METHODS OF CROSSING AT ROUNDABOUTS FOR VISUALLY IMPAIRED PEDESTRIANS: REVIEW OF LITERATURE

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ABSTRACT

Because roundabouts offer so many beneficial features to a community, it is important that they are made as safe as possible for all users and comply with the Americans with Disabilities Act Accessibility Guidelines. There have been several studies conducted with the purpose of creating a safer crossing environment for visually impaired pedestrians at roundabouts. These studies focus on four methods: crosswalk placement, sound applications, signalized options, and automated yield detection. The purpose of this review paper is to explore these possible solutions, identifying the advantages and disadvantages, the practicality, and the overall performance of each solution. The research done here will also address which methods may be most appropriate for low volume roundabouts, moderate volume roundabout, and high volume roundabouts, as well as for one-lane roundabouts and two-lane roundabouts. When evaluating each option, it's also important to estimate the effect it will have on the flow of traffic. An ideal solution will allow access to all users while maintaining the initial benefits of a roundabout.

INTRODUCTION

Over the past few years, the use of modern roundabouts in transportation planning in the United States has grown tremendously, supported by their success in Europe and Australia. In the United States, roundabouts are beginning to be used in place of traditional intersections in some new roadways and have actually replaced old intersections in others. As public perception of them improves, they are likely to be used more frequently.

Roundabouts offer many benefits to vehicular transportation that a traditional intersection often cannot offer. One such benefit is a lower overall operating cost. Unlike traditional intersections, roundabouts require no electric traffic signals to direct vehicles. As a result, there is no running cost involved beyond the regular street upkeep. They also increase traffic flow because vehicles going through a roundabout have less idling time than vehicles going through a traditional intersection. Vehicles in a roundabout are only required to stop if they are trying to enter the roundabout and must wait for a break between vehicles to do so. In contrast, a traditional intersection can often times have several minutes of stopping time while waiting for a green light. Roundabouts can drastically improve traffic flow, reducing the amount of time spent waiting for the right-of-way.

Roundabouts also provide a safer vehicular transition from one roadway to the next. This is because there are significantly fewer possible vehicle-to-vehicle conflict points. Gross et al. (2013) note that in a traditional four-way intersection, there are 32 possible points where two vehicles could impact each other (Figure 1). In a modern roundabout, the possible vehicle conflict points are reduced to just eight. They claim that a study of 15 one-lane roundabouts in Maryland revealed that the total crash rate was reduced by 60%, the injury crash rate was reduced by 82%, and fatal crash rate was reduced by 100%. A roundabout also discourages wrong-way movements, according to the *U.S. Traffic Calming Manual*. The *Manual* states that when "traffic flow is moderate and flows are balanced across streets," roundabouts are safer than other forms of intersection control (Ewing and Brown 2009, p. 104).

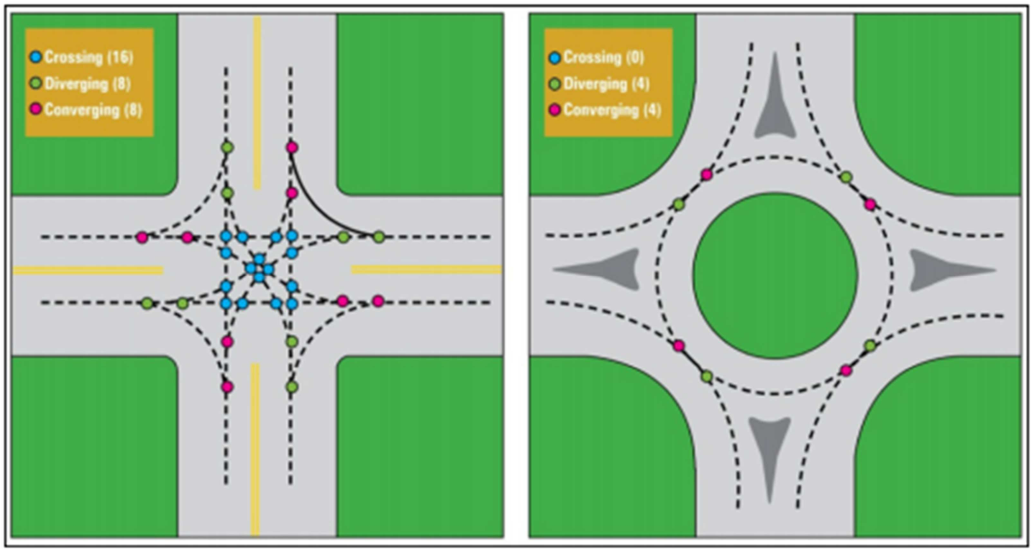


Figure 1: A roundabout has significantly less vehicle-vehicle conflict points (Gross et al. 2013)

Additionally, roundabouts are more environmentally friendly. Spending less time idling in roundabout results in less carbon emissions, reducing overall fuel consumption by up to 30% than when transporting through a traditional intersection (Arizona Department of Transportation 2014). Traditionally, a roundabout requires little upkeep as there are no lights that need to be maintained.

Roundabouts are not only safer for passengers travelling in vehicles, but also provide a safer environment for pedestrians and cyclists as well. They act as traffic calmers, forcing vehicles to slow down as they approach and maneuver through a roundabout. According to the *U.S. Traffic Calming Manual* (Ewing and Brown 2009), roundabouts are designed for a circulating speed of around 25 miles per hour. Motorists are forced to reduce their speed when approaching a roundabout as they prepare to judge an appropriate entrance, which also makes them more aware of their surroundings. The slower speed they must reach during the approach and wait time is much closer to that of a bicycle. Driving at the same speed as a cyclist not only makes a quick stop easier should it be necessary, but it also makes a collision less likely.

When pedestrians cross at roundabouts, the reduced vehicle speed adds to their safety as well. The design of a roundabout also reduces possibility for pedestrian-vehicle collision by placing splitter islands in between each vehicle entrance and exit where the crosswalks are located (Figure 2). This provides a refuge for pedestrians so they only have to worry about crossing one direction of traffic at a time.

