EVALUATION OF HOW DRIVER'S SIGHT LINES IMPACT AVAILABLE STOPPING DISTANCE FOR CONFLICTING THROUGH AND LEFT TURNING VEHICLES AT SIGNALIZED INTERSECTIONS

Adekunle Mofolasayo

Introduction

Road traffic crashes is an issue that has been a concern for humanity at large for some time now. Signalization of intersections is aimed at creating orderliness, smooth and safe movement of vehicles through the intersection in an efficient way. However, mankind is still faced with the challenge of ensuring that signalized intersections can be used in a way that traffic crashes can be avoided at the intersections. One of the conflicts that could result in a traffic crash at signalized intersection is the conflict between the left turning movements, and the opposing through movements, especially at intersections that operates on a permitted left turn phasing. Protected left turn movements at signalized intersection has been found to be a good way to ensure safety for left turning vehicles. Factors such as flow rate (for both left turn and opposing vehicles), opposing speed limit, number of opposing traffic lanes, number of left turns, percentage of heavy vehicles, number of accidents within a specified period, average stopped delay to left turning vehicles, and engineer's judgement are considered in the establishment of protected left turn movements (Roess, Prassas, & McShane, 2011). The impact of protected left turns on the available green times for other traffic movements through the intersection is also a factor to be given due consideration. To minimize delays at an intersection, protected left turns may not be a desirable option, if a road geometry does not include left turning lanes at the intersection. When the volume of traffic that is making a left turn is high, increasing the number of left turn lanes is a desirable option to reduce delay. Traffic conflicts at signalized intersections can also be eliminated by a good use of an interchange. Previous research has noted that interchanges are not economically feasible at every intersection that are problematic and can take a long time to develop (Hochstein, et al. 2010). While increasing the number of left turn lanes can help increase the throughput for left turning movement, increasing the number of left turn lanes could also result in creation of spaces for transient obstructions for both the through movements and the vehicles that are trying to make a left turn from the opposite side. As there is interest in increasing throughput of vehicles to minimize the impact of traffic congestion at signalized intersections, there is also an interest in ensuring safety of road users. This makes review of potential ways to successfully accomplish the two goals an important task.

Presence of transient obstructions that can prevent the driver from seeing a vehicle that is planning a left turning movement on time is a serious factor to consider when making safety reviews of signalized intersections. Except if a real time video recording (that is able to adequately capture events at all the approaches to a signalized intersection) is used, if a traffic crash happens because the drivers could not see each other on time to avoid a crash, due to presence of transient obstructions, it may not be easy for traffic engineers to know which transient obstruction prevented a driver from seeing a conflicting left turning vehicle on time, to avoid the traffic crash. Sight distances at an intersection are normally limited by buildings and other sight-line obstructions that are located near or on the corners. Concept of visibility triangle for an intersection has been presented in previous work to show the distance it will take vehicles to reach a collision point, when there is an obstruction at the corner of the intersection (Roess, Prassas, & McShane, 2011). The same concept of visibility triangles was used to evaluate how transient obstructions (e.g. vehicles on queue, waiting to make a left turn) can obstruct the angle of view of both the vehicles that are waiting to make a left turn movement in the opposite side, and the angle of view of the conflicting through movements. The American Association of State Highway and Transportation officials

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(AASHTO) noted that there is potential for different types of vehicular conflict at each intersection and the possibility of occurrence of the conflicts can be reduced by provision of appropriate traffic controls, and proper sight distance. Stopping sight distance is the sum of the distance that the vehicle travels during the perception-reaction time, and the distance it takes to bring the vehicle to a stop (WSDOT, 2016). Reduction in view angle / line of sight, and sight distance of drivers results in the reduction of available time to safely stop the vehicle before reaching a potential point of collision. Increasing the number of left turn lanes of an intersection without an adequate improvement in traffic control system, or a review and subsequent redesign and reconstruction of the opposing left turn lane (where necessary) to ensure adequacy of sight lines and view angle will be hazardous for drivers.

How has the issue of permanent obstructions at intersections been addressed in previous works?
The issue of permanent obstructions has been addressed in previous works. Roess, Prassas, & McShane, 2011 and AASHTO's policy on geometric design of highway and street provided concept to address the issue of permanent obstructions. Figure 1 shows an illustration of visibility triangle at intersection with no traffic control.

