Hazard exposure of bicyclists at urban intersections

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***Abstract*— Traditionally, mobility problems and automobile traffic congestion have increased in cities around the world due to the urban development process, especially in the city of Metropolitan Lima. For this reason, the government of the Peruvian capital has established temporary detours in certain sections of the arterial roads of the network, to invite new cyclists, due to the effects of Covid-19. Today, Lima has a network of 294 km of bicycle lanes, which have been implemented without adequate planning. In view of this, we evaluated the risk of poor planning on the vulnerable user (the cyclist) at an intersection of this road network, with a high rate of motorized congestion. The main objective of this study has been to propose corrective actions to avoid the exposure to danger on the users of the bicycle lane (countermeasures); due to lack of safety at the intersection of La Marina Ave. and Universitaria Ave. In this sense, a risk matrix was developed with the most concurrent factors that occur at this intersection; to then obtain a risk level and take actions in each of them, to mitigate the impact. The result obtained in the analysis of this study for the intersection is classified as a level 2 risk: Important risk, which means that it presents several important danger factors. Finally, in addition to the analyses developed, a treatment scheme was proposed for the intersection to provide greater safety to the users of the bicycle lane, avoiding fatal and non-fatal accidents.**

Keywords—: exposure, danger, urban road safety, countermeasures, risk matrix cyclists, bicycle lanes, bicycle accidents.

I. INTRODUCTION

The increase in the number of cyclists, whether for leisure, recreation or eventual use in recent years has caused a concern for their safety. Studies have been carried out in different countries where the importance of the implementation of a bicycle lane network in urban areas is evidenced, as well as how to correct the problems that arise from the encounter between motor vehicles and users of the bicycle lane, mostly presented at intersections. New approaches are sought to understand and modify urban problems. Articles that support this research topic identify the risks to cyclists, and then propose treatments to reduce the exposure to danger [1].

In a research conducted by G Pesshana et al. (2020), it mentions that in Rio de Janeiro, bicycle travel has increased, since it has bicycle lanes built for more than 30 years and preserved for the safe use of the population. Therefore, a methodology was developed to propose a viable bikeway evaluation index (IBC) that serves as a tool for municipal administrators to diagnose and monitor the quality of bikeway infrastructure in an urban environment [2]. Similarly, the authors Alshehri et al. (2020), using a binary logistic regression model, analyze the factors involved

The main objective of this study is to determine the factors that contribute significantly to the severity of these accidents [3]. The General Controller's Office of the Republic of Peru carried out a Control Report, with the purpose of verifying and evaluating whether the implementation of bicycle lanes was developed in accordance with the Work Plan for Cycle Lanes 2020 and the technical legal provisions in force. The Metropolitan Institute of Planning and the Submanagement of Study, Regulation and Road Safety, confirms an inadequate planning of the cycle road infrastructure in the implementation of the 46 km of temporary bicycle lanes; due to the lack of studies of vehicular flows, traffic and / or transport [4].

The objective of this study is to develop and propose corrective actions on the evaluation of accidents at the intersection under study, which can be used as a practical tool by municipal authorities and transportation planners, traffic engineers and others. A treatment scheme will be proposed to avoid vehicular and cyclist congestion at the intersection.

II. INPUT

A. Tools

A.1. Dangerousness Index Traffic Light Phase

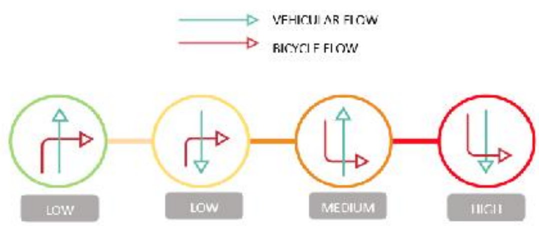

Fig 1. Main conflicts at signalized intersections according to scale of danger, adapted from the Guide to the Composition and Operational Design of Cicling.

A.2. Risk Method with Weighting Matrices.