There is one major instance, however, in which safety is not currently increased for pedestrians crossing at roundabouts. For visually impaired pedestrians, roundabouts actually decrease their safety while crossing the intersection. There are several reasons for this occurrence. First, at a traditional intersection, it is fairly easy for visually impaired pedestrians to determine the light cycle, as well as when vehicles have come to a stop and it is safe to cross. They are able to detect a pattern in the light cycle that allows them to know which directions of traffic are stopped. When asked about their typical street crossing methods, several visually impaired people who participated in a roundabout study by the Federal Highway Administration (FHWA 2006) stated that they typically listen to a full light cycle at a traditional intersection before getting ready to cross. The vehicle movement is also fairly predictable, as visually impaired pedestrians are able to hear which direction vehicles are moving and when they have come to an idling position. They rely on these factors to know when it is an appropriate time to cross the street. At a roundabout there is no such predictable sequence or light pattern. Vehicles move in and out with no set time or requirement to stop. It is also much more difficult for visually impaired pedestrians to audibly determine if there is a gap in traffic suitable to cross. This is because the vehicles move in a circular fashion that makes it harder to discern direction or if a vehicle is continuing through the roundabout or leaving.

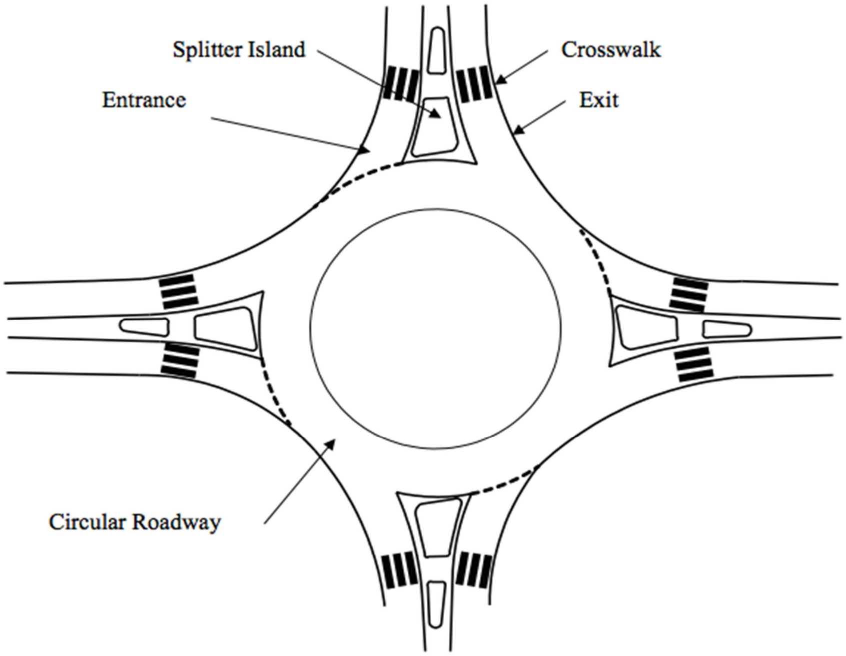


Figure 2: A typical crosswalk, showing the location of crosswalks and splitter islands (FHWA 2006)

METHODS

This is a review paper. This paper analyzes literature and prior research that was conducted with the purpose of identifying safe treatments and solutions for visually impaired pedestrians crossing at roundabouts. It reviews relevant literature, organizes several different solutions, and explores pros and cons of different solutions.

ANALYSIS OF LITERATURE

Crosswalk Placement

Perhaps the simplest adjustment that can be made to improve crossing conditions at roundabouts for visually impaired pedestrians (hereafter referred to as VIPs) is crosswalk placement. A typical roundabout locates the crosswalk one vehicle length before the entry to the roundabout and one vehicle length after the exit to the roundabout. Schroeder et al. (2008) refer to this design as proximal crossing, as shown in Figure 3.

Figure 3: Proximal crosswalk at a roundabout in Golden, CO. Image from Google Maps.

The idea behind proximal crossing design is that it allows pedestrians to cross behind a car waiting to enter the roundabout (Ewing and Brown 2009). This keeps the pedestrians out of the way of an entering car and increases their safety. For a VIP, however, the audible clues are not ideal when crossing at a proximal crosswalk, especially when at a two-lane roundabout. At two-lane roundabouts, the VIPs must then discern if both lanes of traffic are clear before crossing, not just one. A participant in a FHWA study "remarked that the crosswalks were too close to the intersection; it would be better if the crosswalk were midblock and away from the noise of the intersection" (FHWA 2006, p. 17). This is one of the possible crosswalk designs that could assist crossing for VIPs. Schroeder et al. (2008) call it distal crosswalk placement (Figure 4).

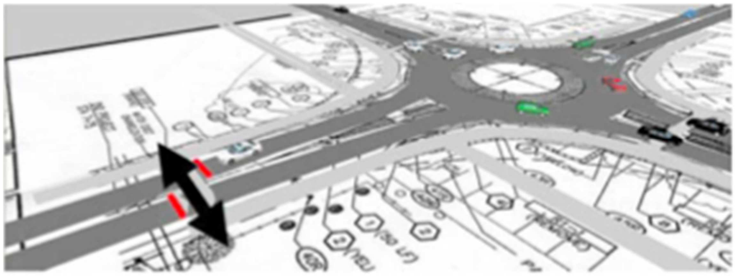


Figure 4: Distal crosswalk placement shown by the arrows (Schroeder et al. 2008)

Placing the crosswalks farther upstream from the entrance and exit of the roundabout would give a better crossing environment to VIPs. The farther the crosswalk is from the roundabout, the more likely the cars will sound like a traditional intersection. The cars that pass the crosswalk will be traveling in one predictable direction, allowing a VIP greater opportunity to audibly detect a gap in traffic suitable for crossing. In order to maintain highest effectiveness, it's important that a distal crosswalk placement be accompanied with a splitter or island in the middle of the road. This gives pedestrians a refuge by dividing the crossing in two stages. Especially in the case of a VIP, crossing only one direction of traffic at a time increases safety and efficiency.

