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Impact of intersection geometry and signage on pedestrian safety for vulnerable users: Analysis using microsimulation, SSAM and VIDA Irap

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Abstract– Pedestrian safety is a critical issue affecting all citizens, especially in urban environments where the interaction between vehicles and pedestrians is constant. One of the major factors contributing to pedestrian insecurity are risky behaviors, which are often performed without thinking about the consequences. Crossing the street while distracted, not respecting traffic signals, walking in the road, or crossing the street in unauthorized places are common practices that increase the probability of accidents. Imprudent pedestrian habits generate unnecessary risk for all road users. Specifically, the analyzed intersection, characterized by high pedestrian flow (proximity to a hospital and a school), presents an elevated risk and compromises the safe mobility of vulnerable users due to infrastructure deficiencies and signage. Four scenarios were evaluated to improve pedestrian safety at the critical intersection, starting with Case 1 (baseline) which represented the current configuration. This baseline scenario, characterized by basic pedestrian crossings and limited signage, generated the highest number of conflicts and the lowest safety level according to iRAP. Case 2 introduced specific traffic signal improvements and adjustments to pedestrian crossing times, achieving a slight reduction in conflicts. Subsequently, Case 3 reinforced these measures by incorporating physical infrastructure such as refuge islands, wider sidewalks, and improved visibility, reaching an intermediate safety level. Finally, Case 4 (optimal scenario) integrated an exhaustive combination of interventions to maximize safety. These measures included the addition of an extra pedestrian crossing, expanded refuge islands, reduced turning radius, exclusive lanes, and complete signage.

Keywords-- Pedestrian safety, safety, geometric design, signaling, microsimulation, PTV VISSIM, SSAM, VIDA iRAP.

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Impacto de la geometría de las intersecciones y la señalización en la seguridad de los peatones vulnerables: Análisis mediante microsimulación, SSAM y VIDA Irap.

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Abstract*— Pedestrian safety is a critical issue affecting all citizens, especially in urban environments where interaction between vehicles and pedestrians is constant. One of the biggest contributing factors to pedestrian insecurity is risky behavior, often performed without considering the consequences. Distracted crossings, disregarding traffic signals, walking in the roadway, or crossing the street in unauthorized areas are common practices that increase the likelihood of accidents. Reckless pedestrian habits create unnecessary risk for all road users. Specifically, the intersection analyzed, characterized by high pedestrian traffic (proximity to a hospital and a school), presents a high risk and compromises the safe mobility of vulnerable users due to deficiencies in infrastructure and signage. Four scenarios were evaluated to improve pedestrian safety at the critical intersection, beginning with Case 1 (baseline), which represented the current configuration. This baseline scenario, characterized by basic crossings and limited signage, generated the most conflicts and the lowest safety level according to iRAP. Case 2 introduced targeted traffic signal improvements and adjustments to crossing times, achieving a slight reduction in conflicts. Subsequently, Case 3 reinforced these measures with the addition of physical infrastructure such as refuge islands, wider sidewalks, and improved visibility, reaching an intermediate level of safety. Finally, Case 4 (the optimal scenario) integrated a comprehensive combination of interventions to maximize safety. These measures included the addition of an extra pedestrian crossing, enlarged refuge islands, a reduced turning radius, dedicated lanes, and complete signage.

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I. INTRODUCTION

Pedestrian safety is a fundamental aspect of urban road design, especially at intersections, where there is a high level of interaction between pedestrians and vehicles. These areas present a significant risk to the most vulnerable users of the road system, such as children, the elderly, and people with reduced mobility, who have lower physical capabilities and require safer crossing conditions to avoid accidents [1]. Various studies have demonstrated that the geometric redesign of infrastructure is an effective strategy for mitigating these risks, allowing for the elimination of conflict points and the optimization of traffic flow through grade separations or the physical separation of users [2]. However, the unchecked growth of motorized traffic has generated "barrier effects" that reduce pedestrian accessibility by up to 70%, increasing the risk of social exclusion by limiting their safe access to essential services [3].

