REVISTA PERCURSO

VISIBILITY STUDY IN URBAN INTERSECTIONS WITH NO TRAFFIC LIGHTS IN THE CITY OF MARINGA, PARANÁ

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ABSTRACT: Intersections are a key part of city road systems, requiring careful design and implementation because they have many conflict points between different vehicle types and pedestrians. These areas are often linked to high accident rates. Therefore, drivers' main elements on urban roads need careful attention during design, as they involve numerous conflict points that require clear vision for safe decision-making. This article aims to develop a user-friendly tool based on a method to determine visibility distance at urban intersections without traffic lights. It considers the space-time-speed relationship, applying findings from intersections in Maringa, Paraná, that experienced many accidents in 2020 and 2021. The methodology includes deriving equations to calculate visibility distances at intersections with ‘Stop' and ‘Give Preference’ traffic controls, and transforming these into a visual aid, like an abacus. The tool allows for quick determination of visibility distance by visual inspection, accounting for common vehicle and road parameters in the country.
Keywords: Crossroads. Visibility triangle. Stop. Give Preference. Abacus.

ESTUDO DE VISIBILIDADE EM CRUZAMENTOS URBANOS SEM SEMÁFOROS NA CIDADE DE MARINGÁ, PARANÁ

RESUMO: As interseções são um elemento-chave nos sistemas viários urbanos, exigindo projeto e implementação cuidadosos devido aos inúmeros pontos de conflito entre diferentes tipos de veículos e pedestres. Essas áreas estão frequentemente associadas a altos índices de acidentes. Portanto, os principais elementos de visibilidade para os motoristas em vias urbanas precisam de atenção especial durante o projeto, visto que envolvem diversos pontos de conflito que requerem visibilidade clara para a tomada de decisões seguras. Este artigo tem como objetivo desenvolver uma ferramenta de fácil utilização baseada em um método para determinar a distância de visibilidade em interseções urbanas sem semáforos. Considera-se a relação espaço-tempo-velocidade, aplicando-se dados de interseções em Maringá, Paraná, que registraram muitos acidentes em 2020 e 2021. A metodologia inclui a derivação de equações para calcular as distâncias de visibilidade em interseções com sinalização de parada obrigatória e prioridade de passagem, e a transformação dessas equações em um auxílio visual, semelhante a um ábaco. A ferramenta permite a determinação rápida da distância de visibilidade por inspeção visual, levando em conta os parâmetros comuns de veículos e vias no país.
Palavras-chaves: Cruzamentos. Triângulo de visibilidade. Pare. Dê preferência. Ábaco.

List of notations (examples below)

v – allowable vertical displacement

α – coefficient of thermal expansion of concrete

T_2 – temperature of the slab bottom surface

T_1 – temperature of the slab top surface

L – length of the longer span of the slab

l – length of the shorter span of the slab

h – effective depth of the slab, as defined in **BS EN1994-1-2**

f_y – yield stress of the reinforcement

E – modulus of elasticity of the reinforcement

1. INTRODUCTION

The intersection is a crucial element of the road system because it impacts the efficiency, safety, and capacity of the roads. According to the DNIT Intersection Project Manual (2005), an intersection is defined as the area where two or more roads meet or cross, including all space intended to facilitate the movement of vehicles passing through it. Intersections are generally classified into two categories based on the planes in which movements occur: at-grade and grade-separated.

According to Barbosa (2005), intersections are characterized by the presence of multiple movements originating from different flow currents that compete at the same point; therefore, they require external intervention to coordinate the movements. Defined as the points where roads intersect, intersections must be easy to understand to promote smooth traffic flow. These are classified either by the plane in which the movement occurs, which can be level or uneven, or by the nature of the movements, which may be crossing, converging, or diverging movements.

According to Simões (2016), intersections are considered the most dangerous parts of the road system because many vehicles are moving in different directions at the same time. One key factor in keeping these areas safe is ensuring good visibility for drivers so they can see and understand the movements happening around them and make safe decisions.

Intersections are high-risk for road accidents because they experience heavy traffic and have many conflict points due to various allowed movements. However, the chance of accidents can be greatly reduced through proper sight distance projection and effective traffic control. Preventing these conflicts also depends on the driver's understanding and abilities (AASHTO, 2001). Therefore, the driver's field of vision must be free of obstructions, which are usually caused by parked vehicles, stopped buses, trees, public telephones, poles, building alignments, or trade signs.

At traffic light intersections, the driver is signaled when it is safe to move. On the other hand, at intersections without signs, with ‘Stop’ or ‘Give way signs’, it is up to him to judge the most appropriate moment to cross. In the first two cases, the vehicle is required to stop before the intersection and then, when possible, resume its movement. In the latter case, the vehicle need not stop and can make its decision earlier. For a moving vehicle, the sight distance must allow the driver time to decide whether to stop, accelerate, or reduce speed. For a stationary vehicle, visibility is essential for decision-making, including assessing whether there is enough time to cross the road (DNIT, 2005).

The visibility distance is the distance the driver needs to identify the traffic situation, make their decision, and carry out the desired movement without risking a conflict. According to DNIT (2005), this distance depends on the speeds of the vehicles involved, the time to perception, driver reaction, and vehicle braking. In this way, it is a function of the space-time-velocity trinomial. At intersections, it is recommended that the decision-making visibility distance be adopted as the visibility distance, and this must be at least equal to the stopping visibility distance, which can be defined by the 'extension of the road ahead that the driver must be able to see so that, after seeing an obstacle that forces him to stop, he can immobilize the vehicle without hitting it' (DAER, 1991).

The American Association of State Highway and Transportation Officials emphasizes the importance of adequate visibility distance, noting that it enables the driver to identify the risk situation with enough time to interrupt their movement or adjust their speed, thereby avoiding the potential for crashes. These distances at intersections depend on the type of intersection control and the movement to be performed there. For crossing movements with the 'stop' sign on the secondary road, the distance is calculated based on the speed of the main road and the available time to cross, and these values are tabulated accordingly. Crossing movements with 'give way' signs on the secondary road depend on the speed of the main road and the time required to reach and see it (AASHTO, 2001).

Since the current formulation of the visibility distance provided by DNIT is based on the standards set by the American Association of State Highway and Transportation Officials (AASHTO, which is tailored to North American vehicles and roads and aims to improve road safety in the country, a decision was made to study the visibility distance at urban intersections without traffic lights in Maringa. The goal is to develop an accessible tool that can be widely used for Brazilian vehicles and roads.

This study intends to determine the visibility distance at urban intersections without traffic lights in Maringa, Paraná, by analyzing the space–time–speed relationship. It also aims to create a user-friendly visual tool based on the proposed method for practical visibility-distance calculations and to implement and validate it at intersections with a high rate of recent accidents within the study area.

2. MATERIALS E METHODS

To achieve the objectives already described in this work, the realization of this study was divided into three main stages: the formulation of the visibility distance for intersections without traffic lights, the creation of the tool that will expose the results, and the validation of this tool in intersections of the city of Maringa/PR.