A study done in Tampa, Florida at a single-lane roundabout determined that visually impaired pedestrians experienced better judgment of traffic gaps with crosswalks farther away from the circulatory roadway, noting that this placement "reduces the ambiguity about whether vehicles that are approaching the exit lane are exiting across the crosswalk or continuing in the roundabout" (Long et al. 2005, p. 617). However, this better judgment may be partially offset by an added danger posed by moving the crosswalks farther upstream. The farther away a crosswalk is from the circulatory road, the more time an exiting vehicle has to increase its speed from the exit. This poses an increased danger to any crossing pedestrians if the driver becomes aware of them too late and cannot slow down. Additionally, while this may assist VIPs in their ability to cross at a roundabout, it is possible that non-impaired pedestrians may be less likely to comply with distal crosswalk placement. Since distal placement puts the crosswalk farther away from the roundabout, a walk to the opposite side of the roundabout becomes longer and more inconvenient for other pedestrians.

Another alternative crosswalk design is a zig-zag, in which the entry leg has the crosswalk placed one car length from the roundabout entrance and the exit leg has the crosswalk placed upstream (Figure 5). This crosswalk placement gives the benefit of the distal crosswalk in the exit half but maintains the proximal location in the entry half, creating a two-stage crossing. A two-stage crossing is safer for the pedestrian, allowing them to only worry about one direction of traffic at a time, one key benefit to the proximal location that distal location could leave out if not designed as such. A challenge to the zig-zag design for a VIP is the additional distance they must travel to align themselves with the second half of the crosswalk. As with the distal placement, non-impaired pedestrian compliance may be unsatisfactory due to the increased distance they must walk.

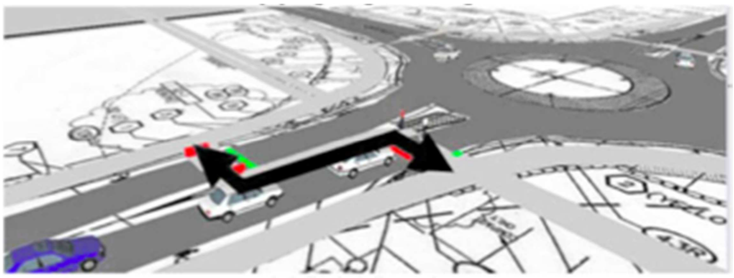


Figure 5: Zig-zag crosswalk placement (Schroeder et al. 2008)

Sound Applications

Another possible solution to the difficulties faced by the VIPs when crossing at a roundabout is a physical roadway application that produces sound when a vehicle passes over top of it. These are commonly referred to as sound or noise strips. An experiment done by the FHWA investigated the effects noise strips have on the detection of gaps in traffic by visually impaired participants. The noise strips, which were made of reinforced Polyvinyl chloride **(**PVC) piping for this experiment, were placed in three locations leading up to the crosswalk (Figure 6). While one row was placed on the upstream edge of the crosswalk, a second row was placed 6 m (20 ft.) upstream of the first row, and yet a third row was placed 7.3 m (24 ft.) upstream of the first row (FHWA 2006, p. 7). The intention of this placement was to indicate to the pedestrians if a vehicle had yielded. The first two strips were four feet apart and created four "clacks" as a vehicle drove its axles over them. The third strip, placed at the edge of the crosswalk, would produce two "clacks." If a pedestrian heard the first four clacks, but not the last two, that would indicate a stopped or yielded vehicle and an opportunity to cross.

The study was done on a two-lane simulation, which is a more difficult roundabout to decipher than a one-lane roundabout. It's important to note that the participants were not told about the noise strips beforehand, nor were they educated on how to use them. Identification of a stopped vehicle in both lanes increased as a whole with the use of noise strips. FHWA states that "the sound strips not only increased the probability of detecting stopped vehicles, but also decreased by more than a second the amount of time needed to make the detection" (FHWA 2006, p. 18). Several participants indicated that, had they known how to interpret the sound strips' pattern, they would have been able to detect yielded vehicles better.

Some participants said that the noise strips actually made it harder for them to tell if a vehicle had stopped because they couldn't hear the noise of the engine as well. The car engine is what most VIPs have been trained to listen to when determining when it is safe to cross a street. The results of the study also indicated that the participants were much less likely to correctly identify a vehicle as stopped or yielded in the far lane than in the lane closest to the crosswalk. This further indicates that two-lane roundabouts require additional solutions beyond what may seem appropriate for VIPs at one-lane roundabouts.

