be higher for cars than trucks. This is because cars have higher speed and acceleration than trucks.

Total number of vehicles crossing the stop line during the entire phase (green or red) was also compared as shown in Table 4-5. Table 4-5(a) shows that the average number of vehicles entering the intersection during the entire green phase was slightly higher for the TSCT scenarios than the no-timer scenario. On the other hand, Table 4-5(b) shows that the average number of vehicles entering the intersection during the entire red phase (i.e., red-light violation) was slightly lower for the TSCT scenarios than the no-timer scenario. All red-light violation events occurred during the end of green phase. However, the numbers of vehicles entering the intersection during both red and green phases were not significantly different between the TSCT scenarios and the no-timer scenario at a 95% confidence interval (p-value > 0.05).

Table 4-5. Average number of vehicles entering the intersection in entire green and red phases in all cycles

	No-timer	**GSCT**	**RSCT**	**GSCT+RSCT**
(a) Green phase				
Car	237	250	239	250
Truck	133	130	136	130
All	370	380	375	380
(b) Red phase*				
Car	0.8	0.4	0.8	0.4
Truck	0.4	0.4	0.2	0.4
All	1.2	0.8	1.0	0.8

*These numbers indicate the numbers of red-light violation in all cycles.

5. CONCLUSIONS AND RECOMMENDATIONS

This study assessed the impacts of Traffic Signal Countdown Timers (TSCT) on traffic safety and efficiency at signalized intersections. To assess the impacts, changes in driver behavior and traffic flow in the presence of TSCT at the intersections along a section of Huron Church Road in Windsor, Ontario, Canada were predicted using the Vissim traffic simulation software. The simulation results were compared across four scenarios: no-timer, GSCT, RSCT, and GSCT+RSCT scenarios. Driver behavior parameters in Vissim were dynamically changed for different phases in the presence of GSCT and RSCT using Vissim-COM interface based on the findings in previous field observations and simulation studies. The key findings from the study are summarized as follows:

First, it was found that rear-end conflicts were the most common and significant contributors to total conflicts at the signalized intersections in both the presence and absence of TSCT, compared to lane-change and crossing conflicts.

Second, among the different TSCT scenarios, the GSCT+RSCT scenario was the most effective in enhancing both traffic safety and efficiency compared to the no-timer scenario. The GSCT+RSCT scenario reduced the Crash Potential Index (CPI) by 37% compared to the no-timer scenario. It was particularly effective in reducing truck-involved collision risk. Additionally, the GSCT+RSCT scenario increased the average speed by 31% and significantly increased the number of vehicles entering the intersection during the first 5 s of green phase by 85%.

Third, the GSCT increased vehicle speed near the stop line during the green phase while the RSCT prompted vehicles to begin decelerating earlier, further from the stop line during the red phase. These TSCTs allowed more vehicles to pass through the intersection without reducing speed during the green phase and encouraged gradual deceleration of approaching vehicles during the red phase. As a result, these behavioral changes contributed to reducing rear-end conflicts and improving traffic flow, thereby enhancing overall traffic efficiency. In general, the TSCT facilitated earlier decision-making, which in turn reduced the frequency and severity of rear-end conflicts.

Lastly, the effects of TSCT on cars and trucks differed. It was found that cars experienced a greater reduction in CPI than trucks in the GSCT+RSCT scenario compared to the no-timer scenario. However, trucks exhibited a higher increase in speed than cars in all TSCT scenarios. This suggests that TSCT can help cars avoid conflicts with trucks while also allowing trucks to move faster without conflicting with cars.

This study demonstrated that TSCT can bring significant benefits to both safety and efficiency in car-truck mixed traffic. However, despite adjusting simulation parameters to reflect real-world driver behavior based on observations from previous studies, the simulation could not be fully calibrated using observed data from the studied site. Additionally, the difference in traffic signal compliance rates and reactions to TSCT between car and truck drivers could not be captured due to a lack of data. Moreover, the drivers’ decision-making behavior at the signalized intersection could not be directly controlled in the simulation model. However, the drivers’ decision was affected by the changes in traffic conditions which occurred due to changes in the driver behavior parameters such as the distributions of speed, acceleration, and deceleration, and reaction time.