The intersection model studied was based on the most common types of intersections with a high number of conflict points. Thus, among the intersections of four branches, two-way roads with two-way streets, two-way roads with one-way roads, and one-way roads with one-way roads, among others, were analyzed.

Then, based on the National Department of Transportation Infrastructure Urban Crossing Manual (DNIT, 2010), the project vehicle was defined, which must be well represented among the vehicles that travel the streets of the city of Maringa/PR, reflecting the physical and operational features. In the case of urban roads, to determine the visibility distance, it is recommended that automobiles (passenger cars) be used as the project vehicle, due to the height at which the driver is inside the vehicle.

It is also essential to understand the fleet in circulation so that the exact choice of the project vehicle and its characteristics can be made. According to the State Department of Transit (DETRAN, 2021), in May 2021, the city of Maringa/PR had a total fleet of 304,779 vehicles, most of which are classified as cars. In this way, based on the recommendations presented and the characterization of the main types of vehicles in the city of Maringa/PR, the light vehicle, that is, the automobile, was used as the project vehicle. As its main characteristics, a total width of 2.1 m and a total length of 5.8 m were considered. Also, given the safety-first scenario and the most common conditions of occurrence, the acceleration used was 2.0 m/s^2, and the deceleration was 3.0 m/s^2.

3. FORMULATION OF VISIBILITY DISTANCE EQUATIONS

The formulation of the safe visibility distance began as a function of the trinomial: space, time, and speed. Thus, this was prepared considering the four main characteristics of intersections: the geometry of the roads, the maximum speeds allowed on the roads, the acceleration of the design vehicle, and the existing signaling at the intersection.

The formulated equations followed the precepts of Uniformly Varied Rectilinear Motion. This occurred for both cases: crossing with ‘Stop' signs and crossing with ‘Give Preference’ signs. In the first case, taking into account that the vehicle will be positioned behind the crosswalk or the retention lane, the equation took into account the parameters: The maximum speed allowed on the main road, which will guarantee safety in the worst case; The width of the secondary road that the vehicle will cross, considering the width of each lane, the length of the flowerbeds, the width of the median, if any, and the width of the parking lanes; The acceleration of the vehicle; The driver's perception and reaction time; The sight distance at the intersection.

In the second case, ‘Give preference’, the driver must assess whether there is enough time to cross the main road or whether they need to stop or slow down. In this way, it must be positioned at an adequate distance before the intersection of the movement decision. Therefore, this distance was taken into account in the formulation, which was based on the parameters: The maximum speed allowed on the main road and on the secondary road; The width of the secondary road that the vehicle will cross, taking into account the distances already mentioned for the first case, as well as the distance from the decision point to the intersection; The acceleration and deceleration of the vehicle; The driver's perception and reaction time; The sight distance at the intersection.

Based on the above findings, the Visibility Distance Equation was formulated for ‘Mandatory Stop’ signs, in which it was first necessary to determine the time the driver could cross the entire width of the main road, leaving the zone of conflict. For this, Equation 1 was used.

$$S = S_0 + V_0 * t + \frac{1}{2} a * t^2$$

1.

As the driver is forced to stop before the intersection, the vehicle's initial speed is considered zero; that is, $V_0 = 0$. This way:

$$\Delta S = \frac{1}{2} a * t^2$$

2.

It was considered that ΔS represents all the displacement that the vehicle will travel, replacing this with the variable L, that is, $\Delta S = L$. This variable describes the sum of several dimensions, as can be seen in Equation 3, in which t represents the time required to cross the intersection (s), L the total width to be crossed (m), a the vehicle acceleration (m/s²), and t_r the drivers' reaction and perception time (s). Also, the driver's perception and reaction time was added to the time found.

$$t = \sqrt{\frac{2+L}{a}} + t_r$$
3.

And:

$$L = L_{fr} + L_{pi} + L_{cc} + L_{fe} + L_{vp}$$
4.

In which L_{fr} represents the width of the roadway (m), L_{pi} the width from the vehicle stop location to the beginning of the intersection (m), L_{cc} the width of the flowerbethe d (m), L_{fe} the parking lane (m), and L_{vp} the project vehicle length (m).

Then, from the time (t) found by Equation 1 and Equation 3, it was possible to obtain the displacement that the vehicle, on the main road, could travel, being at the maximum speed allowed on this road. In this way, as the vehicle will not need to accelerate, this variable was considered equal to zero $(a = 0)$. So, Equation 1 becomes:

$$\Delta S = V_0 * t$$
5.

The variables were changed ΔS and V_0 per $D_{v,1}$ and $V_{max,p}$, respectively, and it was obtained that:

$$D_{v,1} = V_{max,p} * t$$
6.

Replacing the value of t found in Equation 3, Equation 7 was found:

$$D_{v,1} = V_{max,p} * \left(\sqrt{\frac{2+L}{a}} + t_r\right)$$
7.

Also, as in Brazil, road speed values are expressed in the International System of Units (SI), i.e., km/h, so this value was converted to m/s to facilitate its use. It is known that
$m/s = 3{,}6\ km/h$

In this way, the transformation was carried out, and it was obtained that:

$$D_{v,1} = \frac{V_{max,p}}{3{,}6} * \left(\sqrt{\frac{2+L}{a}} + t_r \right)$$

In which $D_{v,1}$ represents the visibility distance at intersections with 'Stop' signs (m), $V_{max,p}$ the maximum speed of the main road (m/s), L the total width to be crossed (m), a the vehicle acceleration (m/s²), and t_r driver's reaction time and perception (s).

In the first case, the driver's decision point is defined by the road signs, that is, the horizontal 'Stop' sign and the retention lane, or by the presence of the crosswalk. In this case, for the formulation of the Visibility Distance Equation with 'Give Preference' signaling, the initial focus was on determining its location.

When a vehicle must stop due to a conflict, there must be enough space so that a sudden stop does not occur, which could cause discomfort or endanger lives. Thus, this displacement was calculated from Equation 9.

$$V^2 = V_0^2 + 2 * a * \Delta S$$
9.

In this case, as the final velocity of the vehicle will be zero ($V_0 = 0$), it was obtained that:

$$V_0^2 = -2 * a * \Delta S$$
10.

It was considered that the negative acceleration corresponds to deceleration, thus replacing $d = -a$, and the variables were changed V_0 per $V_{max,s}$ and ΔS por L_{pd}. So:

$$L_{pd} = \frac{V_{max s^2}}{2*d}$$

In which L_{pd} represents the distance from the decision point to the beginning of the intersection (m), $V_{max,s}$ the maximum speed of the minor road (m/s), and d vehicle deceleration (m/s²).

Once the decision point was determined, the visibility distance was calculated as in the first case, adding the distance from the decision point to the beginning of the intersection to the distance the vehicle would travel. Thus, from Equation 7, it was obtained that:

$$D_{v,2} = V_{max,p} * \left[\sqrt{\frac{2*(L+L_{pd})}{a}} + t_r\right]$$

12.