The severity of accidents involving vulnerable users is influenced by geometric design factors and seasonal variations that are often ignored in traditional planning [4]. Furthermore, recent studies underscore the need to incorporate a gender perspective into urban planning, given that women and girls experience a significantly greater perception of insecurity due to deficiencies in lighting and signage at crossings [5]. The effectiveness of interventions depends largely on understanding pedestrian behavior, as pedestrians make crossing decisions by weighing factors such as waiting time, perceived risk, and potential penalties [6]. For specific groups such as children, the use of visual signage on the ground and bollards has been shown to attract their frontal attention, improving their awareness of the road environment [7]. However, safety is compromised in environments with high lateral activity and bus stops, where the variability of vehicle speed acts as a determining risk factor [8]. Given the complexity of modern urban environments, technological advances allow for the rigorous and preventative evaluation of the impact of interventions. Microsimulation tools, particularly the PTV VISSIM software, allow for the accurate replication of real-world traffic conditions and the individual behavior of traffic officers, providing a fundamental basis for sustainable planning [9]. Integrating these models with surrogate safety assessment analysis (SSAM) enables the identification of potential conflicts using indicators such as Time to Collision (TTC), achieving accident predictions with over 90% accuracy [10]. Additionally, the use of the iRAP methodology, through the VIDA software, provides an objective risk assessment using a star rating system, facilitating the implementation of low-cost, high-impact countermeasures to protect the most vulnerable road users [11].

In this context, this research proposes to analyze the impact of intersection geometry and signage on the safety of vulnerable pedestrians. The study employs a comprehensive approach that combines traffic microsimulation, conflict analysis using SSAM, and pedestrian risk measurement using the VIDA-iRAP software. The main contribution lies in providing technical evidence on how infrastructure optimization and pedestrian-centered design can transform critical environments into safe, inclusive, and accessible spaces for all citizens.

II. TOOLS

Specialized tools for modeling, analysis and evaluation of pedestrian safety at the intersection were used for the development of the research.

- Data Collection: Manual counting of vehicles and pedestrians, as well as inspection and surveying of existing road infrastructure, to characterize the actual conditions of the study area.
- Microsimulation: Use of PTV VISSIM software to model intervention scenarios and evaluate operational indicators such as waiting times, speeds, and levels of service. It also allowed for the generation of vehicle and pedestrian trajectories for subsequent analysis. The software represents user interaction through individual behavior models, such as car-following and lane-changing, reproducing realistic traffic operating conditions.
- Conflict Analysis: Application of the SSAM (Surrogate Safety Assessment Model) to identify and quantify vehicle-pedestrian conflicts based on the simulated trajectories.
- Safety Assessment: Use of the VIDA iRAP platform for standardized pedestrian risk assessment in each analyzed scenario.

III. METHODOLOGY

The study was developed using a methodology structured in four cases, which represent different geometric design and signage scenarios for the analyzed intersection, from Case 1 to Case 4.

First, the study area was defined, and a detailed analysis of the existing, unmodified intersection was conducted. Traffic counts were recorded, including measuring vehicle speeds 30 meters before the traffic light and evaluating pedestrian crossing times at each approach. Simultaneously, vehicular and pedestrian flows were collected through manual counts during peak hours, and a comprehensive survey of the existing road infrastructure was carried out, including signage, sidewalk condition, and ramps.

Next, a microsimulation model was built using PTV VISSIM software for Case 1, representing the current situation with fixed four-phase traffic light control and no additional signage. This model was calibrated and validated based on the collected real-world data. Subsequently, Cases 2 and 3 were modeled, corresponding to intermediate scenarios in which geometric modifications and signage improvements were progressively incorporated. In each case, simulations were performed in PTV VISSIM to evaluate changes in traffic behavior and pedestrian flow. For each scenario, the Surrogate Safety Assessment Model (SSAM) was applied to analyze potential conflicts, performing a quantitative and qualitative assessment of the number and type of conflicts between vehicles and pedestrians.