For future research, it is recommended to evaluate the impact of various TSCT designs on driving behavior, traffic conflicts, and overall traffic efficiency. For example, not displaying the countdown during the last 5 seconds of the red phase could prevent risky behaviors, such as early starts before the green phase begins. Additionally, studying the network-wide effects of TSCT based on their placement at consecutive intersections could reveal their overall impact on traffic flow. It is also suggested to examine the effects of TSCT on safety and efficiency in mixed traffic conditions involving both human-driven and autonomous vehicles, taking into account their unique performance characteristics and interactions.

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APPENDIX A. LOGIC OF VISSIM-COM INTERFACE

Logic of event-based scripts in Vissim-COM interface

The events were created in the microsimulation platform during specific time intervals and the python code snippet to modify the parameter values were executed during the respective events. As explained the event or signal phase duration is divided into three time intervals as follows: 1) Interval 1: Only the Totten intersection had red (or green) phase, 2) Interval 2: Both intersections had red (or green) phase, and 3) Interval 3: Only the Dorchester intersection had red (or green) phase. For example, in modeling of the RSCT, the red phase in the second signal cycle for the Totten intersection was between 117 and 164 s while the red phase for the Dorchester intersection was between 122 and 177 seconds. Therefore, an event was created with a start time of 117 seconds and an end time of 177 seconds. The duration of this event splits into three time phases based on when the red phase occurs at each intersection. Interval 1 is when only the Totten intersection had red phase (117-121 seconds), Interval 2 is when both intersections had red phase (122-164 seconds), and Interval 3 is when only the Dorchester intersection had red phase (165-177 seconds). In the second step, vehicles are classified based on vehicle types (Cars and Trucks), the road link they are on (NB Huron Church Road, SB Huron Church Road), and their position on the link are identified to determine the signal of influence.

Script for RSCT

In the presence of RSCT, the deceleration rate of the approaching vehicles and the reaction time of the vehicles to the onset of green signal were reduced during red phase. For changing the desired deceleration distribution, the function in vehicle class “IndivDesDecelFunc” was used. The desired deceleration distribution was modified when the vehicles are within the ROI (i.e., 100 m from the stop line). Similarly, the reaction time was reduced using the attribute “ReactTmDistr” available in the Driver Behaviour class.

When the simulation time is in Interval 1, the script distinguished between vehicle types (cars and trucks) on NB Huron Church road (Link 1) and SB Huron Church road (Link 2) based on the link number. For instance, the deceleration functions for the vehicles on Link 1 positioned between 65 m and 165 m of the link (i.e., 100 m from the stop line for NB through traffic at the Totten intersection) were set to the modified deceleration functions for cars and trucks. Otherwise, they reverted to their default functions. Similarly, for the approaching vehicles towards the Totten intersection on Link 2, the same modified deceleration functions were applied for the positions between 267 m and 367 m of the link (i.e., 100 m from the stop line for SB through traffic at the Totten intersection).

When the simulation time is in Interval 2, the script followed similar logic but extended the position ranges to cover all areas influenced by the RSCT at both intersections on both links. Specifically, these ranges are 65 to 165 meters or 300 to 400 meters on Link 1, and 40 to 140 meters or 267 to 367 meters on Link 2. This modifies the deceleration functions for all the vehicles within these specified position ranges during the red phase. For the Dorchester intersection, the script modifies the deceleration functions for the vehicles located between 300 and 400 m on Link 1 and between 40 and 140 meters on Link 2. For vehicles outside these ranges, the script applies the default deceleration values.

The reaction time to the onset of a green signal could not be modified for individual vehicles, as the reaction time attribute (ReactTmDistr) is part of the driver behavior class, affecting all vehicles in the network using the same driver behavior model. Also, since the RSCT only influences the traffic on Huron Church Road, the changes in reaction time during the red phase were set only for the NB and SB Huron Church Road. This ensures that the reaction time does not change for the traffic on the side roads (i.e., Totten Street and Dorchester Road).