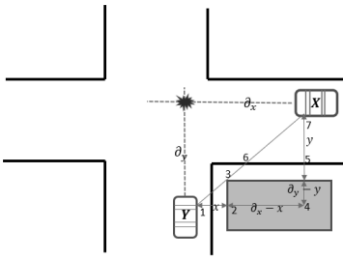

Figure 1. Visibility triangle at intersection.
*Adapted from Traffic Engineering 4th edition (2)

∂_x: is the distance between vehicle X to the point of collision
∂_y: is the distance between vehicle Y to the point of collision
x: is the distance from driver position in vehicle Y to the obstruction, measured parallel to the path of vehicle Y.
y: is the distance from driver position in vehicle X to the obstruction, measured parallel to the path of vehicle X.
Taken triangles Δ123, 147 and 657 (Figure 1) as similar triangles with hypotenuse on the sight line of the two vehicles, the relationship between the available distance between the decision point for vehicles X and Y (∂_x and ∂_y), to a potential point of collision can be expressed as below:

$$\partial_x = \frac{x\partial_y}{\partial_y - y} \quad (1)$$

AASHTO recommends that the driver of a vehicle that is approaching an intersection should have an unobstructed view of the whole intersection and the control devices. AASHTO also recommended removal of any object, within a sight triangle (such as: parked vehicles, roadside hardwares, highway structures, buildings, trees, hedges, walls, the terrain itself, etc.), that is higher than the elevation of an adjacent roadway and could obstruct the driver's view.

Roess, Prassas, & McShane, 2011 recommended that the length along the intersecting highway should be long enough for the driver to both anticipate and avoid potential collisions, i.e. the distance from the decision point (where the drivers in the 2 vehicles can see the other vehicle) to the point of collision should be equal to or greater than the safe stopping distance. It was recommended that the safe stopping distance of vehicles follow the format presented in equation (2). In equation (1) above, it is desirable that both ∂_x and ∂_y should be equal to or greater than the safe stopping distance.

Where: F is the coefficient of forward rolling or skidding friction, F = a/g, a is the rate of deceleration ft/s^2, g is acceleration due to gravity 32.2 ft/s^2, G is grade, %, t is reaction time s, S_{in} is the initial speed mi/h, d_{st} is the safe stopping distance, ft. To avoid collision the final speed of the vehicle has to be zero before the vehicle reach the hazard on the road. Note that the safe stopping distance is also the total stopping distance that is required to safely stop the vehicle before collision, at the given reaction time.

$$d_{st} = (1.47S_{in} * t) + \frac{S_{in}^2}{30(F \pm 0.01G)} \quad (2)$$

For a permitted left turn, some vehicles may come from a stopped position to navigate the intersection. AASHTO gave recommendation for intersection sight distance (ISD):

$$ISD = 1.47\, V_{maj} t_{g.min} \quad (3)$$

Where: V_{maj} is the design speed for the major road, and $t_{g.min}$ is the time gap for the minor road vehicle to enter the major road. Various factors are considered when selecting the time gap for the minor road vehicle to enter the major road. These includes number of lanes to be crossed by the left turning minor road vehicle, the grade of the road, and the type of design vehicle. For example, a time gap of 7.5s is allotted for a passenger car that is turning into a 2-lane major road, but the time gap is increased when there is an increase in the number of lanes to be crossed by the car. Every intersection requires individual analysis. The intersection sight distance that is provided at intersections is also meant to allow sufficient time for drivers of stopped vehicles to decide on the appropriate time to cross the intersecting road (AASHTO). Assuming the initial speed in equation (2) is the same as the design speed in equation (3), on a level ground, using a standard reaction time of 2.5 s (for the safe stopping distance), a friction factor of 0.348, and a time gap of 7.5 s, a comparison of the distances that is provided by equation (2) and equation (3) showed that the intersection sight distance (equation 3) gives more room for drivers to make a good decision than equation 2 (up to ≈ 76.73mi/h). For the selected condition, beyond this speed, the total stopping distance concept yields more distance. Note that on all sections of the roadway, the driver must have a sight distance that is at least equal to the total stopping distance (Roess, Prassas, & McShane). To give more allowance for drivers to stop the vehicles on time, to avoid a collision, it is better to use the intersection stopping distance (eq. 3) whenever the intersection stopping distance is higher than the total stopping distance. However, if any situation ever arises in which the total stopping distance is greater than the intersection stopping distance, it is better to use the total stopping distance in such a case. AASHTO's policy on geometric design of highway and streets includes a table [table 9-6] showing design speeds (between 15mph and 80mph), the corresponding stopping sight distance and intersection sight distance (calculated & design). AASHTO's policy on geometric design of highway and streets also contains various graphs showing design speed versus length of sight triangles.