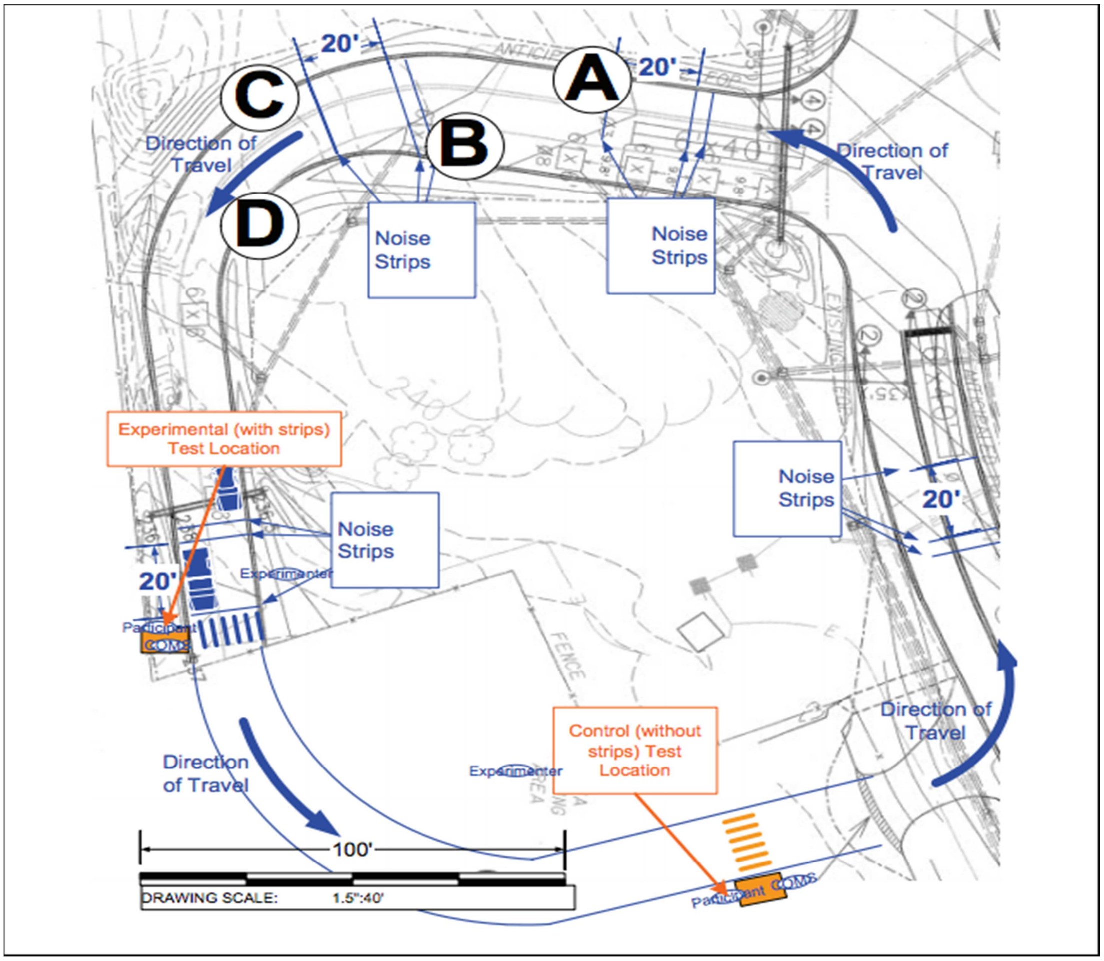


Figure 6: Placement of noise strips in an experimental course (FHWA 2006, p. 8)

A second study done by the FHWA (2006) regarding the noise strips tested how well the strips would work when used with real drivers. The sound strips were applied at an actual roundabout with VIPs using them to determine when to cross. The problem encountered in this study was that the majority of drivers yielded much farther away from the beginning of the crosswalk than desired. Even with signs instructing drivers where to yield, they actually yielded so far upstream that many either did not come in contact with the sound strips at all or did not get more than one set of axles over the strips (Figure 8). The desired distance was three meters or less away from the crosswalk. Only 24 of the 194 cars stopped within the desired distance and caused the desired sound, making utilization of the strips by the pedestrians impossible on a regular basis (FHWA 2006). As shown in Figure 8, cars stopped closer to the crosswalk when the treatment was not present.

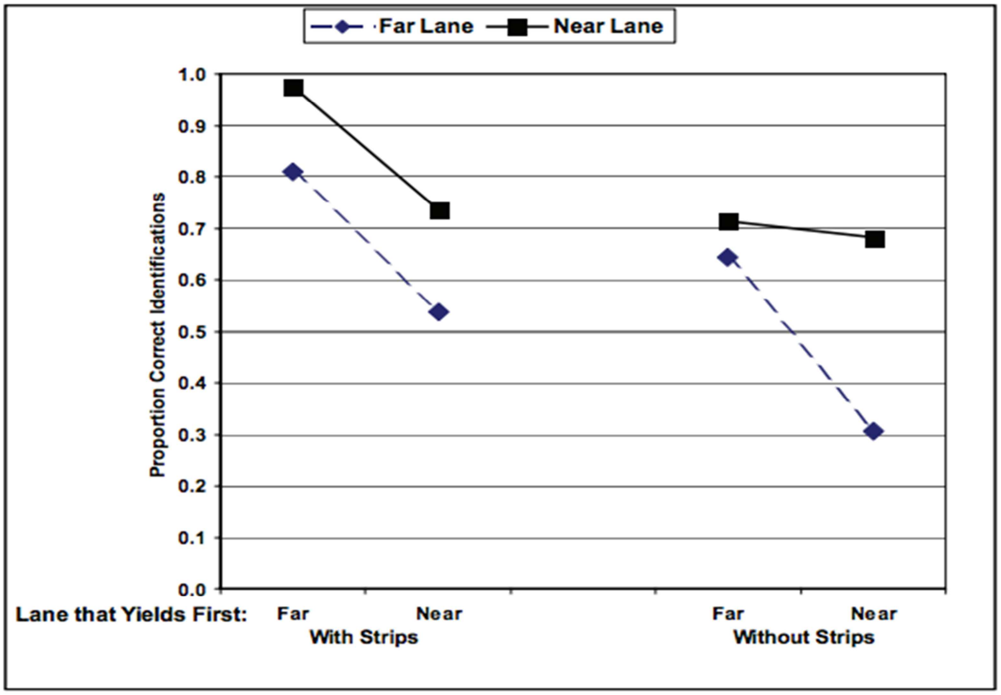
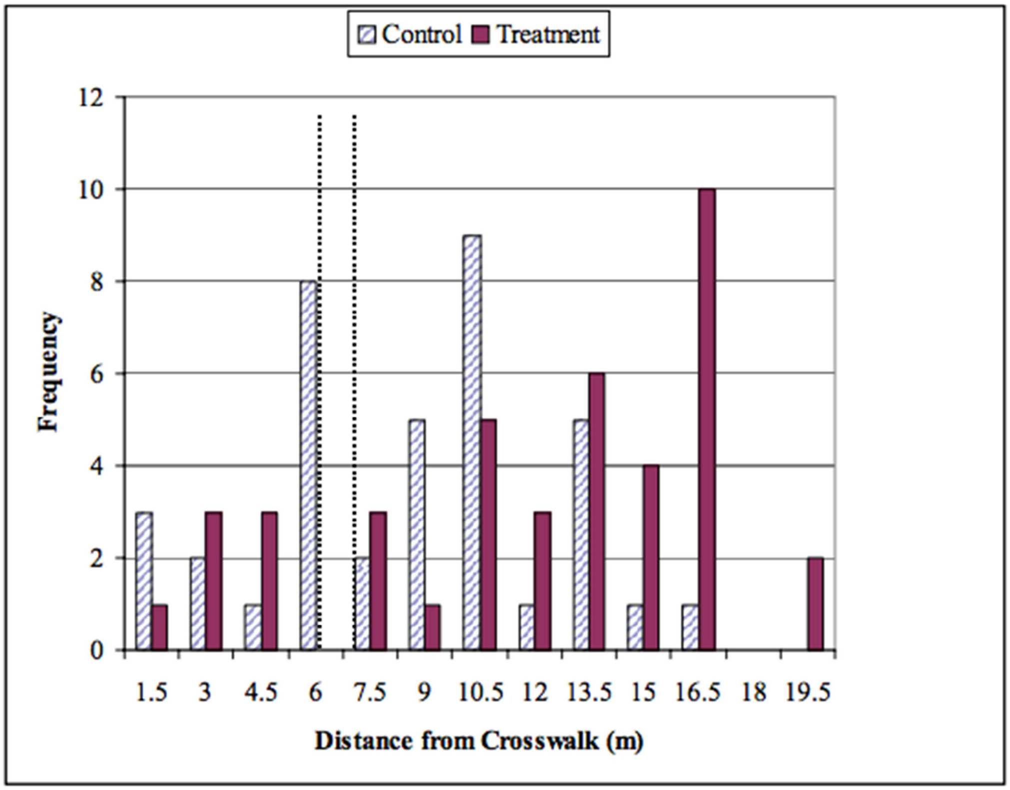