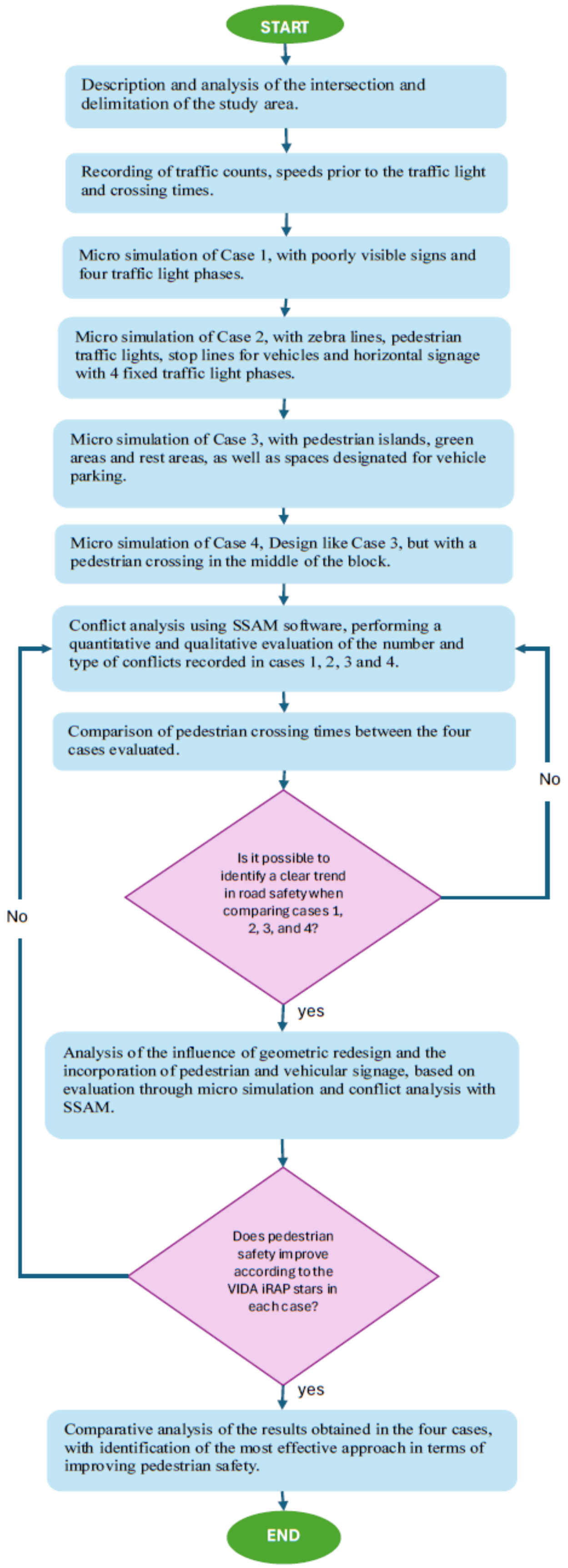
The calibration process of the PTV VISSIM model was performed through the iterative adjustment of key vehicle and pedestrian behavior parameters, such as desired speed, minimum following distance, reaction time, and gap acceptance. For vehicles, using the Wiedemann 74 model, a mean stopping distance of 0.3 was calibrated, with an additive safety component of 3 and a multiplier of 1. For pedestrian behavior, values of 0.20 for Tau, 0.40 for Lambda, and 1.50 for Noise were defined, also incorporating differentiated walking speeds according to user type and crossing times observed in the field.

The model was validated by comparing variables such as traffic flow, travel times, and waiting times, obtaining relative errors of less than 10%, considered acceptable according to the literature. This ensured that the model reproduces the real-world conditions of the analyzed road system.

Finally, in Case 4, the design was simulated, which includes the incorporation of a pedestrian crossing in the middle of the block, comprehensive vehicular and pedestrian signage, as well as relevant geometric adjustments. The results were evaluated with SSAM, and pedestrian crossing times were compared among the four cases.