Design speed is a speed that is selected to establish adequate geometric design for a section of a road (Morrall, & Robinson, 2003); & TAC 1999, 2007). Although the comparison of the intersection stopping distance, and the total stopping distance described above is based on an assumption that the design speed is the same as the initial speed, note that, "design speed is to be selected to exceed, or equal the posted (regulated) speed limit of the road (USDOT)". Surveys show that speed limits are set at 85th percentile of speed, but in reality, speed limits are set less than the 85th percentile of speed on most sites (Fitzpatrick, et al. 2003). Beyond the point of intersection of the distances given by the total stopping distance and the intersection stopping distances, if the design speed is carefully selected to exceed the posted speed limit, the distance that will be provided by the intersection stopping distance may still exceed the distance that will be provided by the total stopping distance of equation 2 (within the normal range of speed that vehicles are expected to be reasonably operated on the roads in many municipalities). For example, for the example previously given, if a design speed is 100mi/h, and the posted speed limit, or the initial speed for equation 2 is 85 mi/h, the intersection stopping distance (equation 3) will give more allowance for the driver to safely stop the vehicle than what total stopping distance (equation 2) will give. In evaluation of the adequacy of the intersection site distance, available sight distance, and safe stopping distance of a

road, it will be good to have adequate knowledge of both the design speed for the road, the posted speed limit and operating speed for vehicles on the road.

The issue with transient obstructions

The impact of obstructions of view of the driver is a serious factor in road traffic safety. Permanent obstructions that hinder the driver's view are objects that have been installed in a place within the safe stopping distance of moving vehicles, but transient obstructions are not permanent at a single location. While permanent obstructions can be removed, it is not feasible to remove vehicles that constitute transient obstruction either when they are in motion, or when they are temporarily in a stationary position, waiting to go through the intersection of a road. It cannot be disputed that various vehicles on the road sometimes constitute an obstruction of view for drivers. Transient obstruction could result in collision of motor vehicles with either pedestrians, other vehicles on the road, animal or any object that is moving towards the path of a vehicle in motion. Figure 2 shows example of transient obstructions in various degrees. It is obvious that the eye level of drivers is different for various vehicles.

The issue of transient obstructions can be approached in various forms. These includes:

(1) Ensuring adequate enforcement and continuous education for drivers on how to ensure that the hazard that comes with transient obstruction does not result in negative consequences on the roads.

(2) Ensuring adequacy of sight lines and view angles of drivers at signalized intersections with permitted left turn phasing.

(3) Ensuring availability of adequate traffic control devices to restrict vehicular movement where the effect of transient obstruction could be an issue.

(4) Exploring the use of technological innovations like connected vehicle systems to help in quick identification of hazards, and prompt communication of potential hazards to other vehicles/drivers on the roads.

(5) Combining vehicle to vehicle communication systems with autobrake systems to achieve a reduced reaction time, yielding a reduced safe stopping distance.

Given that there have been lots of efforts on driver education and enforcement, but still, road traffic crashes are at an alarming rate, the suggested approach about adequate enforcement and education for drivers to be continually aware of the need to slow down (drive cautiously), when the driver's view is obstructed is not one that is reasonable to focus all attention on. There is need to explore other options to help the driver. Note that continuous and adequate driver education and enforcement is necessary in all municipalities. Perhaps, this may be a reminder for a driver to be extra cautious when the view is obstructed. Since there are speed limits on the roads, it may be somewhat challenging for law enforcement officers to give a fine to a driver whose view is obstructed by transient obstruction, but is traveling at the speed limit. It is known that even when traveling at the speed limit, if a driver did not realize the presence of the hazard on time (before reaching the safe stopping distance, equation 2), the driver will not be able to stop the car to avoid a collision. If the approach of enforcement and continuous education wants to be better explored, there may be a need to review present demerit award system, to ensure that all drivers are consistently aware that a demerit can be given when a driver encounters a transient obstruction, but the driver did not slow down. For example, in a normal driving situation, a driver that did not slow down, or stop to adequately assess the issue in the driving environment when the driver in the other lane has considerable slowed down or stopped may be fined, because this may result in a possible collision, if the driver that slowed down has seen a potential hazard that could result in a traffic crash for other drivers. Adequate awareness of the severity of the issue with transient obstruction in road traffic safety coupled with adequate enforcement may be helpful to mitigate the hazard.

