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ROAD ANALYSIS OF THE NATIONAL HIGHWAY PE-1S IN TACNA: EVALUATION OF A GRADE-SEPARATED INTERCHANGE TO MITIGATE TRAFFIC CONGESTION

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Abstract: This research aims to conduct a road analysis of the national highway PE-1S that crosses the urban area in the city of Tacna, focusing on the evaluation of a grade-separated interchange as a solution to traffic congestion. Using Synchro software, traffic flows are examined, and strategies are identified to optimize circulation in an urban environment characterized by a growing number of vehicles. Congestion in Tacna, exacerbated by deficiencies in signage and the geometric design of intersections, negatively impacts the quality of life of drivers and vehicle performance. This research proposes the construction of a grade-separated interchange by lowering the national highway, which is expected to improve the level of service to grade A, allowing for more efficient vehicle flows. The research is based on traffic counting methods and road analysis, providing a solid foundation for decision-making in road infrastructure. Through a comprehensive approach, the aim is not only to improve infrastructure but also to manage traffic effectively, thereby addressing both current and future congestion issues in the city of Tacna.
Keywords: Road analysis, Synchro software, Overpass, Traffic congestion, Vehicle flow analysis, and Level of service.

Introduction

According to previous research, [1]Traffic congestion has become a critical challenge for many cities in Latin America, and Tacna is no exception. Globally, cities such as Bogota and São Paulo are recognized for their high congestion rates, which reflects a worrying pattern in urban growth and the increase in the vehicle fleet [2]. In Peru, the economic development of the last decade has driven a notable increase in the number of vehicles in circulation, generating serious congestion problems in several cities, including Tacna [3]. This phenomenon not only affects mobility, but also has an impact on the quality of life of citizens, who face long waiting times and frustrations in the driver on a daily basis. In Tacna, the intersections of the PE-1S national highway present critical conditions, where the deficiency of the asphalt layer, poor geometric design and inadequate signage contribute to a chaotic traffic environment. These conditions not only impact vehicle performance, but also increase fuel consumption and wear and tear on cars, generating a domino effect that affects both drivers and the transportation system as a whole.

This research proposes to analyze the level of service at the key intersections of the city, specifically in Av. A.B. Leguía and Av. Gregorio Albarracín, using Synchro Trafficware software as the main tool. As he states, the [4]Road analysis is a methodology that allows evaluating the movement of vehicles and developing strategies to improve traffic management, using CFI type crossings with respect to delay due to detention [5]. Traffic service quality is assessed at the microscopic level using the speed ratio (SR), speed variation coefficient (CV) and congestion index (CI) from vehicle speed [6]

To ensure an adequate level of service, it is essential to control the volume of traffic and plan an infrastructure that balances demand with track capacity, [7]therefore, an adequate road infrastructure must be planned, taking care of a balance of traffic demand with the capacity of the road. He indicates that, as cities expand and the number of vehicles on the road increases, traffic accidents have become a major problem.[8][9]

Implementing progressive measures, such as improved signalling, synchronising traffic lights and redistributing urban transport, can generate significant results in reducing congestion [10], and using novel techniques based on vehicle-to-vehicle (V2V) communications designed to detect traffic congestion, on the other hand, indicates that traffic congestion causes delays, inconveniences and economic losses to drivers, as well as air pollution.[11][12]

The service level, which is measured based on the delay in seconds, provides a qualitative assessment of vehicular flow, from optimal conditions (Level A) to critical conditions (Level F). To estimate the level of service, the driver's perception is used, including other indices such as travel time and average speed, he says. According to , to address congestion in Tacna, it is proposed to use the Synchro Trafficware software, which operates under the HCM 2010 methodology [13] [14][15] [13], to determine effective solutions. Microscopic simulation of traffic reveals that most pedestrians exhibit space-seeking behavior, which affects wait time estimates, and capturing their interaction with traffic flow improves model accuracy.[16]