Additionally, the VIDA iRAP platform was used to quantify pedestrian vulnerability and risks in each scenario, facilitating an objective evaluation of the impact of the geometric design and signage on the road safety of vulnerable users. Figure 1 below details the process.

Fig. 1. Methodological process for pedestrian safety simulation and analysis.



This methodological approach made it possible to identify clear trends and quantify the improvements in pedestrian safety resulting from the proposed interventions, providing valuable technical evidence for the design of safer and more inclusive urban intersections.

IV. APPROACH AND CONTRIBUTION

This research presents an innovative initiative to improve pedestrian safety at urban intersections in Metropolitan Lima, focusing on geometric design specifically for vulnerable users. The intervention aims to optimize the physical configuration of the crossing to reduce conflicts between vehicles and pedestrians, thereby decreasing accidents and improving accessibility and protection for these priority groups.

The study combines advanced techniques such as microsimulation, SSAM conflict analysis, and evaluation with VIDA iRAP, allowing for a detailed quantitative analysis of the impact of the suggested geometric modifications. This integrated approach facilitates the identification of critical points and the technical validation of evidence-based solutions, contributing to decision-making in urban and road planning.

The proposed geometric design (Case 4) was developed from the identification of critical points at the base intersection (Case 1), through vehicle-pedestrian conflict analysis with SSAM and the observation of informal crossings. Its formulation was based on geometric design criteria established in the MTC's DG-2018 Geometric Design Standards, complemented by guidelines from the AASHTO Green Book and the Global Street Design Guide, which informed the definition of turning radio, lane widths, and intersection configurations.

Unlike the current design, Case 4 incorporates an additional pedestrian crossing, the expansion of refuge islands, the reduction of turning radii, and the implementation of dedicated lanes, prioritizing pedestrian safety and improved traffic flow.

A. Projection

It is projected that the implemented geometric design, through the inclusion of elements such as enlarged pedestrian islands, reduced turning radii, and improved pedestrian crossing markings, will significantly reduce the frequency and severity of pedestrian conflicts at the studied intersection. Case 4 aims to improve the experience and safety of vulnerable users, promoting a more inclusive and safer road environment.

B. Quantitative Analysis

The assessment was carried out using dynamic simulations that took into account the actual flows of vehicles and pedestrians, along with the quantification of conflicts using SSAM and the risk assessment with VIDA iRAP. Preliminary results indicate a significant reduction in risk and conflict indicators, validating the effectiveness of geometric design as a preventive measure in urban environments.

V. SIMULATIONS AND ANALYSIS OF PEDESTRIAN SAFETY

A. *Microsimulation with PTV VISSIM*

A microsimulation model was developed in PTV VISSIM to replicate vehicle and pedestrian traffic flow at the intersection, incorporating real traffic count and peak-hour data.

Due to high pedestrian demand caused by the proximity of a hospital and a school, a pedestrian crossing was added in the center of the roadway to facilitate safe crossings and reduce the exposure of vulnerable users to traffic.

Indicators such as waiting times, vehicle speeds, and number of conflicts were evaluated, allowing for the measurement of the effectiveness of the geometric design in pedestrian safety. The model was calibrated with field data to ensure the accuracy of the analysis.