The world has witnessed the advent of innovative technologies such as connected vehicle technology; e.g. Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication systems. A combination of

technology that is able to detect the movement of potential hazards that are outside the driver's view angle, and a technology that is able to adequately communicate why a leading or an adjacent vehicle is slowing down (such as connected vehicle technology) will be good, to ensure that other vehicles in which the view angle of the driver is hindered by transient obstructions, can receive an alert for the need for a reduction of speed, on time to avoid potential collision. If all vehicles on the road have efficient vehicle to vehicle communication system, that can both detect hazard that are not within the sightlines of some drivers, and ensure efficient communication of the hazard to other drivers in the path of the hazard (in good time to avoid a collision), the issue of transient obstruction can be reduced. Efficient auto brake system will be a good complement to the connected vehicle system to ensure that a vehicle that is likely to be involved in a collision, when the driver's line of sight is severely restricted by transient obstructions would have automatically begin the braking action before the driver could perceive and react to the hazard. Previous study has recommended that more research be made on 'how to update existing vehicles in the traffic stream to having collision avoidance technologies' (Mofolasayo 2018). Other technologies such as light detection and ranging data (LiDAR) that has the capacity of scanning the driving environment and is able to identify obstructions that may be outside the view angle of the driver also exist. More research on how this technology may be further developed and used to improve road traffic safety is recommended.

Figure 2. Transient obstructions in varying degrees

At this time, not all vehicles on the road are equipped with the V2V and V2I technologies. While the connected vehicle systems undergo testing to ascertain its safe use for vehicles on the roads, there is need to ensure that all intersections are adequately reviewed to minimize the hazard of transient obstructions. Although the effect of transient obstruction at intersections can be addressed by implementing traffic control systems, or ensuring a redesign of the road to minimize the potential impact of transient obstructions within street segments, in the absence of technologies in which the first vehicle to notice a potential hazard is able to communicate the presence of the hazard to other vehicles / drivers, traffic safety at mid-blocks will still be heavily dependent on driver's awareness of the potential hazard of transient obstruction, and the driver's readiness to take adequate action on time to avoid the hazard. If a driver did not realize the presence of a hazard (due to the presence of transient obstruction) in time to avoid collision, the consequence will not be pleasant.

Do we need more evaluation of the potential impact of transient obstructions at mid-blocks and at unsignalized intersections?

As noted above, AASHTO recommended the removal of parked vehicles or any object that is higher than the elevation of an adjacent roadway, and could obstruct the driver's view within a sight triangle. Hence, vehicles that are parked too close to an intersection, and could hinder the view of other motorists need to be removed. To ensure that vehicles which could obstruct the driver's view within a sight triangle is not parked on the road, every municipality need to ensure adequate review of sight triangles of every intersection within various communities and ensure that the limits of the sight triangles are marked out with adequate signs, "no parking: here to corner". There is need for adequate enforcement of such system. Although, a yellow paint on the curb may inform drivers that parking is not allowed in such a place, if

some curbs are covered with snow during the winter period and if there is no other sign that indicates the 'no parking limit', it is not unlikely that some drivers may not know where the limit for no parking is.