Figure 7: Correct identification of yielded vehicles increased with strips. Identification was higher in the near lane (FHWA 2006, p. 14).



Note: 1 m = 3.28 ft.

Figure 8: Cars didn't stop within the desired distance when the sound treatment was present (FHWA 2006, p. 25).

The FHWA (2006) stated in their study that their goal was to implement a “self-explanatory” treatment for improved detection of yielded vehicles for visually impaired pedestrians in order to avoid the expenses of outreach and training, but it is clear after this study that education for both the VIPs and drivers will be needed. The physical implementation of this solution on the roadways and the maintenance would be relatively low-cost.

Signalized Pedestrian Crossing

Another possible infrastructure modification that could be implemented to help alleviate difficulties in crossing traffic at roundabouts is pedestrian signals. Signalized crossing provides a completely protected crossing environment for the pedestrian, stopping traffic when activated. There are two popular pedestrian-actuated signal types that would be useful at roundabout crossings for VIPs: a conventional signal and a high-intensity activated crosswalk (HAWK) signal. The HAWK signal is also known as a Pedestrian Hybrid Beacon (PHB).

A conventional signal works just like a pedestrian-actuated signal does at a traditional intersection. Once activated, the minimum vehicle green time expires and traffic is stopped by a solid yellow light followed by a solid red light. The pedestrians will then see a “walk” signal that will flash “don’t walk” towards the end of the red light phase. The vehicle light turns green again and traffic moves (Figure 9). This signalized treatment would benefit a VIP because it gives them a protected cross and imitates the signalization of a traditional intersection with which they are most familiar. An audible signal indicating that the signal reads “walk” and it is safe for pedestrians to walk would additionally benefit a VIP.

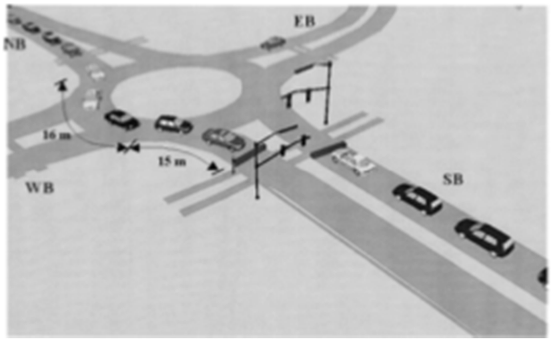


Figure 9: An example of a conventional signal stopping traffic at a roundabout (Rouphail, Hughes, and Chae 2005)

A HAWK signal works in a similar fashion. While there is still a minimum vehicle green time, the signal indication for vehicles remains blank until a pedestrian makes a call to the signal (and the minimum green time has elapsed). At this point, the vehicle light begins flashing yellow to alert the driver that a pedestrian is waiting to cross. The light then turns solid yellow, followed by solid red. At this time, the pedestrian “walk” signal is given, just like a conventional signal. Once the pedestrian signal begins to flash “don’t walk,” the vehicle signal begins to flash red. This indicates to the vehicles that they may proceed with caution, provided no pedestrian is still crossing. Schroeder et al. (2008)

compares the flashing red vehicle signal to a “nighttime flashing mode.” The vehicles must still stop and give right of way to pedestrians, but don’t have to wait for the entire red light phase to complete before continuing like in a conventional signal. Figure 10 shows the sequences for both conventional and HAWK light phases.