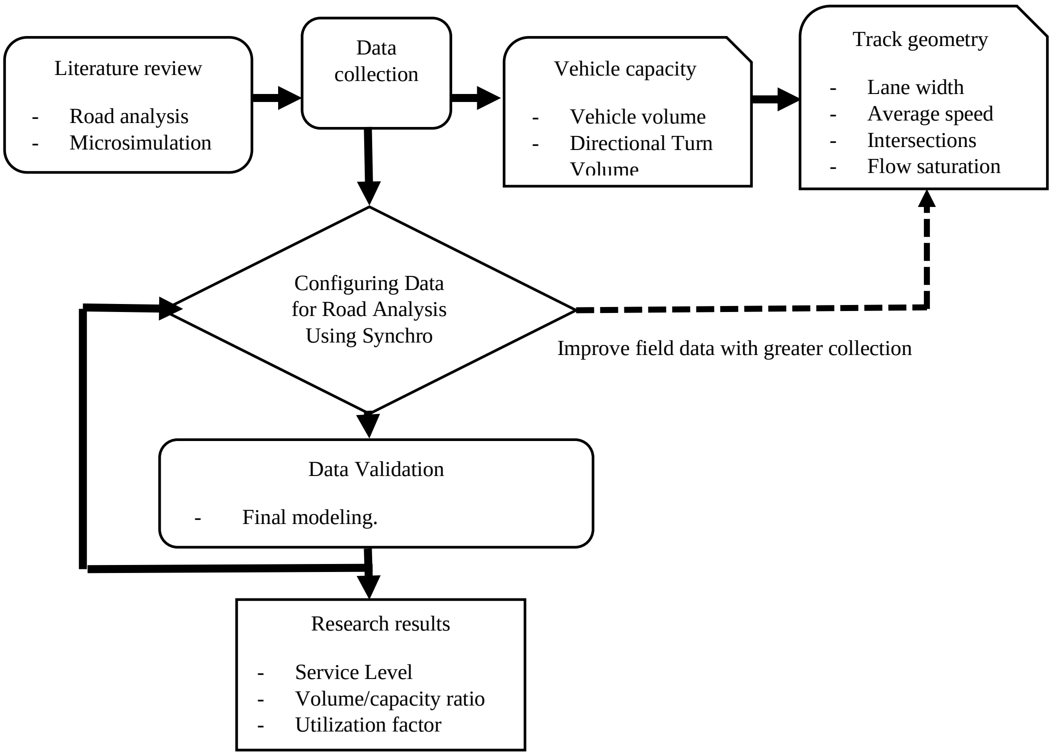
Microscopic evaluation Traffic Disruption at Urban Intersections is a valuable tool that allows planners to analyze vehicle behavior in detail and anticipate potential bottlenecks in the future [17]. Synchro becomes more important because it makes it easier to verify the traffic light cycle, vehicle ordering, exclusive turning lanes and 2D and 3D simulations.[18]

In this context, the present research aims to develop a road analysis of an overpass on the PE-1S national road, in order to optimize the vehicular flow and offer an effective solution to congestion problems. Through a comprehensive and data-driven approach, it seeks not only to improve road infrastructure, but also to contribute to the well-being of citizens and promote sustainable urban development in Tacna.

Materials and methods

The methodology of this research was structured in several key stages to carry out an exhaustive road analysis of the PE-1S national highway in Tacna, with the aim of evaluating the feasibility of an overpass as a solution to traffic congestion. The phases of the methodology used are described below:

Figure 1. Phases of the methodology for Road Analysis



Note. Configuration of the methodology for the research, considering the review of the scientific literature to the road analysis through 2D and 3D results.

According to Figure 1, the first step involved a thorough review of the recent scientific literature related to road analysis and traffic congestion. Databases such as Scopus and Web of Science were used to identify relevant published articles. This review allowed to establish a solid theoretical framework and to understand the best practices and methodologies existing in the field of traffic analysis.

Next, data collection was carried out through vehicle counts. Manual counts were carried out in the North-South and South-North directions during three working days of the week, covering a period of 12 hours per day. This approach made it possible to obtain a detailed profile of the volume of traffic, classified by type of vehicle, at the intersections of the PE-1S national highway with Av. A.B. Leguía and Av. Gregorio Albarracín [10].

In addition to the gauging, an analysis of the geometry of the road was carried out, which included the measurement of the width of the lanes, the average speed of circulation and the characteristics of the intersections. This information is crucial to understanding the current conditions of the infrastructure and its ability to handle the volume of traffic.