Bareket & Fancher (1993) studied the effect of large trucks on traffic safety and operations. Truck combinations that were evaluated in the study includes: STAA Tractor semitrailer (48ft) [total length: 60 ft], 57 ft tractor semitrailer [total length: 69 ft], STAA (Western Double) [72 ft], Turner truck (LCV) [85 ft], Rocky Mountain Double (LCV) [96 ft], Triple (LCV) [104 ft], Turnpike double (LCV) [119 ft]. Bareket & Fancher's study noted that in some situations Longer Combination Vehicles (LCVs) might become obstructing or hazardous elements to other drivers. On street segment, the view of the driver of a car that is travelling beside a long combination vehicle may be hindered. If the driver of a vehicle or LCV had to suddenly stop because a pedestrian is crossing the road from the driver's side, the vehicle in the other lane may not see the impending hazard on time. Hence, whenever the view of a driver in the 2nd lane is hindered by a moving vehicle (transient obstruction), the driver in the 2nd lane needs to slow down or stop, if the vehicle in the 1st lane stopped or slowed down. One of the issues here is that the driver in the 2nd lane may not realize that the driver in the 1st lane has stopped or slowed down, in good time to avoid a collision. The angle of view of other drivers on a road will be further reduced with increase in length of the trucks. Hence, the distance that should have been part of the safe stopping distance of vehicles will be reduced with increase in length / size of the transient obstruction. Note that transient obstructions on the roads is not limited to only large trucks. Vehicles on our roads are not transparent. The degree of obstruction from other vehicles on the road depends on the height of the eye level of the drivers, the height, width and proximity of the vehicles to each other. On highway, the use of escort vehicle is not uncommon, to improve safety for road users in certain situations. The issue with transient obstructions on the roads should not be ignored. Even school buses use stop-signs to ensure that safety is improved. Systems to create a quick awareness for other driver whenever a transient obstruction that could hinder the view of other drivers is present needs to be given more attention. Bareket & Fancher noted that no accepted procedure exists to assess passing sight distance while accounting for the length of the vehicles involved. Bareket & Fancher highlighted the need for a national policy on additional passing distance that is required to accommodate heavy trucks: a policy that considers safety requirements for increased length of no-passing zones, demand for trucking along the route and the traffic delays that is involved. Jafari, Al-Kaisy, & Washburn, (2018) on a study about passing lane optimum length on 2-lane highways found that traffic performance continues to improve with increase in the length of passing lane, (within the passing lane lengths investigated in their study [0.5mi to 3.0 mi]). This report focuses more on how to address the issue of transient obstruction at signalized intersections with left turn phasing. Some of the steps that can be taken to address the issue of transient obstructions has also been highlighted. The issue of transient obstructions is a big topic in road traffic safety. Further research is recommended on how to eliminate the impact of transient obstructions within various segments of roads in all municipalities.

Applying the concept of sight lines to signalized intersection with permitted left turn phasing

The presence of a traffic control signal may bring the impression that there is no need for the concept of sight triangle to be taken seriously where there is a level 3 control (traffic control signal), because drivers are expected to obey the traffic signal. Meanwhile, for permitted left turns, because drivers have to rely on personal judgement to select appropriate gap to make a left turn movement, situation in which a permitted left turn is allowed on a traffic control signal is similar to the basic rules of the road in (level 1 control). For vehicles that arrive at an intersection (at about the same time) where no traffic control is present, basic rules of the road indicate that vehicles on the left need to yield to vehicles on the right (AASHTO). Similarly, in permitted left turns, vehicles trying to make a left turning movement, need to yield to vehicles that are on the through movement. To reduce the chance of traffic crashes at signalized intersections with permitted left turns, there is need to ensure that the distance available for the drivers to stop, beginning from the decision point (where the conflicting vehicles can see each other) is large enough to avoid collision. Figure 3 illustrates a scenario in which a left turning vehicle is trying to navigate through an intersection that has 2 opposing lanes, and 2 left turn lanes in the opposite direction.

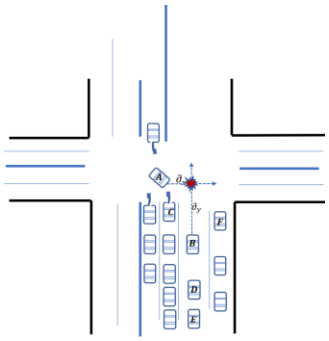

Figure 3. Illustration of left turning movement at intersection

The illustration shown above is meant to represent a situation in which the south bound left (SBL) movements has a permitted left turn phase on a traffic signal. In the absence of any queue of vehicles on the north bound left (NBL) vehicles (i.e. the 2 left turn lanes in the opposite side), the driver in vehicle A should be able to see vehicles on the North Bound through (NBT) lanes clearly. However, the presence of a queue of vehicles on the NBL lane (that blocks the view of the driver that is trying to make a left turn SBL) may create transient obstruction which may limit the angle of view of the driver of some vehicles on both the north bound through and South bound left movements. It is known that the height of vehicles on the road varies, likewise, the eye level of the drivers varies. In some instance, what may constitute an obstruction of sight for the driver of a passenger car may not be an obstruction of sight for the driver of a truck, because of the difference in height of the vehicles in relation to the eye level of the drivers. Hence, when performing safety review of the adequacy of the available sight distance of a signalized intersection with a permitted left turn (because the height of vehicles varies, vehicular movement on the road is random and some vehicles could constitute an obstruction of sight to other vehicles), it is better to assume that all vehicles passing through the intersection will create an obstruction of sight (as illustrated below) and ensure that adequate systems are employed to provide appropriate sight distances for all vehicles.