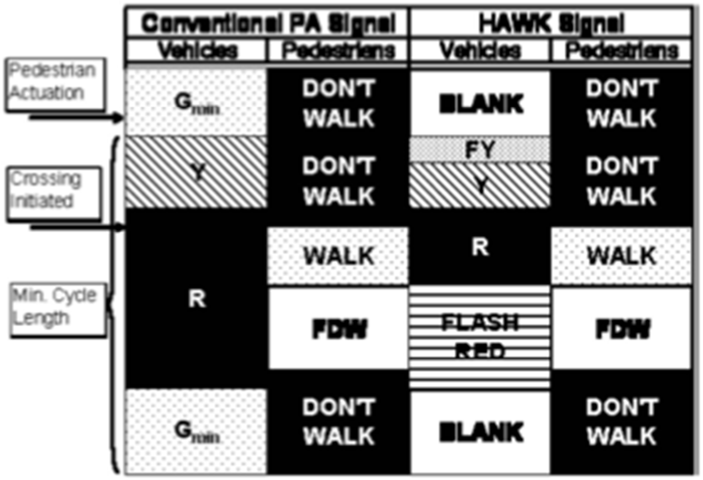
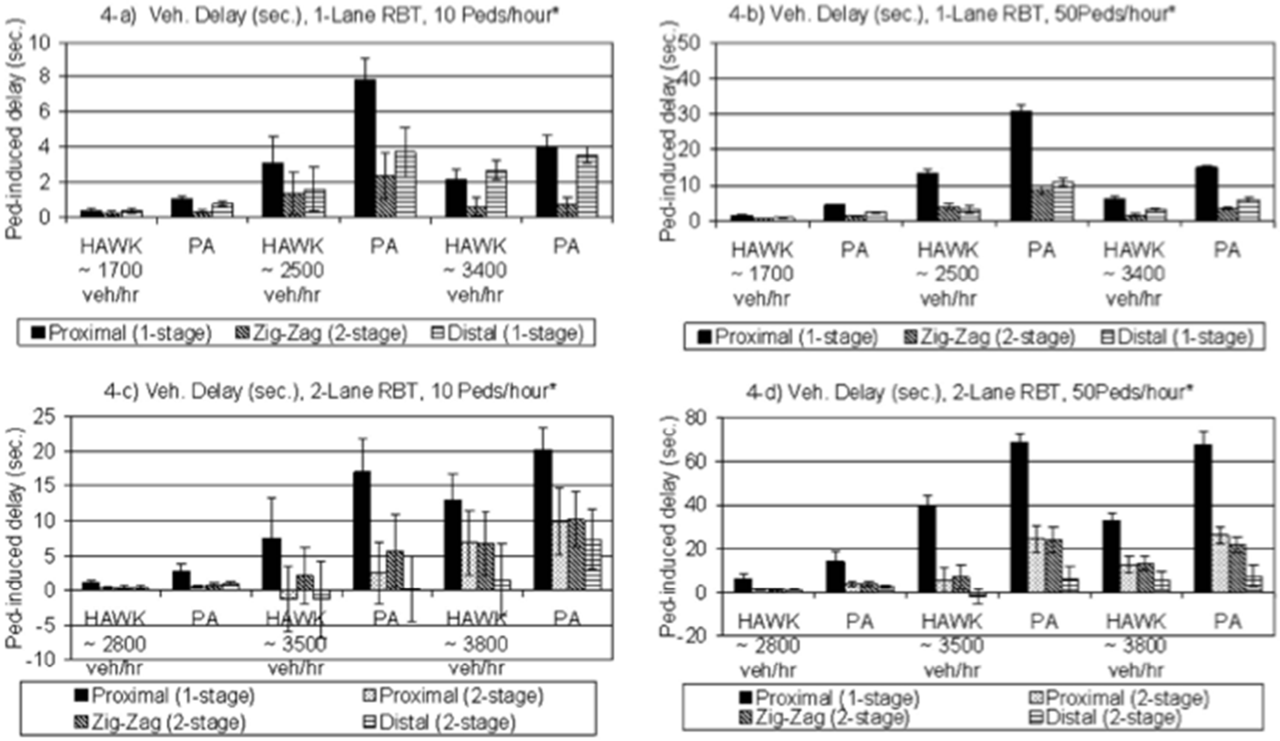


Figure 10: The light phases for both conventional and HAWK signals

The idea behind the HAWK signal is to maintain as much of the traffic flow as possible while still allowing pedestrians a protected crossing. Just like the conventional signal, an audible indication of the walk phase would additionally benefit a VIP. A consideration that must be given when using signalization at roundabouts is how a vehicle red light phase will affect the flow and backup of traffic. A study by Schroeder et al. (2008) using microsimulation by VISSIM measured this effect, called “pedestrian-induced vehicle delay,” using both signal options in all three crosswalk placement options discussed earlier in this paper at both a one-lane roundabout and a two-lane roundabout. The effectiveness was also measured in three different vehicle volumes, 1700 vehicles per hour, 2500 veh/hr, and 3400 veh/hr, with two different pedestrian volumes, 10 peds/hr and 50 peds/hr. Figure 11 shows the summarized results of this study. Each graph shows the vehicle delay in seconds for the scenarios simulated. There are three different vehicle volumes. Each volume shows two signal types, which show the results for each of the three crosswalk designs. The top two graphs illustrate the vehicle delay for a one-lane roundabout, each at a different pedestrian per hour volume. The bottom two graphs illustrate the results for a two-lane roundabout at two different pedestrian volumes.

The results of the microsimulation showed that in all cases, the HAWK signal performed better, resulting in shorter pedestrian-induced vehicle delays. For both conventional and HAWK signalized simulations, pedestrian-actuated signals produced the greatest vehicle delay at a roundabout with a proximal crosswalk location, which “is due to the proximity of the crossing to the circulating lane, resulting in high queue spill-back potential” (Schroeder et al. 2008, p. 267). Figure 9 shows an example of this queue spill-back that happens within the roundabout itself with proximal crosswalks. Rouphail et al. (2005) notes that a pedestrian-actuated signal at the splitter island will cause this kind of queue and the resulting delay.


4-a) Veh. Delay (sec.), 1-Lane RBT, 10 Peds/hour*

4-b) Veh. Delay (sec.), 1-Lane RBT, 50Peds/hour*

4-c) Veh. Delay (sec.), 2-Lane RBT, 10 Peds/hour*

4-d) Veh. Delay (sec.), 2-Lane RBT, 50Peds/hour*

Figure 11: The results of the microsimulation determining which circumstances result in the shortest vehicle delay when using a signalized crossing (Schroeder et al. 2008).

The zig-zag crosswalk design provided the highest benefits at a one-lane roundabout. The upstream location of the crosswalk at the exit leg provides extra queue storage for vehicles leaving the roundabout at that exit while the “walk” phase is activated. This allows circulating vehicles to continue to move on to their own exits and not be delayed by a signal at another leg of the roundabout. The zig-zag design also used a two-stage crossing, meaning that the “walk” phase of the signal would be active for a much shorter time than a one-stage crossing. Pedestrians only cross one direction of traffic at a time in a two-stage crossing. This means only one direction has to be stopped and the “walk”/red vehicle phase is half the time. According to Schroeder et al.’s (2008) findings, the zig-zag design, due to its queue storage and two-stage crossing, saved up to 70% of the vehicle delay time that occurred in a proximal crosswalk design.