Fig. 2. Plan view of case 4

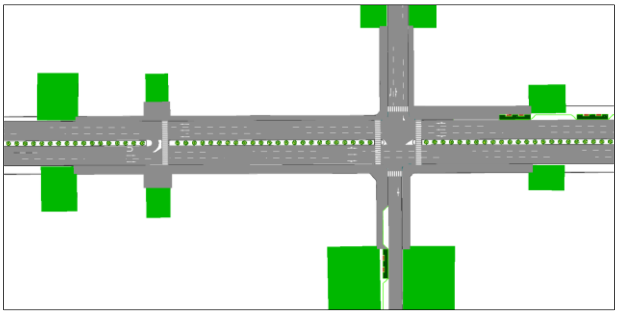


Fig. 3. Active Phase 4 (Pedestrians) – Case 4

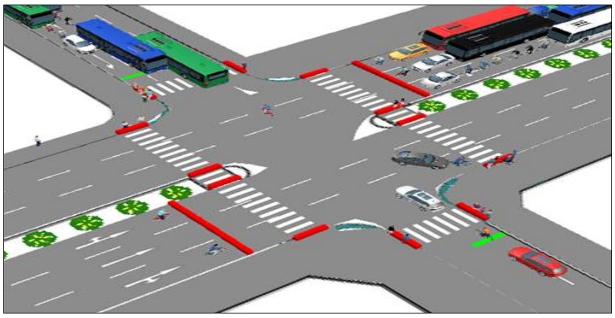
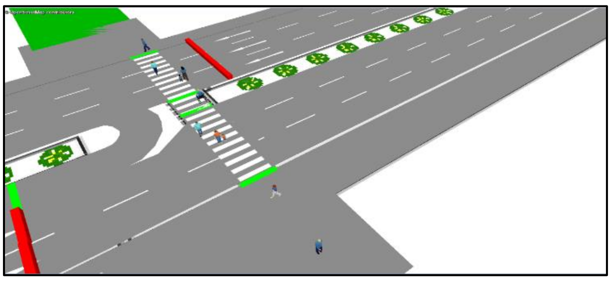


Fig. 4. View of the pedestrian crossing in front of the hospital and school – case 4



B. *Analysis of conflicts with SSAM*

The Surrogate Safety Assessment Model (SSAM) was used to identify and quantify potential conflicts between vehicles and pedestrians based on the trajectories generated in PTV VISSIM.

- Conflict identification: SSAM processes trajectory files containing the position, speed, and time of each user and evaluates interactions using surrogate safety indicators. A conflict is considered to have occurred when critical thresholds are exceeded: Time to Collision (TTC < 1.5 s), which represents the time remaining until a collision under constant conditions, and Post-Encroachment Time (PET < 5 s), which measures the time separation in the use of the same space.
- Conflict Classification: The identified events are classified according to the angle of convergence between trajectories into crossing conflicts (intersecting trajectories), rear-end collisions, and lane changes (lateral interaction), allowing for the characterization of the type of risk present at the intersection.
- Conflict Quantification: The identified conflicts are aggregated to obtain risk indicators. In Case 4, a total of 2,360 conflicts were recorded, of which 1,677 were rear-end collisions, 438 were crossing collisions, and 245 were lane changes, demonstrating a reduction compared to the baseline scenario and allowing for the evaluation of the effectiveness of the proposed interventions.

The total number of incidents between vehicles and pedestrians, broken down by type of interaction, for scenarios 1 and 4 are detailed below. As Table 1 shows, case 4 achieves a notable reduction in the total number of critical events and in each specific category.

Fig. 5. Conflicts of case 01

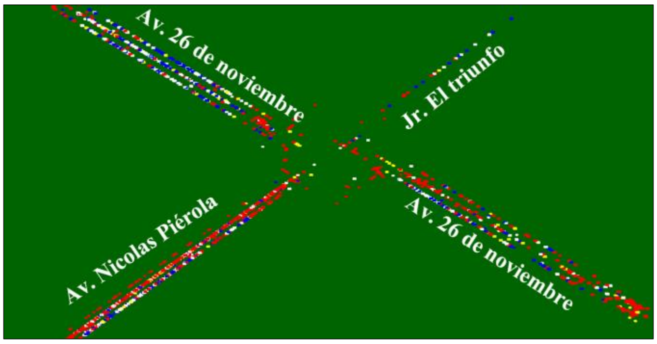


Fig. 6. Conflicts of case 01

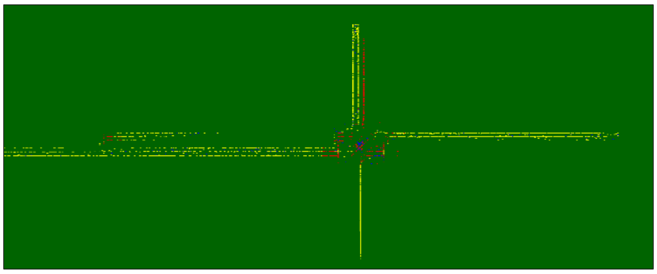


TABLE I. *Vehicle-pedestrian conflicts by type in case 1 and case 4*

Conflict	Crossing	Rear end collision	Lane change	Total
Case 1	2476	2626	395	5497
Case 4	438	1677	245	2360