For instance, the green phases started at the Totten intersection at 45 s and at the Dorchester intersection at 58 s. Therefore, in the presence of the RSCT, an event was created to change the ReactTmDistr to 0.5 s between 45 s and 58 s to include the green phase onset for both intersections. This event only applied to the Huron Church Road traffic. Additionally, between these 0.5-s reaction time events, another event was created to revert the reaction time of vehicles to the default value of 2 s.

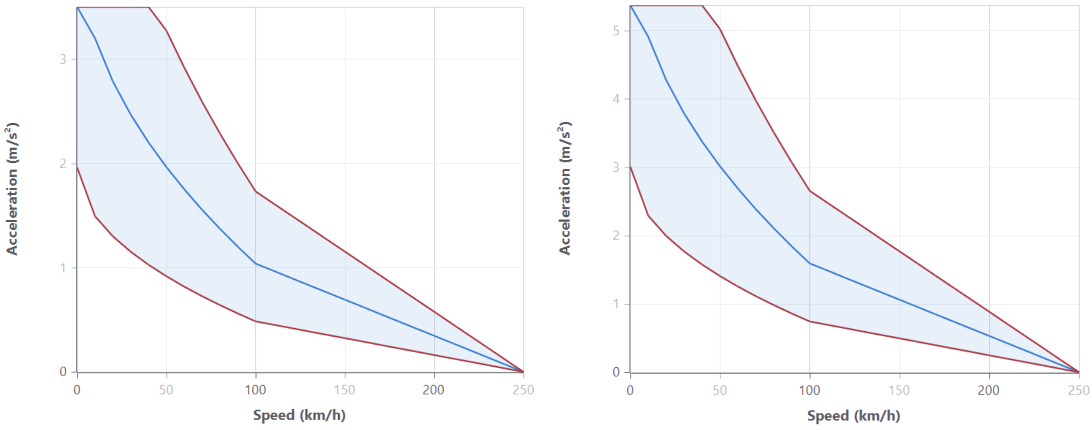
Script for GSCT

In the presence of GSCT, the traffic compliance rate, acceleration rate, and speed of vehicles increases but the deceleration rate decreases according to the literature. Thus, the compliance rate was set to the modified values for the traffic signals which control the through movements in the northbound and southbound Huron Church Road before the simulation started. Similar to the RSCT, the desired acceleration and desired deceleration distributions were modified during green phase for both vehicle types. The desired acceleration and desired decelerations were accessed through the functions "IndivDesAccelFunc," and "IndivDesDecelFunc", respectively, in the vehicle class. The vehicle speed was also modified by setting the desired speed distribution (accessed through "DesSpeed" attribute) to the required value in the script. Events were created during the green signal phases in all signal cycles, and the script for GSCT was called during these events.

Similar to the script for RSCT, the duration of event was split into three intervals and vehicles were classified based on their type, link number, and position. Unlike the RSCT, all parameters are available in the vehicle class and can be accessed for individual vehicles. Thus, a single event file was created for each cycle to modify all required parameter values.

In Interval 1, the script modifies the desired acceleration and deceleration distributions for the vehicles within the region of influence in the NB and SB Huron Church Road at the Dorchester intersection. The desired speed distribution was also set to the designated value for vehicles in this region. For vehicles outside these ranges, the script applies the default parameter values. In Intervals 2 and 3, the parameter values were modified according to the region of influence during the green phase.