The distal crosswalk location had the same benefit as the zig-zag location’s queue storage for a one-lane roundabout, but when used as a one-stage crossing, incurred more delay than the zig-zag, which “suggests that while additional queue storage is important, the impact of shorter vehicle red times is more significant” for one-lane roundabouts (Schroeder et al. 2008, p. 267).

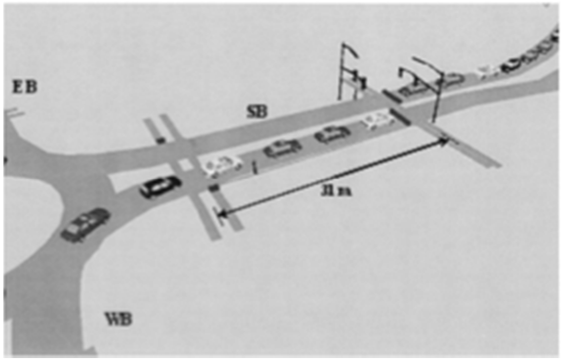


Figure 12: Distal crosswalk location with a queue at a signalized crossing (Rouphail et al. 2005, p. 216)

At a two-lane roundabout, the findings were very similar. Two-stage crossing and the HAWK signal significantly decrease vehicle delay. The only difference between a one-lane and a two-lane roundabout is the crosswalk design that seems to be most effective in reducing delay. In the one-lane roundabout, the zig-zag design was most effective. In the two-lane roundabout, the distal crosswalk location outperformed the zig-zag. The team hypothesized that this is due to the extra queue storage the two-lane distal exit leg provides.

While this option for assisting VIPs in crossing at roundabouts provides the most protection and guarantees a gap in traffic, consideration must also be placed on how it affects the flow of traffic that makes a roundabout so beneficial. There is relatively little cost difference for the infrastructure and maintenance between a traditional intersection and a roundabout when pedestrian-actuated signals are used.

Automated Yield Detection System

With the rise of technology, it is being used to solve daily problems in nearly every discipline worldwide. Transportation planning is no exception. Several different prototypes have been developed with the goal of assisting the crossing of VIPs, specifically by audibly detecting a gap in traffic or by detecting if a vehicle has yielded to a waiting pedestrian. The Institute for Transportation Research and Education (ITRE) affiliated with North Carolina State University has developed a system for this purpose, called the Automated Yield Detection System (AYDS). ITRE has conceptualized a design for an AYDS that “uses video-based sensing algorithms in combination with a traffic signal controller and audible pedestrian signals to assist blind pedestrians to cross at otherwise unsignalized crossing locations” (ITRE 2012). The video sensing detects when a vehicle has yielded to the waiting pedestrian and audibly alerts the pedestrian that it is an appropriate time to cross. This technology allows traffic to keep flowing through the roundabout naturally while providing a safe crossing environment for VIPs. This particular automated detection system does not tell a pedestrian when there is a gap in traffic, something they must still try to discern on their own. As such, the creators of the system caution the VIPs, telling them that they must still rely on their own judgment when crossing and that the AYDS is only for assistance.

The AYDS, a portable system, was tested in April of 2008 at a one-lane roundabout in Raleigh, North Carolina. Visually impaired participants crossed the roundabout using the audible cues given by the system (Figure 13). The performance was successful and showed promise for more development. The percentage of vehicle yields utilized for crossing by VIPs increased by 33% with the use of the AYDS in the tests. The AYDS would allow pedestrians a safe and relatively protected crossing without completely stopping traffic. As of right now, there has not been adequate research on the effectiveness and reliability of automated detection systems, so this remains a possible solution for the future.

FINDINGS

Alternate Crosswalk Placement

Advantages and Disadvantages

A distal crosswalk allows exiting cars more time to see a pedestrian crossing because they have already left the roundabout and are no longer concentrated on that maneuver. Distal crosswalk placement makes traffic acoustics more like that of a traditional intersection since the passing traffic will be headed in two distinct directions. This makes judgment easier for a VIP. An ideal distal crosswalk would have a splitter island in between the two directions of traffic, providing a refuge and allowing a pedestrian to only have to worry about crossing one direction of traffic at a time. A distal crosswalk allows an exiting car to speed up before reaching the crosswalk. It deters a car approaching the roundabout from slowing down before reaching the crosswalk. This makes a driver less likely to see a crossing pedestrian and less able to slow down. Faster traffic could also result in less opportunities for crossing gaps.

A zig-zag crosswalk design keeps the characteristic of the distal crosswalk during the exit leg, which is the hardest with which to audibly discern a gap. The entry leg maintains the typical proximal location, ensuring that a car is at its minimum speed when approaching a waiting pedestrian. A zig-zag design also guarantees a two-stage crossing, which is safer than a one-stage crossing. Adjusting the placement of a crosswalk is a fairly easy and simple change to make to a roadway infrastructure compared to a couple of the other options presented. It is also almost entirely maintenance free and requires little cost upkeep. No public education or outreach is needed. A zig-zag crosswalk design requires more travel time for all pedestrians. For a VIP, this means that they have to align themselves with the correct pathways several times, slowing down and possibly complicating the crossing process. For a non-impaired pedestrian, the inconvenience of the extra travel distance may result in a lower compliance rate than a traditional proximal crosswalk location. Just the presence of a crosswalk, no matter where it is placed, does not provide a protected crossing environment.

Figure 13: A visually impaired participant crosses in front of a yielded vehicle after hearing an audible cue from the AYDS (ITRE 2012)

Practicality

The practicality of implementing an adjusted crosswalk placement is high. If changing the placement of an existing crosswalk, it is much simpler and more economic than adding both signalized crossing and an AYDS. If building a new roundabout, there is no extra cost involved. Crosswalks, no matter where they are placed, require very little upkeep.