Table 1 shows the 2010 HCM criteria, which help determine service levels by considering the delay in seconds.[13]

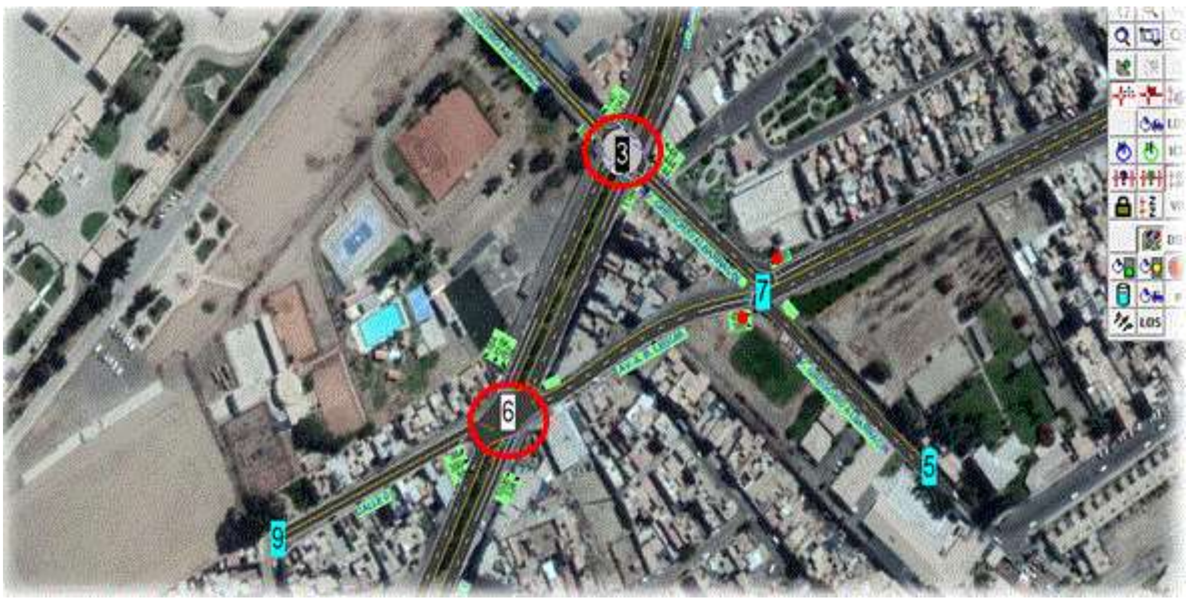
Table 1. *Evaluation Indexes by Service Levels*

Service Level	Delay(s)
To	< 10
B	10 - 20
C	20 - 35
D	35 - 55
And	55 - 80
F	> 80

Note. Quantification of delays by service level, taken from HCM 2010 .[13]

The data collected was configured in the Synchro Trafficware software, as seen in Figure 2, which allows for a detailed analysis of vehicular flow. Before the final simulation, the data were validated to ensure their accuracy and representativeness. The configuration included data entry on traffic volume, intersection geometry, and vehicle turning patterns [15].

Figure 2. *Intersection Configuration*



Note. Configuration of the national road and intersections, (node 3) Av. Gregorio Albarracín and (node 6), Av. Augusto B. Leguía, entered the Synchro [15]

The methodology employed in this research ensures a comprehensive and informed analysis, which not only addresses current congestion problems, but also offers sustainable solutions for the future of mobility in the city.

Results and discussion

The results of the research and the discussion associated with these results are presented below.

Results

The results of this research highlight the complexity and severity of traffic congestion at the intersection of the PE-1S national highway with the urban roads of Tacna. Analysis of vehicular flows reveals that the intersection experiences significant disruptions, resulting in congestion and inconvenience for users.

Table 2 presents the vehicle capacity data, where a total of 30,011 vehicles were registered on the day of greatest influx, which corresponded to Tuesday. This finding underscores the need for a thorough analysis of traffic patterns and current road conditions to implement effective improvements.