Replacing L_{pd} by the value determined in Equation 11:

$$D_{v,2} = V_{max,p} * \left[\sqrt{\frac{2}{a} * (L + \frac{V_{max,s^2}}{2*d})} + t_r\right]$$

13.

In which $D_{v,2}$ represents the visibility distance at intersections with ‘Give Preference’ signs (m), L the total width that the vehicle will have to cross (m), $V_{max,p}$ the maximum speed of the main road (km/h), $V_{max,s}$ the maximum speed of the minor road (km/h), d the vehicle deceleration (m/s²), and t_r the driver’s reaction time and perception (s).

Based on the results, it was also possible to determine the visibility triangle at the intersections, which represents the area free of any object that obstructs visibility, such as buildings, parked vehicles, and trees (DNIT, 2005).

As shown in Figure 1, the visibility triangle is designed in such a way that the distance "b" corresponds to the visibility distance found and the distance "a" corresponds to the stretch that starts at the point where the vehicles on the road main route to the driver's decision point or stopping point in cases where the driver is forced to stop moving.

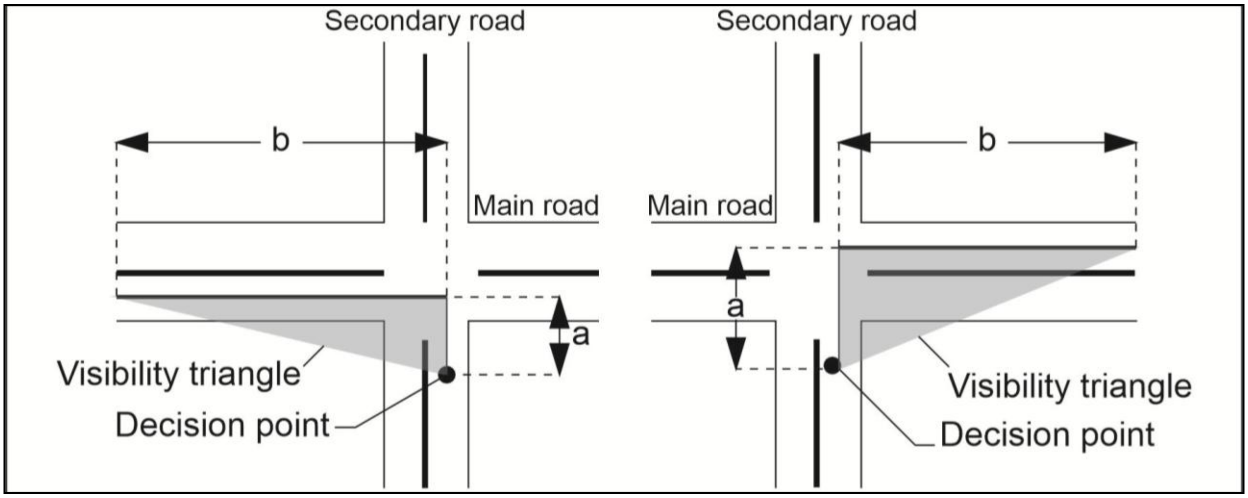

Figure 1. Example of the visibility triangle at intersections. Source: Adapted from AASHTO

Abacuses

The second stage consisted of developing the tool to display the results, characterized by the elaboration of abacuses (nomograms).

The abacus for intersections with traffic control at 'Stop' signs consists of three variables. To display the results of the intersection with traffic control implemented by the 'Give Preference' signaling, it was necessary to build an abacus with more unknowns, totaling four variables in addition to the result, to account for the driver decision point, secondary road speed, and vehicle deceleration.

The abacuses were generated using the PyNomo software, developed in Python. To aid its use, codes were created for each equation type, grouping them into 10 categories. In this way, it is necessary to find what best fits and adapt it to the existing situation (ROSCHIER, 2015).

4. STUDY IN INTERSECTIONS IN THE CITY OF MARINGA/PR

To carry out the third stage, which consists of applying the results obtained from the abacus at intersections in the city of Maringa, the intersections with the highest number of accidents were identified. For this, the SIATE – Integrated Trauma and Emergency Care

Service, which belongs to the Fire Department, and is activated whenever there are victims in the event, was consulted.

To select the intersections to be studied with 'Stop' signs, all intersections that had suffered more than 5 accidents during the analyzed period were classified and organized in ascending order. From this, Google Maps analyzed the characteristics of the roads that compose them and their direction. Each intersection that presented the highest number of accidents was then chosen for the case in which the roads were two-way, in which one was one-way and the other two-way, and in which both were one-way. The same was done for intersections with ‘Give Preference’ signs, but checking those with more than three traffic accidents, as in this case, the frequency was generally lower.

A group of six different intersections where field research was carried out was then obtained. At the site, it was first observed whether the characteristics, such as signaling and road direction, matched those previously observed. Then, the characteristics of the roads were analyzed, including the number of lanes, the presence of parking lots, flowerbeds, pedestrian crossings, and others. All these aspects were documented in photographs taken on site.

Subsequently, measurements were taken of the dimensions of the lanes, parking lanes, sidewalks, flowerbeds, pedestrian lanes, parking ban lanes, retention lanes, and any other aspect relevant to the research. These measurements were repeated four times: twice on each road, once before, and once after the intersection.

With the directions of the roads already known, an analysis was carried out of all movements that could occur within that intersection to determine which points required the visibility distance to be determined, and to pay closer attention to this location. Thus, all elements within the visibility triangle at heights that would hinder the driver's vision were analyzed. These elements were computed and recorded.

Once data collection is complete, the study of the visibility distance at each intersection can begin. First, all intersections were drawn in AutoCAD from the registered dimensions, and a tabulation of the other quantitative and qualitative data was prepared. Then, the generated abacuses were used to determine the visibility distance, which was also drawn in the same software to form the visibility triangle. From this drawing, it was possible to visualize all the elements that interfere with the driver's line of sight.

5. RESULTS AND DISCUSSION

The equation for sight distance in cases with ‘Stop’ signs was previously derived. Adopting the acceleration values of the project vehicle (a)equals a 2.0 m/s^2 and reaction and perception time (t_r) equal to 2.5 s, as already justified in this work, the result shown in Equation 14.

$$D_{v,1} = \frac{V_{max,p}}{3,6} * \left(\sqrt{L} + 2,5\right)$$

14.

In which $D_{v,1}$ represents the visibility distance at intersections with ‘Stop’ signs (m), L the total width that the vehicle will have to cross (m), and $V_{max,p}$ the maximum speed of the main road (km/h).

For the visibility distance equation in cases with ‘Give Preference’ signs, the same values were adopted for acceleration, reaction time, and perception time, and the vehicle deceleration value (d) was set to 3,0 m/s^2. In this way, Equation 2 was derived, yielding the final product.

$$D_{v,2} = \frac{V_{max,p}}{3,6} * \left\{\sqrt{L + \frac{{V_{max,s}}^2}{77,76}} + 2,5\right\}$$

15.