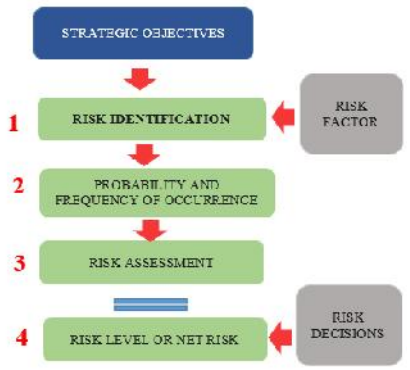

Fig 2. Phases of the elaboration of a risk matrix. Adapted from the Chilean Risk Prevention Experts Portal.

B. Methodology

The tools to take actions and reduce the exposure of cyclists to danger are focused on the evaluation with a **danger index and the elaboration of a risk matrix** in the studied intersection, to then propose **corrective urban road safety measures (countermeasures)**.

Data collection was carried out through virtual surveys of users of the bicycle lane, which intercepts the intersection of Avenida La Marina and Avenida Universitaria, in addition to the record of police statistics on traffic accidents in the area, obtained by the San Miguel district police station, in order to develop a statistical and quantitative analysis.

After that, to be able to perform an operational evaluation by means of a Risk Matrix and a Danger Index, to identify the factors that endanger the users of the bicycle lane. Knowing the current situation, risk treatments are proposed based on the results in terms of safety, conflicts and comfort, in order to mitigate fatal and non-fatal accidents between motor vehicles and cyclists.

C. Data collection

C.1. Location of the intersection to analyze

The intersection of Av. Universitaria block 24 - Av. de la Marina block 16 belongs to the end of the Pershing - La Marina temporary bicycle lane that starts from Av. Salaverry. This has a total length of 3.8 km and is part of the 46 km of temporary bicycle lanes implemented during 2020 by the Municipality of Lima.

Fig. 3. Permitted turns at the intersection of the bicycle lane (Av. Universitaria at 24th block - Av. de la Marina at 16th block).

C.2. Statistical Collection

a) Police Reports

The collection of police data on traffic accidents involving bicycles and motor vehicles helped us to define the intersections with the greatest conflict along the Pershing and Marina avenues. These data were obtained through a letter of request to the National Police of Peru (PNP) approved by the person in charge of the San Miguel police station. Figure 4 shows the area distribution involving the San Miguel PNP Police Station, which involves the intersection of the Pershing-La Marina bicycle path under study.

Fig. 4. Map of the area involving the PNP San Miguel Police Station.

b) Virtual Surveys

A survey was carried out with the users of the Pershing-La Marina Av. bicycle path to collect their opinions on the exposure to danger they perceive on a daily basis along the entire stretch of the path. This survey was based on questions about how often they ride on the road, if they have witnessed any type of accident, how many hours and number of trips they make per day, what factors they believe cause accidents on the bicycle path, and the perceived safety when riding on the bicycle path. To this end, the number of samples for the elaboration of the surveys was calculated: N (population) was found by means of equations 1, 2 and 3.

$$Nj =_4 X \sum_i \frac{n_i}{v_i} \qquad Ec.1$$

Donde:

X= Length in km of the cycle path

ni= Total number of people counted by each runner and by activity

vj= Own speed of each group in km/h.

For equation 1, the following assumptions and requirements are noted:

- Aphorists will be randomly located along the intercept road and in each corridor pathway.
- The length of the corridors will be sufficiently long, so that a person will not be counted (gauged) more than twice during the counting time.
- A characteristic speed is assigned to each activity: bicycle (10 km/h), electric bicycle (24 km/h), electric scooter (15 km/h), skateboard (7.5 km/h).
- It is necessary to know the distance of the bikeway circuit (Pershing-La Marina bikeway 3.8 km).

The counting time was defined for this research during the first 15 minutes of each hour of service, which was in the morning (7:30 to 7:45). Two people located one in front of the other are in charge of counting by corridor and type of users of the bicycle lane. Likewise, the schedule with the highest number of users is chosen, and then the number of people per corridor is estimated, using the sum of Nj found (Equation 1). The result is detailed in Table 1.

TABLE I.

Highest count during 15 minutes of users of the Pershing-Marina bicycle lane at each point evaluated..