Figure 4 shows the sight lines, and visibility triangle for the intersection. To ensure safety for the conflicting through and left turning movements, the available sight distance at the intersection should be at least equal to the intersection sight distance required for safety at the intersection. Recall, the available sight distance must be at least equal to the total stopping distance (Roess, Prassas, & McShane). When the ISD is greater than the total stopping distance, the available sight distance to be provided must be at least equal to the intersection sight distance.

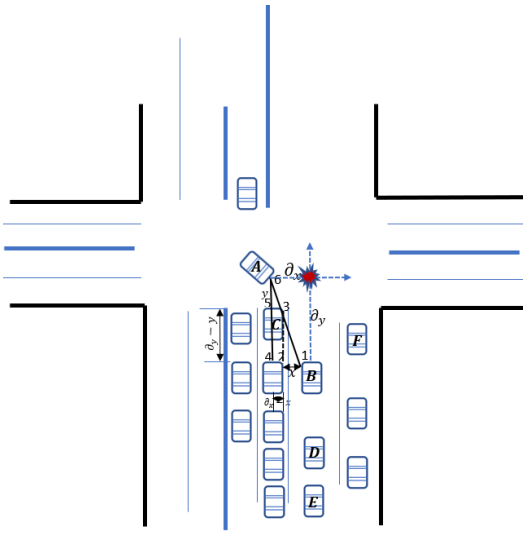

Figure 4. Sight line and visibility triangle at intersection

If ∂_y is less than the stopping distance that is required to safely stop the vehicle, (in the presence of transient obstructions that limits the angle of view and sight lines of the conflicting vehicular movements), the intersection may experience frequent traffic crashes in such situation. Triangles Δ123, 146, and 356 are similar triangles with common hypotenuse (line 1-3-6) used to represent the sight line of vehicles A and B. Similar to the illustration for equation 1,

$$\partial_y = \frac{y\partial_x}{\partial_x - x} \quad (4)$$

Figure 5. Vehicle waiting for a permitted left turn movement

Figure 5 is an illustration of a situation in which a vehicle wants to make a left turn movement where there are 2 opposing through movement, and 2 lanes for the opposite left turn. In situations with the same geometric design as the one shown in figure 5, if a considerable queue of vehicle (that can cause an obstruction of view of the driver waiting to make a left turn) remains in the 2 left turn lanes, by the time the opposing through vehicles, and the single vehicle waiting to make a left turn have the green light, the line of sight of the single vehicle that is trying to make a left turn, and the line of sight of some vehicles in the opposing through lane may be restricted by the transient obstructions (vehicles on queue waiting to make a left turn movement), and may result in higher chance of traffic crash between the vehicles trying to make a left turn, and the conflicting through movement.

Seeing that transient obstructions, and not only permanent obstruction are factors that needs adequate attention for safety of both through and left turning movement at an intersection, there is need to evaluate potential corrective actions for intersections where transient obstruction may constitute a safety hazard.

Potential corrective actions for stopping sight distance that has been reduced by transient obstructions (vehicles)

(1) Redesign, and reconstruct the intersection to ensure that the line of sight of a left turn movement is not hindered by the opposing vehicles that are waiting on queue for their portion of green time.
(2) If available space on site is not enough to reconstruct a left turn lane (to improve line of sight), in a situation where the opposing left turn has more than one lane, move the stop line for the 2nd left turn lane backwards, to an extent where the line of sight of the through movements, and the opposing left turn lane is adequate for safety.

If a redesign, and reconstruction of the intersection is considered (for example, if transient obstructions restrict the sight line of the through and the left turning vehicular movements) to improve sight line for the through and left turning vehicles, a design that moves the single left turn lane, a little more to the left, to ensure that both the vehicles that are waiting for the permitted left turn phase, and the opposing through vehicles are able to see each other clearly (at least for a distance that will ensure that the vehicles can safely stop before reaching a potential point of collision) will be good. If the sight line for a left turn lane is severely hindered by transient obstructions (vehicles waiting on queue to make a left turn in the opposite side of the road), another option will be to ensure that the re-design, and re-construction of the

intersection includes an additional left turn lane to the existing single left turn lane (ensuring that the sight line for the newly constructed lane allows adequate visibility to at least the sight distance that is required for safe stopping of the conflicting vehicles before they reach a potential point of collision), and ensure that signs prohibiting permitted left turn are provided for any lane whose sight line may be hindered by transient obstructions.