In which $D_{v,2}$ represents the sight distance at intersections with ‘Give Preference’ signs (m), L the total width that the vehicle will hve to cross (m), $V_{max,p}$ the maximum speed of the main road (km/h), and $V_{max,s}$ the maximum speed of the secondary road (km/h).

To create a tool that enabled easy visualization of the results, two abacuses were generated: one for crossing conditions at the ‘Stop’ sign and one for crossing conditions at the 'Give Preference' sign.

The Abacus 1 – Visibility distance for 'Stop' signs, produced from Equation 1, can be analyzed in Figure 2. It consists of three parallel lines with different scales. Its use is very simple, so that knowing two of the unknowns, which will usually be the maximum speed on the main road and the width to be crossed by the vehicle, it is possible to draw a straight line connecting the values already known, to cross the third line at a point that will convey the sought result.

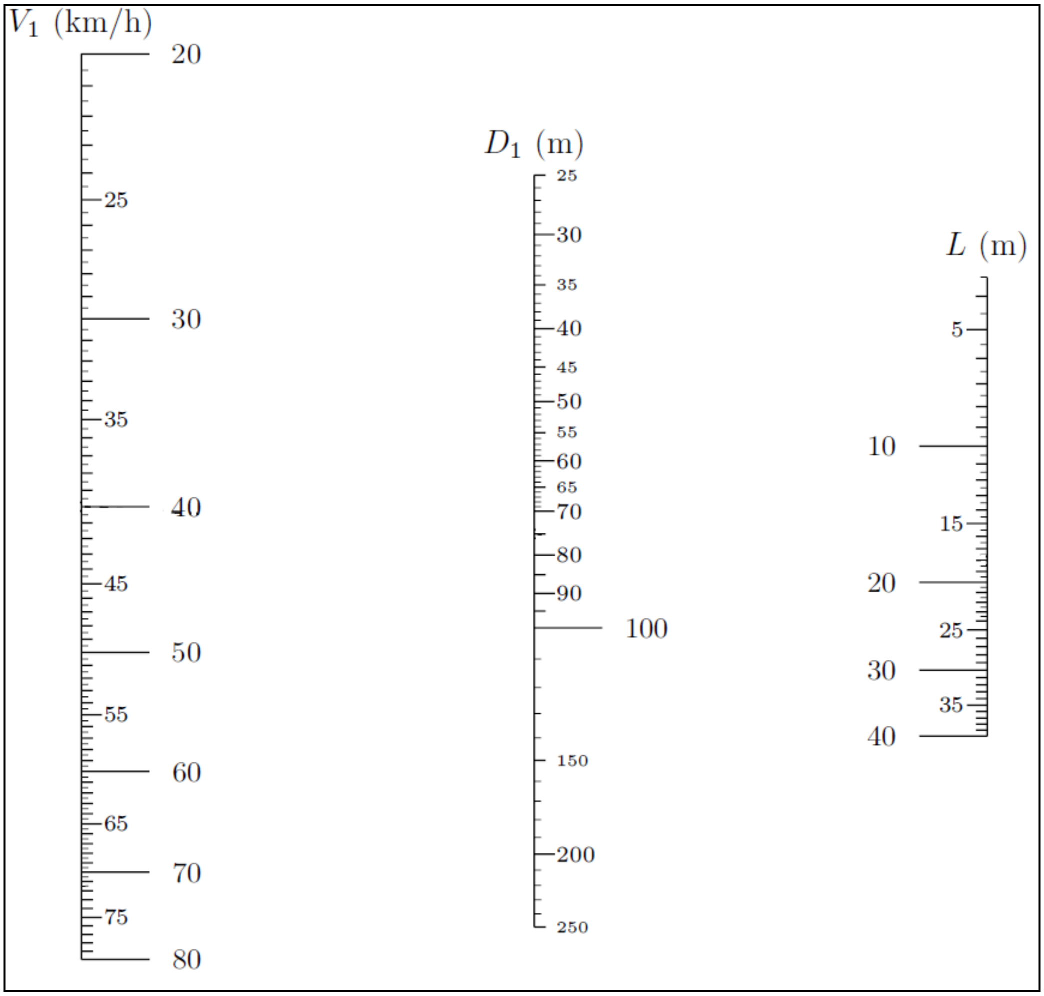

Figure 2. Abacus 1 – Visibility distance for 'Stop' signs

Abacus 2 – The visibility distance for 'Give Preference' signs was calculated using Equation 2, which contains unknowns. Thus, this was generated as two if they were two separate abacuses, first solving the sum $\left[L + \frac{V_{max,s}^2}{77,76}\right]$, and then connecting this value with the other variables in the equation.

For the correct reading of the abacus, you must first enter the unknown L by drawing a straight line until you find the curve representing the maximum speed of the secondary road. With this point determined, a straight line is drawn to the end of the diagram. Then another line is drawn up to the maximum speed of the main road, which crosses the line representing the visibility distance, and the result is found by its scale. This abacus is shown in Figure 3.