Performance and Recommended Use

Alternative crosswalk designs seem to be very beneficial to aiding in the crossing of VIPs at roundabouts, but may not be enough when used alone. Alternative crosswalk designs, whether distal or zig-zag, would perform best when in conjunction with other solutions presented in this paper, such as the sound treatment and the signalized crossing. If used as the only solution for assisting crossing for VIPs at roundabouts, they would be best at a roundabout with a low-moderate vehicle volume when gaps in traffic suitable for crossing may occur naturally. At a high traffic volume roundabout, more assistance is needed because gaps in traffic won't come naturally very often.

Sound Treatments

Advantages and Disadvantages

Sound treatments on the pavement give VIPs the ability to audibly discern if a vehicle has yielded or has continued through to enter or exit the roundabout. The physical treatment won't be very expensive to apply to roadways and will require little upkeep and maintenance.

There is no sound to indicate if there is a gap in traffic, only if a vehicle has yielded. As a result, this solution does not address the acoustics difference of a roundabout from a traditional intersection and doesn't help a VIP discern a gap. The VIP must rely on a vehicle stopping to cross the roundabout. There is also currently little public knowledge about the purpose of the sound strips. The sound treatment also does not make crossing any safer for non-impaired pedestrians as does the alternative crosswalk placement and the signalized crossing.

Practicality

Knowledge of the sound strips is not currently widespread enough to implement at a large scale. Education of VIPs and drivers, however, could make a sound treatment a practical solution. Physical roadways don't have to be altered to install noise strips. They are low maintenance and inexpensive.

Performance and Recommended Use

At this time, more studies need to be conducted where both the VIPs and drivers are aware of the purpose of the strips. As it stands, the FHWA intended these to be "self-explanatory," which is clearly not the case. If education is addressed, these could be very helpful.

When implemented, sound treatments should be used at low vehicle volume and low pedestrian volume roundabouts until they are more understood by the public. In the future they could be expanded to moderate vehicle roundabouts. They would be best used in combination with a distal or zig-zag crosswalk location, but could be used alone at a traditional proximal crosswalk in a low vehicle volume roundabout. When they are more understood, they could be added to any other solution to further aid in appropriate crossing time detection by VIPs.

Signalized Crossing

Advantages and Disadvantages

Signalized crossing at roundabouts is the only solution that offers a protected crossing for pedestrians. Signalized crossing stops traffic so that a pedestrian can cross without worrying about detecting gaps or yields. A HAWK signal offers the vehicle a flashing red signal during the flashing "don't walk" pedestrian phase so cars can proceed as soon as the pedestrians are done crossing. This allows the flow of traffic to be minimally interrupted while still giving the pedestrians a protected right of way.

A signalized crossing is the most vehicular intrusive of the solutions presented. It stops the continuous flow of traffic, one of the main benefits of a roundabout. The stopped traffic may result in a queue of vehicles that backs up into the roundabout, causing a higher risk of accident. The physical implementation of signals is also by far the most expensive and complicated installation of the solutions.

Practicality

Signalized crossing at roundabouts is very practical. Signals are already understood by drivers and pedestrians alike. The protected crossing gives the safest crossing environment for all pedestrians, especially VIPs. Installing signalized crossing at an existing roundabout will be a major project. The signals use energy and will require maintenance and more costly upkeep than just a crosswalk or a sound treatment.

Performance and Recommended Use
The signalized crossing option outperforms other solutions in terms of effectiveness of safe crossing for VIPs, but is the only option that stops traffic completely. Based on the research done, it's possible to use a mix of two-stage crossing and alternative crosswalks to minimize the disruption to traffic flow when using a HAWK signal. To reach highest effectiveness, a signalized crossing should be combined with an audible cue that it is time to cross. The HAWK signalized solution is ready to be used widespread.

The HAWK solution would fit best in a moderate-heavy traffic volume roundabout with all pedestrian volumes. It can be adapted with a combination of alternative crosswalks, two-stage crossing, and varied "walk/don't walk" times to fit whatever roundabout environment it will be in. The conventional signal is not recommended except in cases of regular extremely high pedestrian volumes.

Automatic Yield Detection System

Advantages and Disadvantages
The AYDS aids VIPs in determining when a vehicle has yielded, which means it is safe to cross. The system addresses how to make crossing safer for VIPs. It does not disrupt the flow of traffic and allows it to continue naturally. The AYDS is portable, allowing it to be installed at any roundabout.

The system only detects when a vehicle has yielded, which, like the sound strips, does not help a VIP detect a gap in traffic that would be suitable to cross. This means a VIP must rely on a vehicle to stop to allow him or her to cross. It is a very costly system that is in the early stages of development. The AYDS does not make crossing any safer for non-impaired pedestrians as does the alternative crosswalk placement and the signalized crossing.

Practicality
Because the AYDS only exists as a prototype so far, this system should only be implemented on an experimental basis. If developed for commercial use, the AYDS could prove to be a practical implementation for discerning yielded traffic, but not gaps. It will be an expensive technology to install, but it's portable so it could be installed at any existing roundabout with ease. The AYDS will require one hundred percent accuracy in determining if a vehicle has yielded, otherwise it may direct a VIP across the walk when it is not actually safe.

Performance and Recommended Use
The test results for the AYDS are promising. The VIP who participated in the tests were able to use the system as it was intended successfully. It may need to address detecting gaps in traffic to be an even better system. At this time, the AYDS should be used and monitored at low-moderate vehicle volume roundabouts as an experimental purpose.

CONCLUSION

The research evaluated here shows that at a low vehicle volume and low pedestrian volume roundabout, a distal or zig-zag crosswalk design may be the best fit for assisting VIPs in crossing. This alternative crosswalk design can be combined with sound strips as they become more understood by the public to further assist in the audible detection of yielded vehicles. At a moderate-high vehicle and pedestrian volume roundabout, a HAWK signalized crossing would be the best fit. This can be combined with two-stage crossing, alternative crosswalk locations, and/or sound strips to be most effective. It's also important to include an audible signal to indicate to a VIP that it is time to cross. As roundabouts become more popular in the United States, these methods of increasing accessibility for visually impaired pedestrians will remain extremely important. With the development of new technology and improved understanding by the public, accessibility will be enhanced as multiple methods are combined to achieve even better results.

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