Table 2. *Vehicles measured by day and type on the national highway*

TIPO DE VEHICULO	TRAFICO VEHICULAR							TOTAL	IMD_S
	LUNES	MARTES	MIERCOLES	JUEVES	VIERNES	SABADO	DOMINGO	SEMANA	
MOTOS		73.00	58.00	81.00				212.00	71
AUTO		14,253.00	15,577.00	14,399.00				44,229.00	14,743
STATION WAGON		4,952.00	3,018.00	4,588.00				12,558.00	4,186
PICK UP		3,474.00	1,721.00	1,652.00				6,847.00	2,282
PANEL		729.00	1,597.00	729.00				3,055.00	1,018
RURALCombi		2,949.00	2,935.00	4,133.00				10,017.00	3,339
MICROBUS		872.00	1,445.00	977.00				3,294.00	1,098
B2		345.00	343.00	395.00				1,083.00	361
B3		179.00	164.00	172.00				515.00	172
C2		356.00	322.00	324.00				1,002.00	334
C3		1,375.00	1,331.00	1,340.00				4,046.00	1,349
C4		66.00	49.00	53.00				168.00	56
T2S1		33.00	30.00	30.00				93.00	31
T2S3		242.00	234.00	236.00				712.00	237
T3S1		63.00	59.00	60.00				182.00	61
T3S3		50.00	46.00	48.00				144.00	48
TOTAL	0.00	30,011.00	28,929.00	29,217.00	0.00	0.00	0.00		29,386

Note. Data measured in directions of N-S and S-N, which were weighted to determine the ADT, Tuesday, the day of greatest concentration and the classification by type of vehicles.

The hourly variation of traffic, as shown in Table 3, indicates that peak hours are concentrated between 7:00 AM and 8:00 AM, with a notable increase in the number of vehicles. This information is crucial for planning road interventions, as it allows you to identify the times of greatest demand and adjust infrastructure and signage accordingly.

Table 3. *Hourly variation of greater traffic*

HORA	TRAFICO VEHICULAR			TOTAL	TOTAL	TOTAL
	MARTES	MIERCOLES	JUEVES	SEMANA	PROMEDIO	%
7:00 AM - 8:00 AM	3,422.00	3,396.00	3,379.00	10,197.00	3,399.00	**11.57%**
8:00 AM - 9:00 AM	3,022.00	2,927.00	2,928.00	8,877.00	2,959.00	**10.07%**
9:00 AM - 10:00 AM	1,916.00	2,089.00	1,983.00	5,988.00	1,996.00	**6.79%**
10:00 AM - 11:00 A	1,349.00	1,338.00	1,446.00	4,133.00	1,378.00	**4.69%**
11:00 AM - 12:00 A	2,310.00	2,188.00	2,331.00	6,829.00	2,276.00	**7.75%**
12:00 AM - 01:00 P	2,906.00	2,940.00	2,816.00	8,662.00	2,887.00	**9.82%**
01:00 PM - 02:00 PM	2,007.00	2,119.00	2,019.00	6,145.00	2,048.00	**6.97%**
02:00PM - 03:00 PM	1,254.00	1,332.00	1,244.00	3,830.00	1,277.00	**4.35%**
03:00 PM - 04:00 PM	1,877.00	1,732.00	1,809.00	5,418.00	1,806.00	**6.15%**
04:00 PM - 05:00 PM	1,798.00	1,511.00	1,666.00	4,975.00	1,658.00	**5.64%**
05:00 PM - 06:00 PM	2,235.00	1,948.00	2,116.00	6,299.00	2,100.00	**7.15%**
06:00 PM - 07:00 PM	2,797.00	2,484.00	2,615.00	7,896.00	2,632.00	**8.96%**
07:00 PM - 08:00 PM	3,118.00	2,925.00	2,865.00	8,908.00	2,969.00	**10.10%**
TOTALES	**30,011.00**	**28,929.00**	**29,217.00**	**88,157.00**	**29,385.00**	**100.00%**

Note. The volume of traffic during 12 hours is shown to determine the peak time from 7:00 AM to 8:00 AM, as can be seen in Table 3.

Table 4 shows the range from 7:45 AM to 8:00 AM where the highest concentration of traffic was recorded, suggesting that traffic management measures should be more intensive during these hours.