Turn	Schedule	Bikes	Electric Bicycle	Electric Scooter	skateb oard	Nj
Morning	7:30- 7:45	11	0	2	3	95
		37	11	13	0	

For the estimation of the total number of users at the time of counting. Equation 2 will be used:

$$= \sum_{i} N_j \qquad Ec. 2$$

Where:

M = Estimator of the total number of people at the time of count.

Nj = Number of people per point (found in Table 2).

Where M is equal to the sum of Nj equal to 95.

The maximum number of users during the total day of the bicycle lane is estimated by taking into account that the number of hours the bicycle lane is used during the day is 18. Equation 3.

$$P_{max} = K \times M = 18 \times 95 = 1710 \text{ user} \qquad Ec. 3$$

Where:

K = Number of hours the cycle path lasts.
M = Estimator of the total number of people at the time of counting.

Finally, the calculated values are replaced in Equation 4 to calculate the sample number:

$$n = \frac{Z^2 \times p \times q \times N}{e^2(N-1) + Z^2 \times p \times q} \qquad Ec. 4$$

Where:

n= Sample
Z= Confidence level (5%)
p= Population in favor
q= Population against
N= Population
E= Sample error

$$n = \frac{1.95^2 \times 0.5 \times 0.5 \times 1710}{0.095^2 \times (1710-1) + 1.95^2 \times 0.5 \times 0.5} = 99.17$$

$$n = 100 \quad sample$$

With the equation obtained, it was determined the approximate number of 100 samples needed to carry out the surveys, with a correct estimation of variables and required parameters. Next, one of the most important statistics of the surveys conducted will be shown:

- **Factors that are causative of accidents on the bicycle lane**

At this point according to the results of the surveys conducted, the factors mentioned are: Characteristics of barriers and signage within the bikeway, sex of cyclist, high levels of traffic flow, weather conditions, the time of day and position and infrastructure of the bikeway; which, represent 38%, 1%, 28%, 19%, 11% and 8% respectively, as shown in the following pie chart Fig. 5.

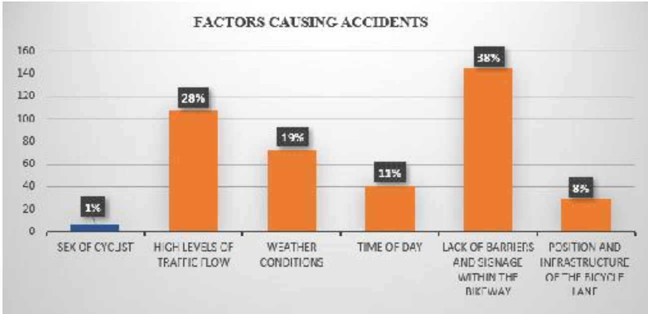

Fig. 5. Statistics on factors endangering cyclists on the Pershing-Marina bikeway based on surveys.

III. ANALYSIS

Based on the police statistics provided by the PNP Police Stations of San Miguel, we proceeded to identify the critical intersections along the Pershing-Marina bikeway in stages within June 1, 2020 to June 1, 2021. Once the percentages of accidents occurred were identified, it was concluded:

TABLE II.

Pershing- de La Marina Bikeway conflict point.

POINTS OF CONFLICT	
STAGE 1	
Av. De la Marina cuadra 17 con Av. Universitaria cuadra 24	44%

A. *Dangerousness Index*

A.1. ANALYSIS OF SIGNALIZED INTERSECTIONS IN CRITICAL AREAS

The analyzed intersection is the critical point identified as a result of the location of the implemented bicycle lane. First, the turns in motion of motor vehicles that conflict with the flow of cyclists are identified as shown in Fig. 6. After that, a score is assigned in relation to the danger scales for signalized intersections (High: 3 points, Medium: 2 points, Low: 1 point).