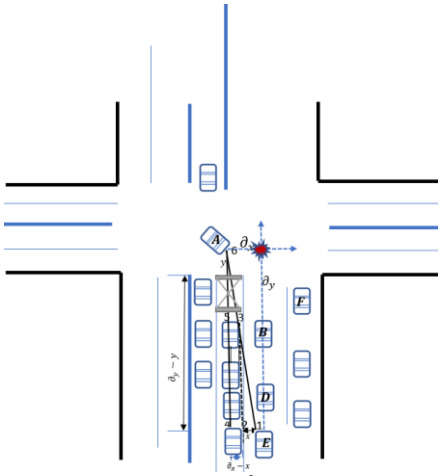

Figure 6. Impact of removal of the 1st vehicle of a 2nd left turn lane on the sight line of conflicting left turning and through movements

In figure 4, it is obvious that while vehicle C may limit the sight line and view angle of the driver in vehicle A, in the absence of vehicle C (figure 6), the view angle of the driver can be improved. Figure 6 shows that the driver in vehicle A will be able to see vehicles B, D, E and F. Hence, in a situation where a protected left turn phasing is not desired for the opposing left turning vehicles, and if a review of the sight lines of the intersection indicated that transient obstructions in a left-turn lane adversely affect the sight line, and the distance that is available to safely stop the applicable conflicting vehicular movement, figure 6 confirms that moving the stop line for the hazardous left turn lane (backwards) will help improve the line of sight of both the vehicles trying to make a left turn, and the conflicting through movement. Improvement of the sight line that comes with moving the stop line backwards as in figure 6 should also help ensure that the time and distance that is available to safely stop vehicles that have conflicting movement with the left turning vehicles is increased. Figure 6 indicates that vehicles A, B, D and F will be able to see each other clearly. Vehicle E (in figure 6) will also have an increased time, and distance to avoid collision with vehicle A than vehicle B had (in figure 4). If moving the stop line for the lane that constitute transient obstruction backwards is being considered, it will be a good idea to consider appropriate adjustments to both the yellow, and the green time of the signal lights. It will also be a good idea to ensure that adequate signs exist that notify drivers about the location of the stop line for the concerned lane. Note that the standard guidelines for evaluation of the need for protected left turns still needs to be followed, the suggested evaluation of adequacy of sight lines is recommended to ensure that the need for adequacy of available sight lines, and available sight distance is not being neglected because of the presence of traffic signals where a permitted left turn movement is allowed.

For intersections in which basic rule of the road (level 1) control is desired, if the available sight distance is less than the distance that is required to safely stop the vehicles before they reach the potential point of collision, basic rules of the road (level 1 control) cannot be applied. For such a situation, potential ways to improve safe stopping distance includes: reduction of speed limit, removal or reduction of sight obstructions to provide adequate sight distances, and implementation of intersection control like yield control, stop sign or traffic signals (Roess, Prassas, & McShane). In a similar way, if evaluation of sight lines for an intersection with permitted left turn phasing indicates that in the presence of transient obstruction, the available sight distance will not be adequate to ensure a safe stopping of vehicles before

they reach a potential point of collision, a permitted phasing is not recommended. Note that figure 6 shows a system that may be applied to dissuade drivers from encroaching into the area where they may constitute a transient obstruction, but it may still present some challenge if the signal light changes to red while a vehicle has already crossed the stop line and the vehicle stop while already in the position where it can constitute an obstruction of view for the through and conflicting left turning movement.

How can a review of sight triangles be done for conflicting left turn and through vehicles?
A noteworthy outcome of the geometric design process is an efficient and safe transportation system (Wood & Donnell 2017). Motorists depend on traffic engineers to provide adequate road design for safe movement of vehicles. Efforts to improve road traffic system should include an ongoing road safety audit. To check for the adequacy of sight distances for left turn, and conflicting through movement for an intersection, in a road safety audit, the following process may be followed:

Site inspection
Drive throughs of the intersection could be done. In such drive through, the engineer responsible for the audit should pay attention to the sight distances, noting the farthest point that the driver could see from all conflicting sides. The possible effect of transient obstructions (as discussed) should be taken into consideration when establishing the farthest distance, the driver could see. The farthest distance that the drivers could see should be measured and compared with the distance that is adequate to safely stop conflicting vehicular movements before they reach a potential point of collision. Considering the potential impact of transient obstruction, if the available sight distance is less than the distance required to safely stop conflicting vehicles on time, to avoid collision, adequate corrective measures should be implemented.