C. Pedestrian Safety Assessment with VIDA iRAP

Pedestrian safety at the intersection was assessed using the iRAP star rating system, with one improvement measure focused on pedestrian protection. Following the implementation of traffic signals, signage was improved, speed management was optimized, and vehicle speeds were reduced, all of which contributed to greater pedestrian safety.

Fig. 7. Low-standard urban road

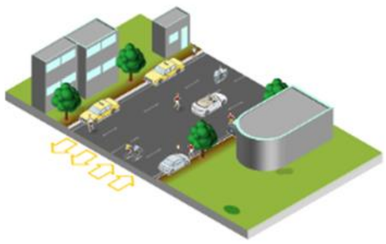


TABLA II. Comparison of the parameters used in Vida Irap.

Data	Low-standard urban road	
Side of the road	Lateral severity-object-driver side	Rigid structure/building or bridge
	Lateral severity - distance to object - passenger side	Rigid structure/building or bridge
	Driver's side shoulder/verge	(>= 1.0 m a < 2.4 m)
	Shoulder/Runway on the passenger side	(>= 1.0 m a < 2.4 m)
characteristics of the road	Curvature	Straight or slightly curved
	Road condition	Well
	Slip resistance	Paved-regular
	Signage	Appropriate
	Public lighting	Present
	Parking for vehicle occupants	Half
	Service road	Half
Intersections	Intersection quality	Appropriate
Flow	% Motorcycles	11% - 20%
Infrastructure for vulnerable users and land use	Pedestrian crossing infrastructure on inspected road	signalized with shelter
	Quality of pedestrian crossing	Appropriate
	Pedestrian crossing infrastructure on secondary road	signalized with shelter
	Fence to contain pedestrians	Present
	Driver's side curb/sidewalk	Physical barrier
	Sidewalk/Cuerpoon on the passenger side	Physical barrier
	Caution sign, school zone	Static signage or horizontal markings in school zones
	School zone crossing guard	School crossing guard present during school entry and exit times
Speeds	Infrastructure for reducing speed (speed bumps, speed reducers, logarithmic lines, etc.)	Present

The pedestrian safety rating improves from 1 star in the current situation to 5 stars in Case 4, demonstrating a substantial increase in the level of protection and comfort for pedestrians.

Fig. 8. Star rating case 04

VI. ANALYSIS OF RESULTS

A. Calibration Times

After implementing the new signaling design, a significant reduction in calibration times was observed at the four access points analyzed. The adaptive cycles allowed for a more efficient response to actual traffic demand, eliminating delays caused by fixed cycles during peak hours. This optimization expedited traffic light changes, reducing unnecessary vehicle stops. Statistically, this improvement is reflected in a decrease in average waiting time per access point, contributing to greater traffic flow and predictability.

B. Pedestrian Crossing Times

The average pedestrian crossing time was reduced by 43.23 seconds, from 197.66 seconds to 154.43 seconds, representing a 21.9% improvement. This reduction optimizes pedestrian comfort, reduces exposure to vehicular risk, and enhances the overall user experience. This increased efficiency also encourages the use of sustainable transportation modes, such as walking, by minimizing waiting times at intersections. From an urban planning perspective, this improvement strengthens active mobility strategies.

C. Validation of case 4

Statistical analysis using Statkey validated the benefits of the design: the confidence intervals for the mean differences ($\mu_1 - \mu_2$) were entirely outside the zero range, and t-tests yielded p-values < 0.05 in almost all cases. This confirms, with 95% confidence, that the observed changes are not due to chance, but rather to the applied intervention. The level of significance achieved provides high internal validity to the study and a solid quantitative basis for recommending the implementation of the new geometric design and signage.