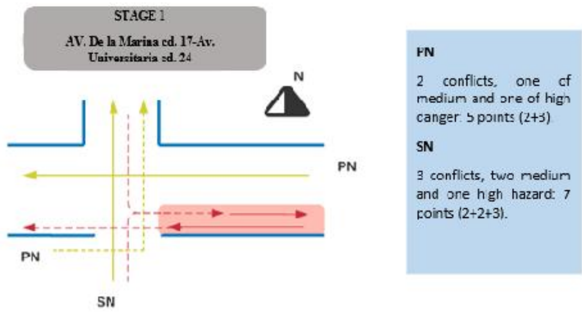

Fig. 6. Representation of turns at the intersection (Av. de la Marina cdra. 17 - Av. Universitaria cdra. 24

Finally, the sum of the scores obtained per intersection will correspond to the PI, being the intersection with the highest score the highest level of danger. For the present, the analyzed intersection is a critical point of the Pershing-

Marina bicycle lane. A summary table of the numerical result of the **IP of the bicycle lane** is detailed below.

TABLE III.

Representation of conflicting turns and danger score of the bidirectional Pershing-Marina bike lane.

	CONFLICT TURNS	DANGER SCORE
PN	2 conflicts, one of medium hazard and one of high hazard.	2 +3 =5
SN	3 conflicts, two of medium hazard and one of high hazard.	2+2+3=7
PN	2 conflicts, one of medium hazard and one of high hazard.	2 +3 =5
	TOTAL	17

B. Risk matrix

The implementation of the risk matrix has been carried out with the objective of determining which are the relevant threats to the safety of the users of the Pershing-Marina bicycle path; which involves the intersection to be analyzed (Av. La Marina with Av. Universitaria). The analysis of the matrix serves as an indicator of the level of risk that occurs daily, in order to use the results to propose concrete actions to reduce it and estimate an impact of continuous improvement. The frequent risks that occur in users of the bicycle path are the following.:

- Presence of accidents that physically harm the cyclist due to the central location of the berm on the road.
- Invasion of the bicycle lane by linear motorcycles, which violates the safety of the cyclist's free transit.
- Lack of horizontal and vertical signage at intersections where cyclists and motor vehicles meet.
- Lack of maintenance of bicycle lanes.
- Recklessness of vehicle drivers towards cyclists at intersections to gain passage.
- Weather conditions.

TABLE IV and TABLE V show the levels of Impact and Probability of occurrence, respectively, of the risks that occur in the section of the bicycle lane analyzed (Pershing-Marina).

TABLE IV.

Table of Probability and Impact for risk analysis.

IMPACT TABLE

LEVEL	DESCRIPTOR	DESCRIPTION
5	Very High	If such an event were to occur, it would have disastrous consequences or effects on the quality of the product, service or process.
4	High	If the event were to occur, it would have high consequences or effects on the quality.
3	Medium	If the event were to occur, it would have medium consequences or effects on the quality of the product or service.
2	Low	If the event were to occur, it would have a low impact or effect on the quality of the product service, or process.
1	Very Low	If the event were to occur, it would have minimal consequences or effects on the quality of the product service, or process.

TABLE V.

Frequency or Probability of Occurrence of Accidents in the risk matrix.

		GRAVITY (IMPACT)				
PROBABILITY		VERY LOW 1	LOW 2	MEDIUM 3	HIGH 4	VERY LOW 5
VERY HIGH	5	5	10	15	20	25
HIGH	4	4	8	12	16	20
MEDIUM	3	3	6	9	12	15
LOW	2	2	4	6	8	10
VERY LOW	1	1	2	3	4	5

B.1. Analysis of the Risk Matrix in the section involving the intersection.

RISK MATRIX

	RISKS	Probabilidad (Ocurrencia)	Gravedad (Impacto)	Valor del Riesgo	Nivel de Riesgo
Av. De la Marina cuadra 17 con Av. Universitaria cuadra 24	Presence of accidents that physically harm cyclists due to the central location of the berm on the road	3	3	9	Importante
	Invasion of the bicycle lane by linear motorcycles, which violate the safety of the cyclist's free transit	4	5	20	Muy grave
	Lack of horizontal and vertical signaling at intersections where cyclists and motor vehicles meet.	4	3	12	Importante
	Lack of maintenance of bicycle lanes.	2	3	6	Apreciable
	Recklessness of vehicle drivers towards cyclists at intersections in order to gain the right of way	5	4	20	Muy grave
	Weather conditions	2	3	6	Apreciable

Fig. 7. Evaluation of the risk matrix at the intersection of Av. Universitaria with Av. La Marina.