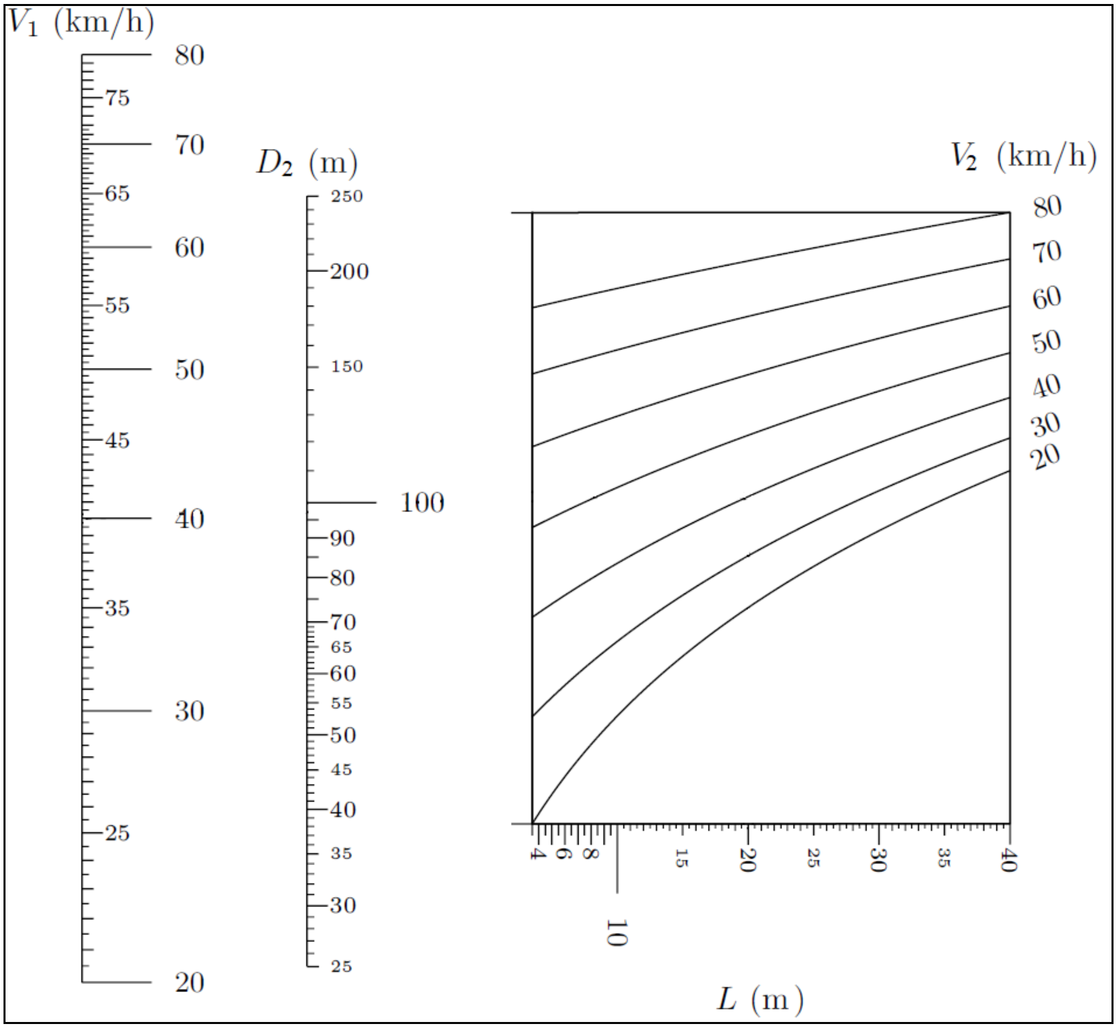

Figure 3. Abacus 2 – Visibility distance for ‘’Give Preference’’ signage

It is important to compare the values obtained in this study with those provided in the DNIT Intersection Design Manual (DNIT, 2005). Considering a maximum grade of 3%, the visibility distance provided by DNIT for 'Stop' signs is 70 m, and for 'Give Preference' signs, it is also 70 m.

A few more values obtained for different cases by the method developed in this work and by the DNIT method were compared. All these cases considered grades up to 3%. Comparing the values obtained by both methods, it is evident that, in both cases, the visibility distance provided by DNIT is smaller; the difference is more clearly shown in the bar graphs in Figures 4 and 5.

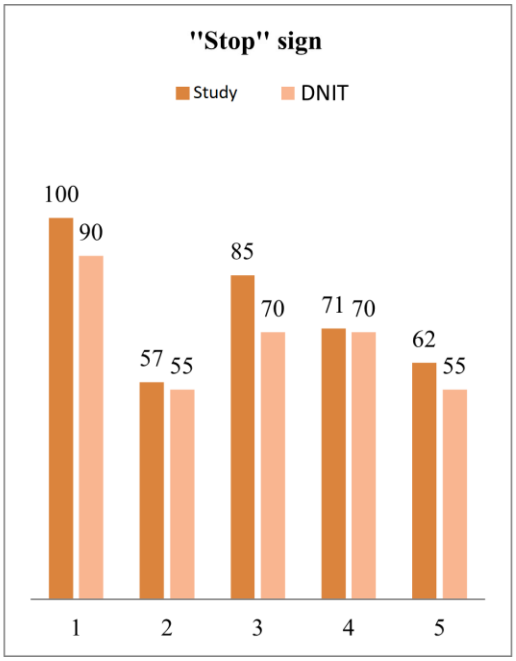

Figure 4. Comparison between distances from visibility ('Stop')

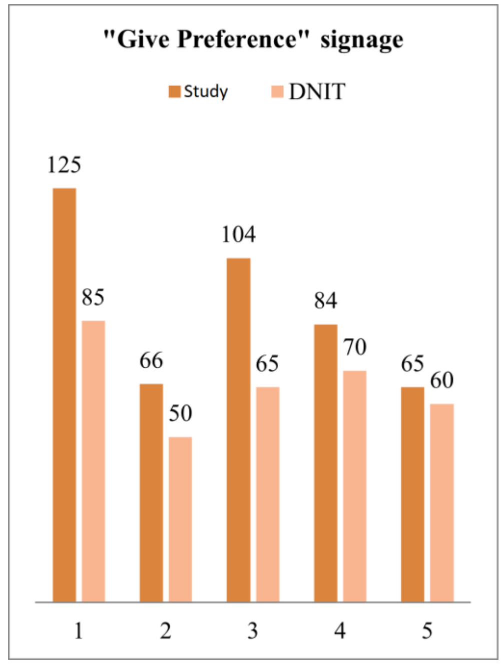

Figure 5. Comparison between distances from visibility ('Give Preference')

This may occur because the DNIT does not account for the dimensions of the road to be crossed, relying only on the number of lanes and still basing the time interval on North American research, rather than adapting to possible changes. may occur due to common vehicle and road characteristics in Brazil.

According to research on intersections with a high number of traffic accidents, six intersections were selected that stood out not only for this figure but also for having different track directions and geometries. The chosen intersections are shown in Table 1.

Table 1. Analyzed intersections

N	Ways	Traffic control	Number of registered accidents
1	Brasil Avenue X Arapongas Street	STOP	11
2	Guedner Avenue X José Moreno Junior Street	STOP	6
3	Saldanha Marinho Street X Floriano Peixoto Street	STOP	5
4	Tamandaré Avenue X Ver. Basílio Sautchuk Street	STOP	7
5	José do Patrocínio Street X Luiz Gama Street	GIVE A PREFERENCE	3
6	La Paz Street X Bolivia Street	GIVE A PREFERENCE	3

The locations of all these intersections in the city of Maringa/PR are shown in Figure 6, each represented by the number assigned in Table 1.