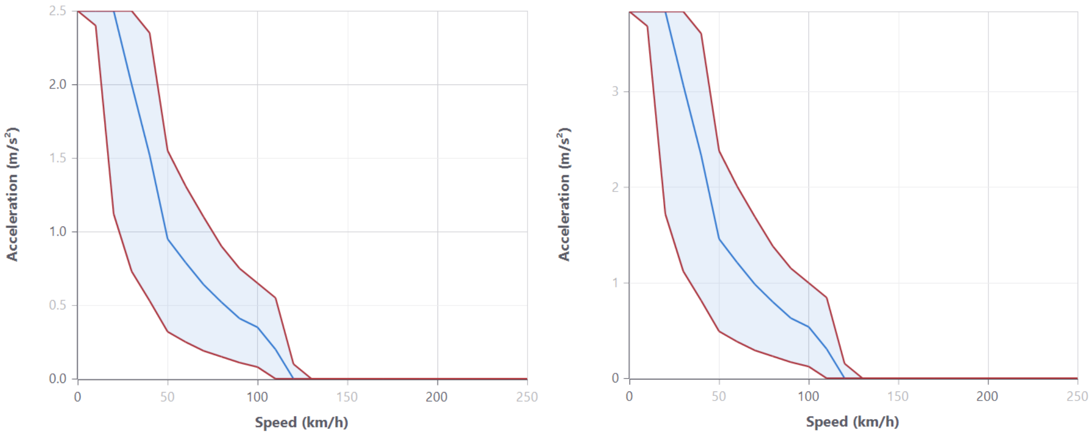
The acceleration and deceleration values of the vehicles cannot be changed dynamically during the simulation run using COM interface. Therefore, modified acceleration and deceleration functions were created for both cars and trucks with the new parameter values identified from the previous studies. These modified functions replace the default functions in the TSCT scenarios. The default and modified acceleration/deceleration functions are shown in Figures A-1 to A-4.



(a) Default (No-timer scenario)

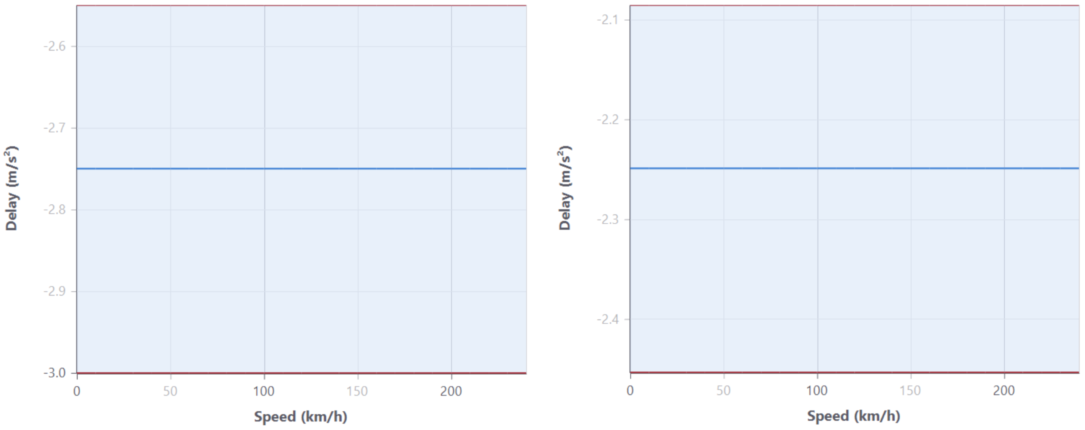
(b) Modified (TSCT scenarios)