IV. Results

Regarding the **Danger Index**, the aim is to avoid conflicts in high danger intersections considered as very dangerous, avoiding cyclist turns directed towards the vehicular flow. Likewise, the representation of danger scores is 17 points for the bidirectional Pershing-Marina bicycle lane, which is considered a dangerous zone.

The Matlab program was used as a tool to facilitate the analysis of risks in bicycle path intersections; using as data: the probability of occurrence and severity of the impact of the intersection Av. de la Marina cdra. 17 - Av. Universitaria cdra. 24.

```
Command Window
INGRESE EL NUMERO DE RIESGOS: 6

INGRESE LA PROBABILIDAD DEL RIESGO N° 1 : 3
INGRESE LA PROBABILIDAD DEL RIESGO N° 2 : 4
INGRESE LA PROBABILIDAD DEL RIESGO N° 3 : 4
INGRESE LA PROBABILIDAD DEL RIESGO N° 4 : 2
INGRESE LA PROBABILIDAD DEL RIESGO N° 5 : 5
INGRESE LA PROBABILIDAD DEL RIESGO N° 6 : 2

INGRESE LA IMPACTO DEL RIESGO N° 1 : 3
INGRESE LA IMPACTO DEL RIESGO N° 2 : 5
INGRESE LA IMPACTO DEL RIESGO N° 3 : 3
INGRESE LA IMPACTO DEL RIESGO N° 4 : 3
INGRESE LA IMPACTO DEL RIESGO N° 5 : 4
INGRESE LA IMPACTO DEL RIESGO N° 6 : 3
```

Fig. 8. Placement of probabilities and impacts of each risk belonging to the intersection.

Then we obtained as a result the risk value (R), the risk level (Rt) shown in Fig. 9:

.

```
Command Window
R =

     9
    20
    12
     6
    20
     6
```

```
Rt =

  6x1 cell array

    'IMPORTANTE'
    'MUY GRAVE'
    'IMPORTANTE'
    'APRECIABLE'
    'MUY GRAVE'
    'APRECIABLE'
```

Fig.9. Results of the risk value (R) and risk level (Rt) of the intersection

Finally, an average risk (Rprom) of 12 was obtained for the intersection, represented as a significant risk as shown in Fig. 10 (Matlab) and Fig. 11 (Excel).

Fig. 10. Average result of the intersection according to its risks.

Fig. 11. Average risk level evaluation using Excel for the conflict point of Av. Universitaria - La Marina.

In light of the results, it is necessary to take corrective actions to help reduce this conflict that endangers the users of the bicycle lane who travel daily through that intersection.

In addition, according to the results of the matrix analysis, risk measures were evaluated for the different points that occur frequently at the intersection, and then the values of each measure were taken according to their level and actions were proposed to reduce the danger at that specific point..

TABLE 6 shows the preventive actions that are foreseen for each risk that occurs at the analyzed intersection. Pershing Avenue - La Marina is a **protected bicycle lane** because it has bollards that separate the vehicular lane from the bicycle lane. Therefore, we are implementing elements that will help us to carry out corrective actions at the intersections to reduce the risk..

The corrective actions for each risk at each point of conflict are shown below.

TABLE VI.

Acciones Correctivas de las Medida de Riesgo en la Av. De la Marina cuadra 17 con Av. Universitaria cuadra 24

Av. De la Marina cuadra 17 con Av. Universitaria cuadra 24				
RIESGO	**P**	**I**	**Medida del riesgo**	**Acciones Correctivas**
Presence of accidents that physically harm cyclists due to the central location of the berm on the road.	**3**	**3**	Avoid	Implementation of traffic lights per lane and refuge islands to react to possible risks.
Invasion of the bicycle lane by linear motorcycles, which violate the safety of the cyclist's free transit.	**4**	**5**	Avoid	Reinforce the separation between the bicycle lane and the vehicle lane or penalize those who invade the cyclists' lane.
Lack of horizontal and vertical signaling at intersections where cyclists and motor vehicles meet.	**4**	**3**	Assume	Implement vertical and horizontal signage at intersections to reduce stress on cyclists and facilitate crossing an intersection.
Lack of maintenance of bicycle lanes.	**2**	**3**	Assume	Periodic maintenance of the pavement and signals where they are deteriorated, to avoid and perceive future accidents.
Recklessness of vehicle drivers towards cyclists at intersections in order to gain the right of way.	**5**	**4**	Avoid	High visibility crossing markings at intersections to help control intersections.
Weather conditions.	**2**	**3**	Assume	Implementation of horizontal signage, retro-reflective striping on the bikeway roadway, and delineator posts.