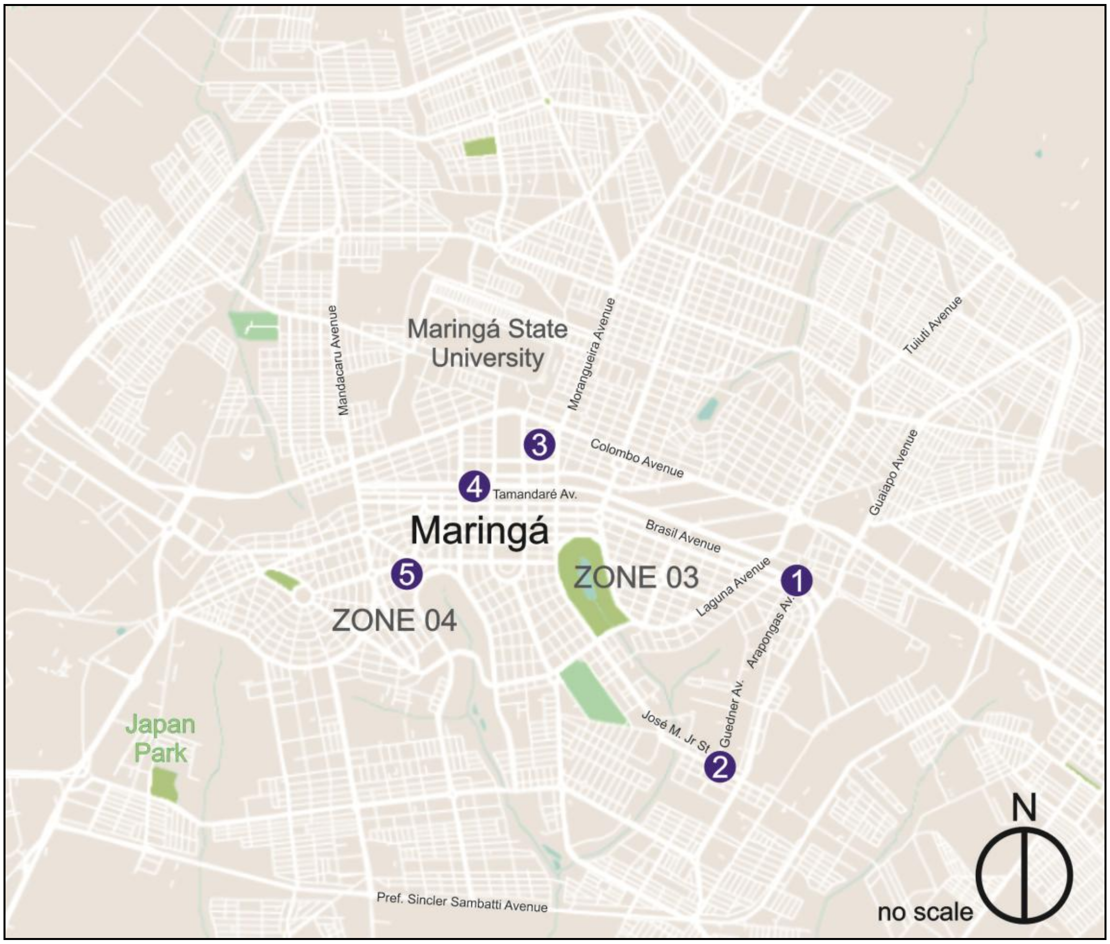

Figure 6. Location of the analyzed intersections in the city of Maringa/PR

In this way, the elements of each road can be measured, the condition of the signs checked, and possible obstacles and causes of the high number of traffic accidents identified. From the measured dimensions and the speed of the roads, the visibility distances for each chosen intersection are determined using the abacus. With this value determined, the visibility triangle was drawn to analyze potential points of obstruction.

Figures 7 and 8 show the results of the analysis of Intersection 1. To determine the visibility distance of the upper section of Arapongas Street (section A), it was that $V_{max,p} = 60\ km/h$ and that $L = 19.4\ m$. For the lower part, that is, section B, it was found that

$L = 13.3\ m$. Thus, the visibility distance for "section A" was equal to 115 meters, and for "section B" it was 102 meters.

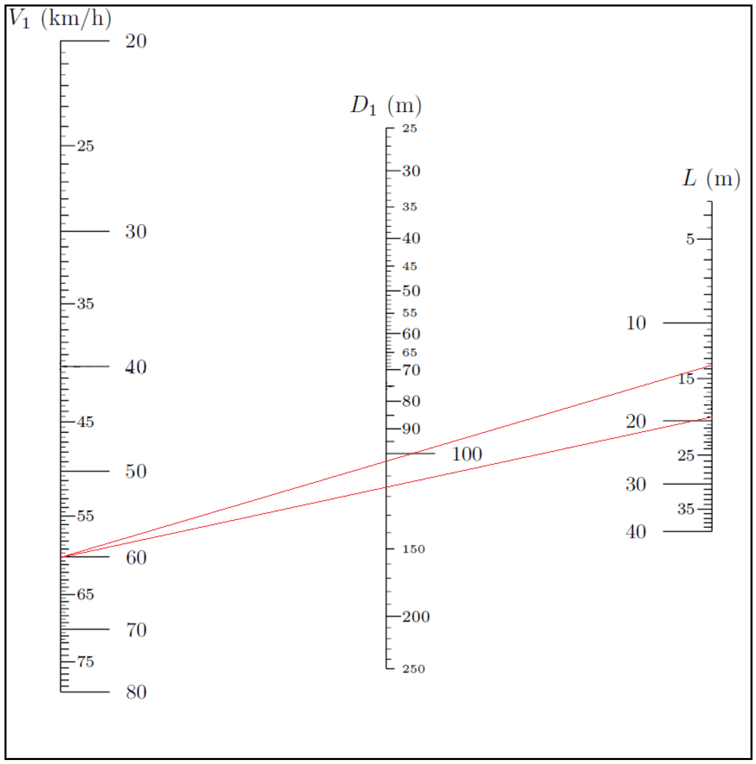

Figure 7. Intersection 1 sight distance

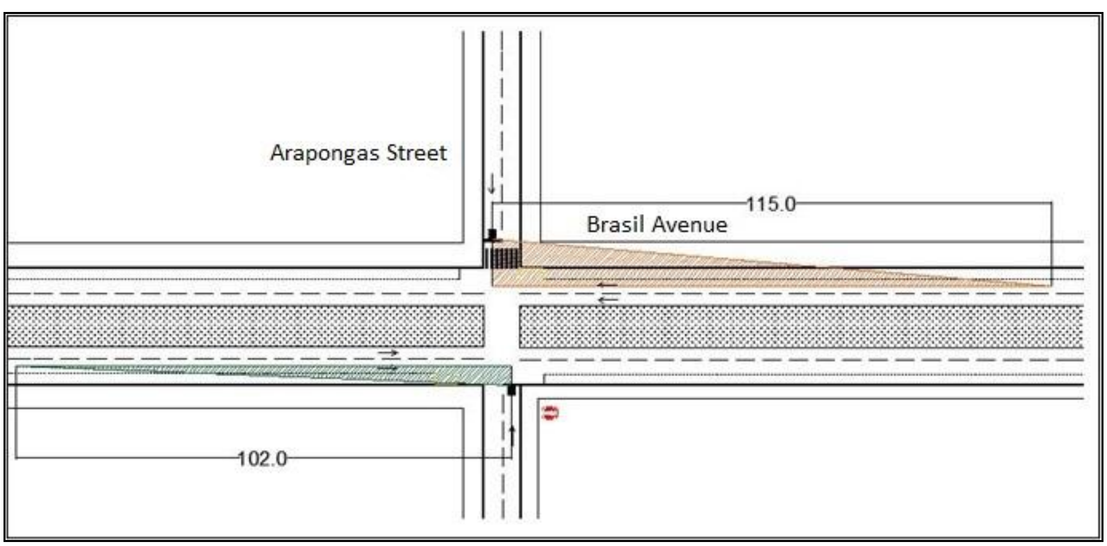

Figure 8. Representation of the visibility triangle of Intersection 1

At intersection 2 it was found, that $L = 21.6\ m$ and $V_{max,p} = 30\ km/h$. When these values were entered into Abacus 1, a visibility distance of 60 meters was obtained, as shown in Figures 9 and 10.