Figure A-1. Default and modified acceleration function of cars



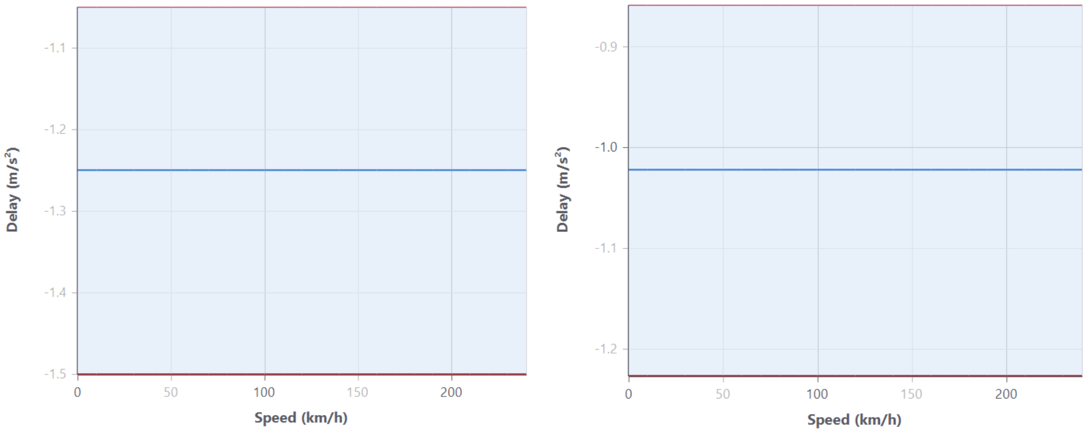
(a) Default (No-timer scenario) (b) Modified (TSCT scenarios)

Figure A-2. Default and modified acceleration function of trucks



(a) Default (No-timer scenario) (b) Modified (TSCT scenarios)

Figure A-3. Default and modified deceleration function of cars



(a) Default (No-timer scenario) (b) Modified (TSCT scenarios)