D. Number of Vehicle-Pedestrian Conflicts

Crossing and rear-end conflicts between vehicles and pedestrians were significantly reduced. This decrease indicates improved coordination of crossing times and physical separation between vehicular and pedestrian flows. By eliminating simultaneous crossings at critical intersections, the likelihood of incidents is reduced, thus enhancing road safety. From a quantitative perspective, the frequency of these conflict events decreased significantly, validating the effectiveness of the design as a risk mitigation measure.

E. iRAP LIFE Star Rating

The iRAP assessment showed an improvement from 1 star to 3 stars, representing a two-level increase in design safety. This qualitative improvement is due to key physical enhancements such as increased visibility, pedestrian refuges, and active safety devices. Achieving 3 stars means the infrastructure now meets international road safety standards, contributing to the systematic reduction of deaths and serious injuries at urban intersections. This rating provides technical support for the design as part of an effective policy for protecting vulnerable road users.

F. Discussion of results

The results obtained validate the effectiveness of geometric redesign and technical signaling in protecting pedestrians. First, the model's accuracy in PTV VISSIM aligns with the findings of Abdeen et al., who argue that rigorous calibration is the fundamental basis for sustainable urban planning. Regarding risk mitigation, the reduction of conflicts in Case 4 is consistent with Hussain et al., whose studies demonstrate that the integration of VISSIM and SSAM enables conflict prediction with over 90% accuracy.

Furthermore, the effectiveness of geometric modifications in eliminating friction points aligns with the findings of Cantisani et al., who emphasize that redesign centered on flow separation optimizes road safety. Finally, the increase from 1 to 5 stars via the VIDA software corroborates the findings of García-Ramírez et al., confirming that the iRAP methodology allows for the implementation of high-impact countermeasures to protect the most vulnerable users.

G. Limitations of the study

The study has limitations related to the analysis of a single intersection with specific characteristics of high pedestrian demand, which restricts the generalizability of the results to other urban contexts. Furthermore, microsimulation and the use of surrogate models such as SSAM depend on calibrated parameters and thresholds (such as TTC and PET), which may not fully capture the variability of real-world behavior or replace historical accident data. Additionally, factors such as temporal variations in demand or external conditions were not considered. Nevertheless, the methodology applied provides a replicable technical basis for evaluating pedestrian safety at intersections with similar conditions.

VII. CONCLUSIONS

Based on the analysis carried out and considering each specific objective set out in this research, the following conclusions are reached:

(1) The analysis of case 1 showed high waiting times for both vehicles and pedestrians, reflecting operational deficiencies mainly associated with rigid and inadequate traffic light cycles.

(2) The simulation of case 1 allowed the identification of high levels of vehicle-pedestrian conflicts, clearly highlighting the need for specific interventions to reduce these critical events.

(3) The geometric design and signage of case 4, validated by simulation, generated significant improvements, highlighting the considerable reduction of vehicle-pedestrian conflicts due to a safer distribution of traffic light phases.

(4) The proposed geometric adjustments, including refuge islands, zebra lines, and accessibility improvements, proved effective in improving both pedestrian safety and vehicular traffic flow.

(5) The simulations carried out in VISSIM, corroborated with statistical analysis using Statkey, confirmed that the reduction of vehicular and pedestrian waiting times is statistically significant, validating the technical effectiveness of case 4.

(6) Statistical analysis confirmed that the observed improvements are not a product of chance, thus ensuring that the design benefits have a high level of confidence and methodological rigor.

(7) The application of SSAM revealed a considerable reduction in the number and severity of vehicle-pedestrian conflicts after implementing case 4, highlighting a notable improvement in road safety.

(8) The rating obtained through VIDA iRAP increased from 1 star to 5 stars, demonstrating that the interventions carried out meet the international standards recommended for safer urban roads.

GRATITUDE

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