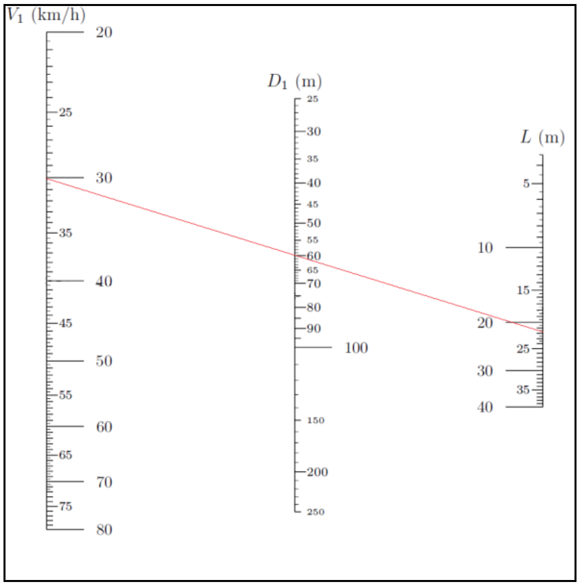

Figure 9. Visibility distance from Intersection 2

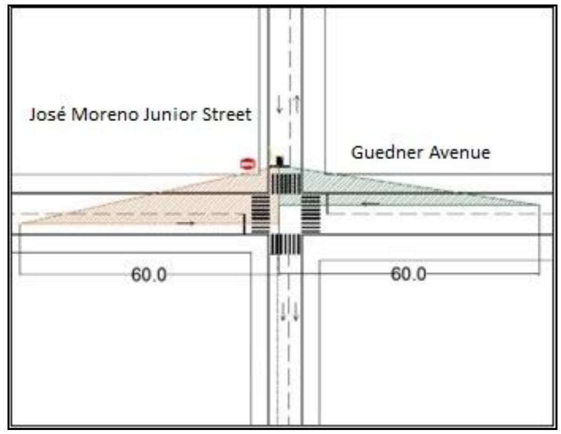

Figure 10. Representation of the triangle visibility of Intersection 2

With the values of $L = 13.4\ m$ e $V_{max,p} = 40\ km/h$ introduced in Abacus 1, we obtained in the visibility distance of 68 meters at Intersection 3, according to Figures 11 and 12. This case was presented as atypical because the driver may stop after the crosswalk, as the crosswalk is set back enough that the vehicle does not have to stop at it. Thus, interferences in the visibility triangle were smaller.

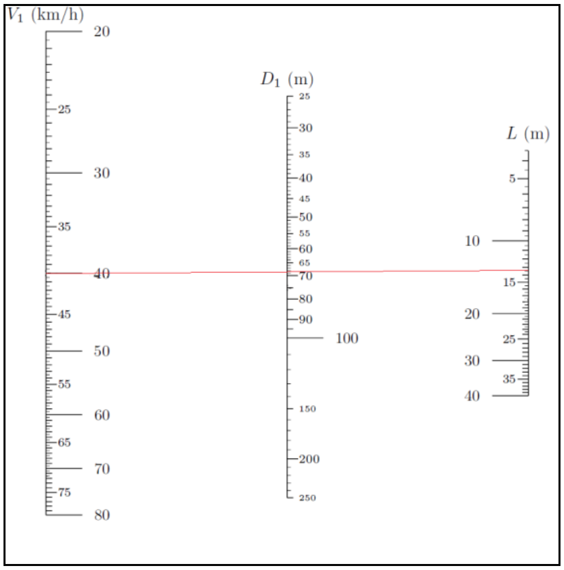

Figure 11. Visibility distance from Intersection 3

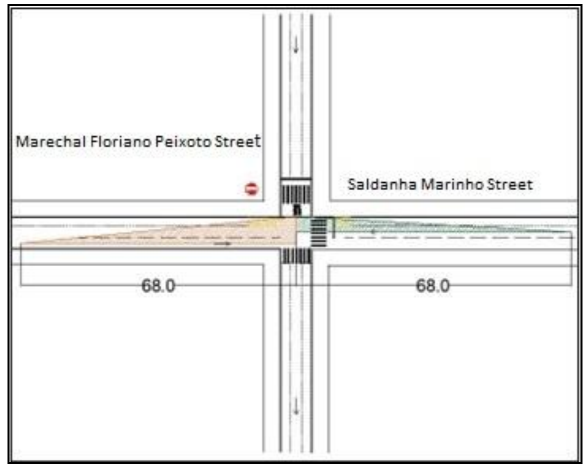

Figure 12. Representation of the triangle visibility of Intersection 3

In the situation of intersection 4, there is only one sight distance, in which $V_{max,p} = 40\ km/h$ e $L = 22.6\ m$. Introducing these values in Abacus 1 yielded a visibility distance of 81 meters, as shown in Figures 13 and 14.

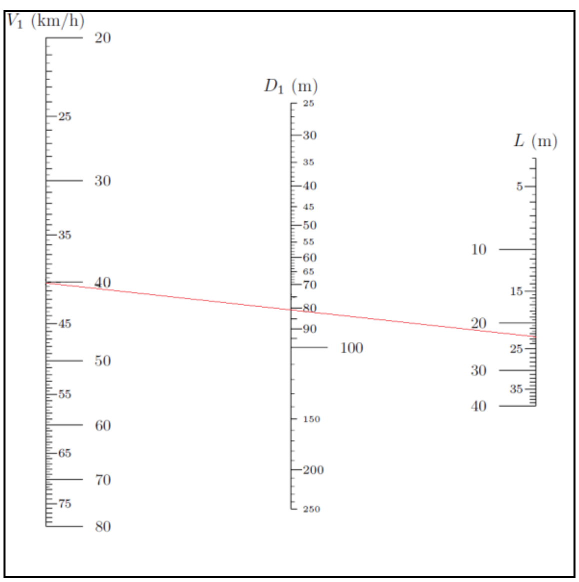

Figure 13. Visibility distance from Intersection 3

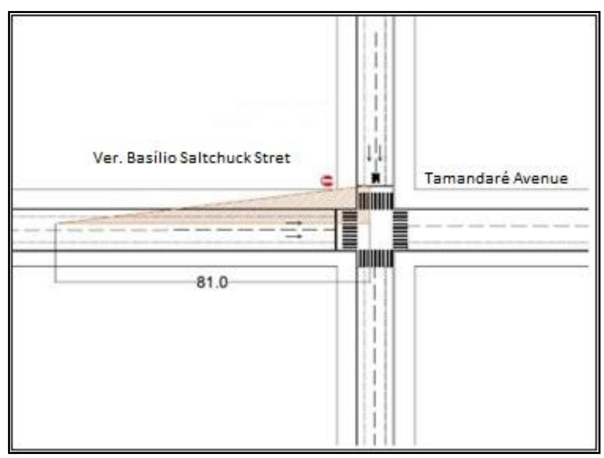

Figure 14. Representation of the triangle visibility of Intersection 3

In the case of Intersection 5, $V_{max,p} = 40\ km/h$, $V_{max,s} = 40\ km/h$, one must $L = 21.9\ m$. Introducing these values in Abacus 2 yielded a visibility distance of 100 meters, as shown in Figures 15 and 16.