Figure A-4. Default and modified deceleration function of trucks

APPENDIX B. PYTHON SCRIPT FOR VISSIM-COM INTERFACE

Script for a GSCT event:

```
import win32com.client
a = Vissim.Simulation.AttValue('SimSec')
all_vehicles = Vissim.Net.Vehicles.GetAll()
for vehicle in all_vehicles:
   vehicle_type = int(vehicle.AttValue('VehType').split(':')[0])
   VehPos = vehicle.AttValue('Pos')
   Vehlink = int(vehicle.AttValue('Lane').split("-")[0])
   if a<=178:
      if vehicle_type == 100 and Vehlink == 1:
         if 65 < VehPos < 165:
            vehicle.SetAttValue('IndivDesDecelFunc',103)
            vehicle.SetAttValue('DesSpeed',66)
            vehicle.SetAttValue('IndivDesAccelFunc',1002)
         else:
            vehicle.SetAttValue('IndivDesDecelFunc',1)
            vehicle.SetAttValue('DesSpeed',60)
            vehicle.SetAttValue('IndivDesAccelFunc',1)
      if vehicle_type == 200 and Vehlink == 1:
         if 65 < VehPos < 165:
            vehicle.SetAttValue('IndivDesDecelFunc',104)
            vehicle.SetAttValue('DesSpeed',66)
            vehicle.SetAttValue('IndivDesAccelFunc',1003)
         else:
            vehicle.SetAttValue('IndivDesDecelFunc',2)
            vehicle.SetAttValue('DesSpeed',60)
            vehicle.SetAttValue('IndivDesAccelFunc',2)
      if vehicle_type == 100 and Vehlink == 2:
         if 267 < VehPos < 367:
            vehicle.SetAttValue('IndivDesDecelFunc',103)
            vehicle.SetAttValue('DesSpeed',66)
            vehicle.SetAttValue('IndivDesAccelFunc',1002)
         else:
            vehicle.SetAttValue('IndivDesDecelFunc',1)
            vehicle.SetAttValue('DesSpeed',60)
            vehicle.SetAttValue('IndivDesAccelFunc',1)
      if vehicle_type == 200 and Vehlink == 2:
         if 267 < VehPos < 367:
            vehicle.SetAttValue('IndivDesDecelFunc',104)
            vehicle.SetAttValue('DesSpeed',66)
            vehicle.SetAttValue('IndivDesAccelFunc',1003)
         else:
            vehicle.SetAttValue('IndivDesDecelFunc',2)
            vehicle.SetAttValue('DesSpeed',60)
```

```
            vehicle.SetAttValue('IndivDesAccelFunc',2)
if a>=179 and a<=236:
    if vehicle_type == 100 and Vehlink == 1:
        if (65 < VehPos < 165) or (300 < VehPos < 400):
            vehicle.SetAttValue('IndivDesDecelFunc',103)
            vehicle.SetAttValue('DesSpeed',66)
            vehicle.SetAttValue('IndivDesAccelFunc',1002)
        else:
            vehicle.SetAttValue('IndivDesDecelFunc',1)
            vehicle.SetAttValue('DesSpeed',60)
            vehicle.SetAttValue('IndivDesAccelFunc',1)
    if vehicle_type == 200 and Vehlink == 1:
        if (65 < VehPos < 165) or (300 < VehPos < 400):
            vehicle.SetAttValue('IndivDesDecelFunc',104)
            vehicle.SetAttValue('DesSpeed',66)
            vehicle.SetAttValue('IndivDesAccelFunc',1003)
        else:
            vehicle.SetAttValue('IndivDesDecelFunc',2)
            vehicle.SetAttValue('DesSpeed',60)
            vehicle.SetAttValue('IndivDesAccelFunc',2)
    if vehicle_type == 100 and Vehlink == 2:
        if (40 < VehPos < 140) or (267 < VehPos < 367):
            vehicle.SetAttValue('IndivDesDecelFunc',103)
            vehicle.SetAttValue('DesSpeed',66)
            vehicle.SetAttValue('IndivDesAccelFunc',1002)
        else:
            vehicle.SetAttValue('IndivDesDecelFunc',1)
            vehicle.SetAttValue('DesSpeed',60)
            vehicle.SetAttValue('IndivDesAccelFunc',1)
    if vehicle_type == 200 and Vehlink == 2:
        if (40 < VehPos < 140) or (267 < VehPos < 367):
            vehicle.SetAttValue('IndivDesDecelFunc',104)
            vehicle.SetAttValue('DesSpeed',66)
            vehicle.SetAttValue('IndivDesAccelFunc',1003)
        else:
            vehicle.SetAttValue('IndivDesDecelFunc',2)
            vehicle.SetAttValue('DesSpeed',60)
            vehicle.SetAttValue('IndivDesAccelFunc',2)
if a>=237:
    if vehicle_type == 100 and Vehlink == 1:
        if 300 < VehPos < 400:
            vehicle.SetAttValue('IndivDesDecelFunc',103)
            vehicle.SetAttValue('DesSpeed',66)
            vehicle.SetAttValue('IndivDesAccelFunc',1002)
        else:
            vehicle.SetAttValue('IndivDesDecelFunc',1)
            vehicle.SetAttValue('DesSpeed',60)
            vehicle.SetAttValue('IndivDesAccelFunc',1)
    if vehicle_type == 200 and Vehlink == 1:
```

```
            if 300 < VehPos < 400:
                vehicle.SetAttValue('IndivDesDecelFunc',104)
                vehicle.SetAttValue('DesSpeed',66)
                vehicle.SetAttValue('IndivDesAccelFunc',1003)
            else:
                vehicle.SetAttValue('IndivDesDecelFunc',2)
                vehicle.SetAttValue('DesSpeed',60)
                vehicle.SetAttValue('IndivDesAccelFunc',2)
        if vehicle_type == 100 and Vehlink == 2:
            if 40 < VehPos < 140:
                vehicle.SetAttValue('IndivDesDecelFunc',103)
                vehicle.SetAttValue('DesSpeed',66)
                vehicle.SetAttValue('IndivDesAccelFunc',1002)
            else:
                vehicle.SetAttValue('IndivDesDecelFunc',1)
                vehicle.SetAttValue('DesSpeed',60)
                vehicle.SetAttValue('IndivDesAccelFunc',1)
        if vehicle_type == 200 and Vehlink == 2:
            if 40 < VehPos < 140:
                vehicle.SetAttValue('IndivDesDecelFunc',104)
                vehicle.SetAttValue('DesSpeed',66)
                vehicle.SetAttValue('IndivDesAccelFunc',1003)
            else:
                vehicle.SetAttValue('IndivDesDecelFunc',2)
                vehicle.SetAttValue('DesSpeed',60)
                vehicle.SetAttValue('IndivDesAccelFunc',2)
```