TABLE VI shows the preventive actions foreseen for each risk at the intersection analyzed. Pershing Avenue - La Marina is a protected bicycle lane because it has bollards that separate the vehicular lane from the bicycle lane. Therefore, we are implementing elements that will help us to carry out corrective actions at the intersections to reduce the risk.

C. Proposed Treatment for the Mitigation of Fatal and Non-Fatal Accidents Involving Bicyclists - Motor Vehicles.

After operationally analyzing the bikeway involving the Pershing-Marina bikeway in the area of cyclist safety; obtaining statistical information with police reports and virtual surveys regarding cyclist safety; and finally analyzing the conflicts that occur on the Pershing-Marina bikeway. In light of this, treatments will be proposed to mitigate accidents between bicyclists and motor vehicles, allowing for improved protection and prioritization of bicyclist safety at intersections. Providing confidence, visibility and comfort to cyclists when traveling on the Pershing-Marina bikeway.

Fig. 12 shows the schematic of the intersection in the state analyzed, how the bikeway works in a bidirectional manner in the east-west vehicular lane.

Fig. 12. Diagram of the current state of the intersection of Av. De la Marina block 17 with Av. Universitaria block 24.

In Fig. 13, the scheme of the proposed intersection of Av. La Marina block 17 with Av. Universitario block 24 is shown, how the bicycle lane would function in a unidirectional manner circulating in the direction of vehicular flow, without causing danger to cyclists and pedestrians, including horizontal and vertical signaling as well as the indications of the traffic lights.

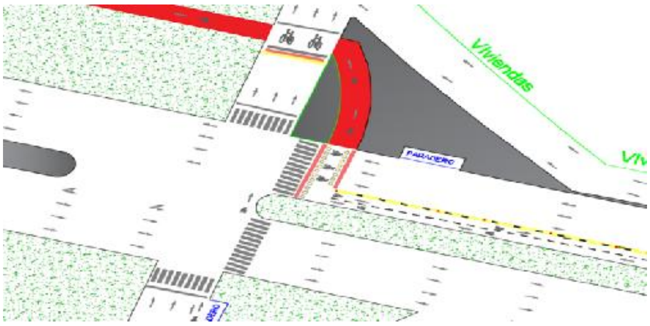

Fig. 13. Diagram of the proposed condition of the intersection of Av. De la Marina block 17 with Av. Universitaria block 24.

V. CONCLUSIONS

The danger index obtained for the Pershing-Marina bicycle path (Av. de la Marina block 17 with Av. Universitaria block 24) was 17 points, considering 3 conflicts in the dangerous intersection, for which it is considered as very dangerous (see TABLE N° III) and which should be reduced with the proposed scheme and corrective measures of this article.

At the intersection of Av. La Marina block 17 with Av. Universitaria block 24, a level of 2 was obtained, meaning an Important Risk (see Fig.10 and 11) according to the analysis of the risk matrix, where six concurrent risks were identified that exist in the avenue according to the police record until 2020 and surveys carried out, therefore corrective actions are proposed to improve and avoid each of the risks.

The proposed design scheme will help improve the operation of the Pershing-Marina bicycle lane (see Fig. N°13) at the intersection considered as a critical point. This proposal includes horizontal and vertical signage, physical separation, islands and traffic signals exclusively for cyclists. This will help counteract the 35% accident rate recorded by the Peruvian National Police on the Pershing-Marina bicycle path. The treatment will also increase cyclist safety and confidence when using the Pershing-Marina bikeway.

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