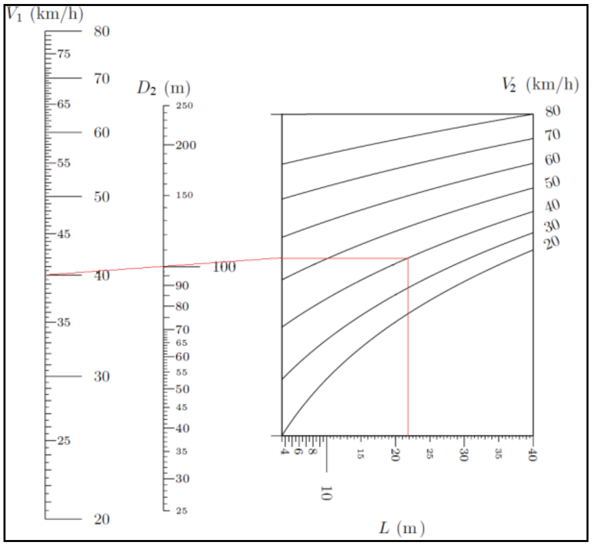

Figure 15. Visibility distance from Intersection 3

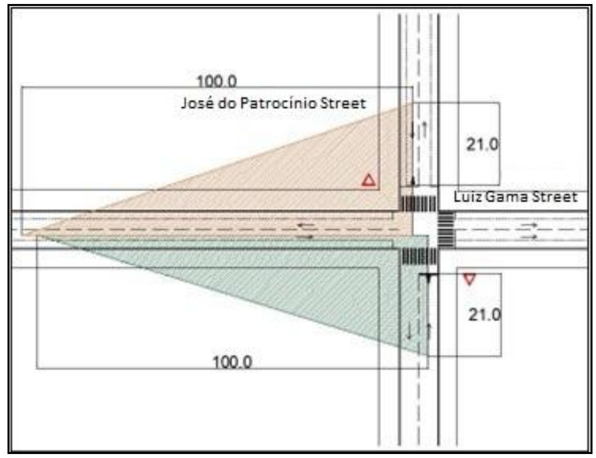

Figura 16. Representation of the triangle visibility of Intersection 3

At Intersection 6, it is known that $V_{max,p} = 40\ km/h$, $V_{max,s} = 40\ km/h$ and one has to $L = 13.4\ m$. Introducing these values in Abacus 1 yielded a visibility distance of 92 meters, as shown in Figures 17 and 18.

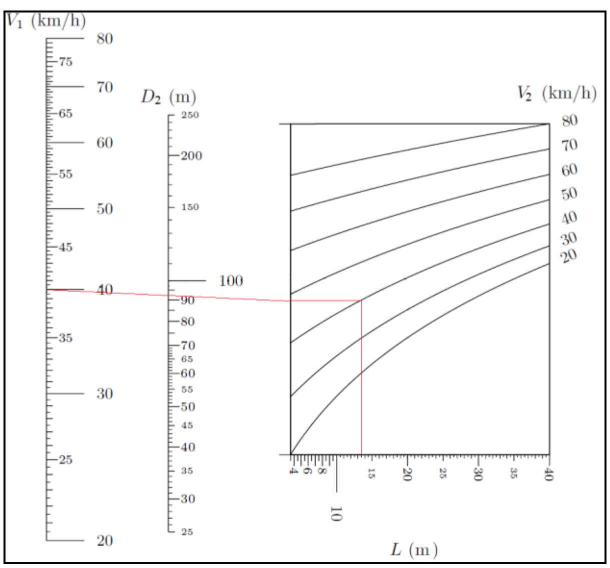

Figure 17. Visibility distance from Intersection 3

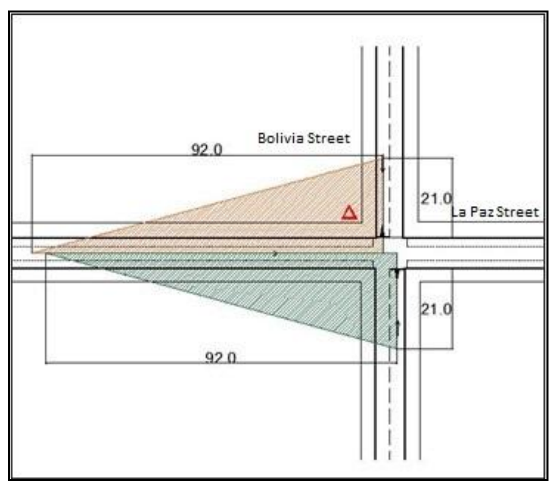

Figure 18. Representation of triangle visibility of Intersection 3

FINAL CONSIDERATIONS

In general, it was noted that all intersections presented interference with their visibility triangle, either from parking lots, trees, or building alignment. In addition, drivers need to be above the crosswalk to have a better view, which, in turn, reduces their safety at the intersection and compromises pedestrian safety. This showed that the lack of visibility at these intersections is a probable cause of the accidents that have occurred. A summary of the results obtained is presented in Table 2.

Table 2 – Interferences in the visibility of the studied intersections

Interferences					
Intersections	Parking spaces	Building Alignment	Lack of signage for speed	Obstruction of vertical signage	Via the local x arterial route
1	X			X	X
2		X		X	
3	X				
4	X		X	X	
5	X	X	X		
6	X	X			

Intersection 1 has the via local with direct access to the arterial route, which is not recommended due to trees obstructing the view of the ‘Stop’ vertical sign and parking spaces interfering with the driver’s perception. At intersection 2, the building alignment and the trees obstruct the driver’s vision. At intersection 3, only parking spaces impair the driver’s visibility. Intersection 4 has a vertical ‘Stop’ sign; the parking spaces obstruct the view of the sign, and there are no speed limit signs, leading drivers to travel faster. At intersection 5, in addition to the lack of signs indicating the maximum speed and parking spaces, building alignment also obstructs decision-making at the intersection. Finally, intersection 6 is obstructed by construction in the building alignment and the parking space.

CONCLUSION

The results showed that the methodology developed in this project yielded higher visibility distance values than those determined by DNIT, resulting in visibility triangles with a larger area. From this, it was found that these values offer greater security to the driver and can be applied more specifically to each case.

Application of the methodology to roads with a high number of accidents in Maringa/PR yielded consistent results and supports the hypothesis that one reason for the significant number of these accidents was the presence of elements obstructing the driver's vision, such as trees, vehicles, and buildings. Also, it was noted that to maintain good visibility, drivers need to be on top of the crosswalk, which compromises the safety of people circulating in these areas.

Given the importance of the subject, it is necessary to continue developing tools that cover roads with different intersection geometries involving four branches, as well as the other possible movements in these places, such as convergence and divergence. If put into practice, the results could lead to fewer accidents in these areas.

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