Use of as-built drawing
It is possible to estimate the available sight distance for both the left turning and the through movements at an intersection from an as-built drawing, or a good map that shows the present geometry of the intersection. Locations for possible transient obstructions could be marked out on the as-built drawing. An estimate of the locations of possible sight line for the vehicles could be done as shown in figures 4, and 6 (taking account of the possible effect of transient obstructions). The distance from the decision point (the farthest distance in which the left turning vehicle, and the conflicting vehicle on the through movement are able to see each other) to the potential point of collision can be drawn and measured from the map (or as-built drawing of the intersection). The distance that is available for the driver to both react and apply the brake (as measured on the map or as-built drawing of the intersection) can then be compared to the distance that is required to safely stop conflicting vehicles at the intersection. If the distance that is available to stop conflicting vehicles is less than the distance that is required to safely stop the vehicles, corrective actions needs to be taken.

AASHTO's policy on geometric design of highways and streets noted that if the available sight distance for an entering and crossing vehicle is at least equal to the stopping sight distance that is appropriate for the major road, then there will be sufficient distance for the drivers to anticipate and avoid collisions. To enhance traffic operations, it is desirable that the intersection sight distance for the major road exceed the stopping sight distance (AASHTO). In other words, a good safety practice will ensure that the available sight distance at the intersection exceed the distance that is needed to safely stop conflicting vehicles before they reach potential point of collision at any intersection. In addition to the existing standards for the establishment of protected left turn phasing at signalized intersection, wherever the review of the present design of an intersection show that the available sight distance is of concern (given the potential impact of transient obstructions), if the available space at the intersection will not allow a redesign of the intersection to improve the sight distance for the left turning, and the conflicting through vehicular movement, in the absence of other adequate control measures that the budget of a municipality can accommodate, appropriate traffic control measures such as protected left turn is recommended for such

intersection. Figure 7, a sign by an elementary school, is a good reminder for people to slow down to avoid collision. Figure 7 also reminds us that a pedestrian is not always taller than some motor vehicles, emphasizing the need to take the challenge of transient obstruction seriously. It is better for drivers to experience additional delay at an intersection than to lose a life.

Figure 7. An elementary school sign reminds us to lose a minute, not a life.

Conclusions and recommendations

Improving driver's ability to see on-coming vehicles on time to avoid impending collision is important to improve traffic safety. Humanity is faced with the challenge of trying to improve the volume of traffic that can pass through various intersections within a short period of time, at the same time it is desirable to ensure that these vehicles can go through the intersection without traffic crash. The alarming number of traffic crashes at various signalized intersections calls for a deeper review of design of signalized intersections. A good road safety audit will not allow any structure that obstruct the driver's view within the safe stopping distance to intersections. To reduce the chance of traffic crashes between left turn movement, and conflicting through movement, any intersection in which the driver's angle of view of conflicting vehicular movement is hindered by transient obstructions (within the distance that is required to safely stop the vehicles) should receive appropriate corrective actions. This study used the concept of visibility triangle to evaluate the impact of line of sight of drivers on the distance that is available to stop the vehicle in adequate time to avoid traffic collision for left turning movements, and the conflicting through movements at signalized intersections that allows permitted left turns. When the distance that is available to safely bring the vehicle to a stop has been severely reduced by transient obstructions, a traffic crash is likely to occur. Potential corrective measures to improve sight distance that has been reduced by transient obstructions, as well as processes to evaluate the adequacy of sight distance of left turning and the conflicting through vehicular movement at signalized intersection was presented. The challenge that exist in choosing between allowing more delay from traffic hold-up at various signalized intersections and safety of road users is one that needs adequate attention. While everyone will like to get to their various destinations on time, it is truly better to have some delays than to lose a life on the road. Hence, when it comes to deciding whether to establish a protected left turn, or not to establish one, it is good to make safety a higher priority over the anticipated delay. This study recommends that evaluation of sight lines, and angle of view of drivers in reference to transient obstructions be given a high priority when performing road safety audits, especially for intersections with permitted left turn phasing.

References available on request from mofoladek@live.com