Script for a RSCT event:

```
import win32com.client
a = Vissim.Simulation.AttValue('SimSec')
all_vehicles = Vissim.Net.Vehicles.GetAll()
for vehicle in all_vehicles:
    vehicle_type = int(vehicle.AttValue('VehType').split(':')[0])
    VehPos = vehicle.AttValue('Pos')
    Vehlink = int(vehicle.AttValue('Lane').split("-")[0])
    if a<=122:
        if vehicle_type == 100 and Vehlink == 1:
            if 65 < VehPos < 165:
                vehicle.SetAttValue('IndivDesDecelFunc',103)
            else:
                vehicle.SetAttValue('IndivDesDecelFunc',1)
        if vehicle_type == 200 and Vehlink == 1:
            if 65 < VehPos < 165:
                vehicle.SetAttValue('IndivDesDecelFunc',104)
            else:
                vehicle.SetAttValue('IndivDesDecelFunc',2)
        if vehicle_type == 100 and Vehlink == 2:
            if 267 < VehPos < 267:
                vehicle.SetAttValue('IndivDesDecelFunc',103)
```

```
      else:
         vehicle.SetAttValue('IndivDesDecelFunc',1)
   if vehicle_type == 200 and Vehlink == 2:
      if 267 < VehPos < 367:
         vehicle.SetAttValue('IndivDesDecelFunc',104)
      else:
         vehicle.SetAttValue('IndivDesDecelFunc',2)
if a>=123 and a<=164:
   if vehicle_type == 100 and Vehlink == 1:
      if (65 < VehPos < 165) or (300 < VehPos < 400):
         vehicle.SetAttValue('IndivDesDecelFunc',103)
      else:
         vehicle.SetAttValue('IndivDesDecelFunc',1)
   if vehicle_type == 200 and Vehlink == 1:
      if (65 < VehPos < 165) or (300 < VehPos < 400):
         vehicle.SetAttValue('IndivDesDecelFunc',104)
      else:
         vehicle.SetAttValue('IndivDesDecelFunc',2)
   if vehicle_type == 100 and Vehlink == 2:
      if (40 < VehPos < 140) or (267 < VehPos < 367):
         vehicle.SetAttValue('IndivDesDecelFunc',103)
      else:
         vehicle.SetAttValue('IndivDesDecelFunc',1)
   if vehicle_type == 200 and Vehlink == 2:
      if (40 < VehPos < 140) or (267 < VehPos < 367):
         vehicle.SetAttValue('IndivDesDecelFunc',104)
      else:
         vehicle.SetAttValue('IndivDesDecelFunc',2)
if a>=165:
   if vehicle_type == 100 and Vehlink == 1:
      if 300 < VehPos < 400:
         vehicle.SetAttValue('IndivDesDecelFunc',103)
      else:
         vehicle.SetAttValue('IndivDesDecelFunc',1)
   if vehicle_type == 200 and Vehlink == 1:
      if 300 < VehPos < 400:
         vehicle.SetAttValue('IndivDesDecelFunc',104)
      else:
         vehicle.SetAttValue('IndivDesDecelFunc',2)
   if vehicle_type == 100 and Vehlink == 2:
      if 40 < VehPos < 140:
         vehicle.SetAttValue('IndivDesDecelFunc',103)
      else:
         vehicle.SetAttValue('IndivDesDecelFunc',1)
   if vehicle_type == 200 and Vehlink == 2:
      if 40 < VehPos < 140:
         vehicle.SetAttValue('IndivDesDecelFunc',104)
      else:
         vehicle.SetAttValue('IndivDesDecelFunc',2)
```

VITA AUCTORIS

NAME:	Vadhul Krishnan Veerakumar
PLACE OF BIRTH:	Chennai, India
YEAR OF BIRTH:	1997
EDUCATION:	SASTRA Deemed University, Thanjavur, India
	(2015-2019) B.Tech. Civil Engineering
	University of Windsor, Windsor, ON, Canada
	(2023-2024) M.A.Sc. Civil Engineering