Table 4. *Directional gauging at 15-minute intervals*

HORA DE CONTEO		LIVIANO			PESADO		
		1	2	3	1	2	3
INICIO	TERMINO	DERECHA	SIGUEN	IZQUIERDA	IZQUIERDA	SIGUEN	DERECHA
7:00 a. m.	7:15 a. m.	42.00	150.00	0.00			
7:15 a. m.	7:30 a. m.	47.00	147.00	0.00			
7:30 a. m.	7:45 a. m.	28.00	181.00	0.00			
7:45 a. m.	8:00 a. m.	35.00	192.00	0.00		143.00	
8:00 a. m.	8:15 a. m.	39.00	139.00	0.00			
8:15 a. m.	8:30 a. m.	44.00	136.00	0.00			
8:30 a. m.	8:45 a. m.	26.00	168.00	0.00			
8:45 a. m.	9:00 a. m.	33.00	178.00	0.00			
9:00 a. m.	9:15 a. m.						
9:15 a. m.	9:30 a. m.						
9:30 a. m.	9:45 a. m.						
9:45 a. m.	10:00 a. m.						
10:00 a. m.	10:15 a. m.	20.00	72.00	0.00			
10:15 a. m.	10:30 a. m.	23.00	71.00	0.00			
10:30 a. m.	10:45 a. m.	14.00	87.00	0.00			
10:45 a. m.	11:00 a. m.	17.00	92.00	0.00			
11:00 a. m.	11:15 a. m.						
11:15 a. m.	11:30 a. m.						
11:30 a. m.	11:45 a. m.						
11:45 a. m.	12:00 p. m.						

Note. Once the rush hour is determined, directional gauging is carried out every 15 minutes and the flows of highest concentration are obtained, as seen in Table 4, from 7:45 to 8:00

AM, considering light and heavy vehicles.

The vehicle capacity within rush hour in 15-minute intervals (Table 4) was obtained, in our case from 7:45 to 8:00 AM, where the vehicle volume must be calculated at an hourly rate using equation (1) [7]:

$$q = \frac{n \times 3600}{T} \quad \text{(veh/h)} \qquad (1)$$

Where:

q = hourly flow   n = flow in 15 min.   T= time of 15 min. or 900 s.

Table 5 shows the data of vehicles per hour at the intersection with Av. Gregorio Albarracín, in each access and type of movement, calculated at rush hour according to equation (1), considering the current and future scenario. The information is entered into the Synchro Trafficware considering the data of the road geometry, traffic light times, type of traffic and others defined by the HCM 2010.

Table 5. *Hourly volume at rush hour at the intersection with Av. Gregorio Albarracín*

Av. Gregorio Albarracín	HORA DE CONTEO		VEHÍCULO LIVIANO - GIROS			VEHÍCULO PESADO - GIROS		
			1	2	3	1	2	3
	INICIO	TERMINO	IZQUIERDA	SIGUEN	DERECHA	IZQUIERDA	SIGUEN	DERECHA
DIRECCION	7:45 a. m.	8:00 a. m.	140	768	0	0	572	0
N - S	Flujo proyectado para 20 años		6803	37317	0	0	14037	0
DIRECCION	7:45 a. m.	8:00 a. m.	0	644	0	0	540	0
S -N	Flujo proyectado para 20 años		0	31292	0	0	13252	0
DIRECCION	7:45 a. m.	8:00 a. m.	144	420	32	0	24	16
E - W	Flujo proyectado para 20 años		6997	20408	1555	0	1166	777
DIRECCION	7:45 a. m.	8:00 a. m.	0	0	44	0	0	12
W - E	Flujo proyectado para 20 años		0	0	2138	0	0	294

Note. It is the volume determined at peak time for the current and future scenario, considering a population growth rate of 2.10% according to the INEI. [19]

Table 6 shows the data of the vehicles per hour at the intersection with Av. Augusto B. Leguía, in each access and type of movement, calculated at rush hour according to equation (1), considering the current and future scenario. The information is entered into the Synchro Trafficware considering the data of the road geometry, traffic light times, type of traffic and others defined by the HCM 2010.

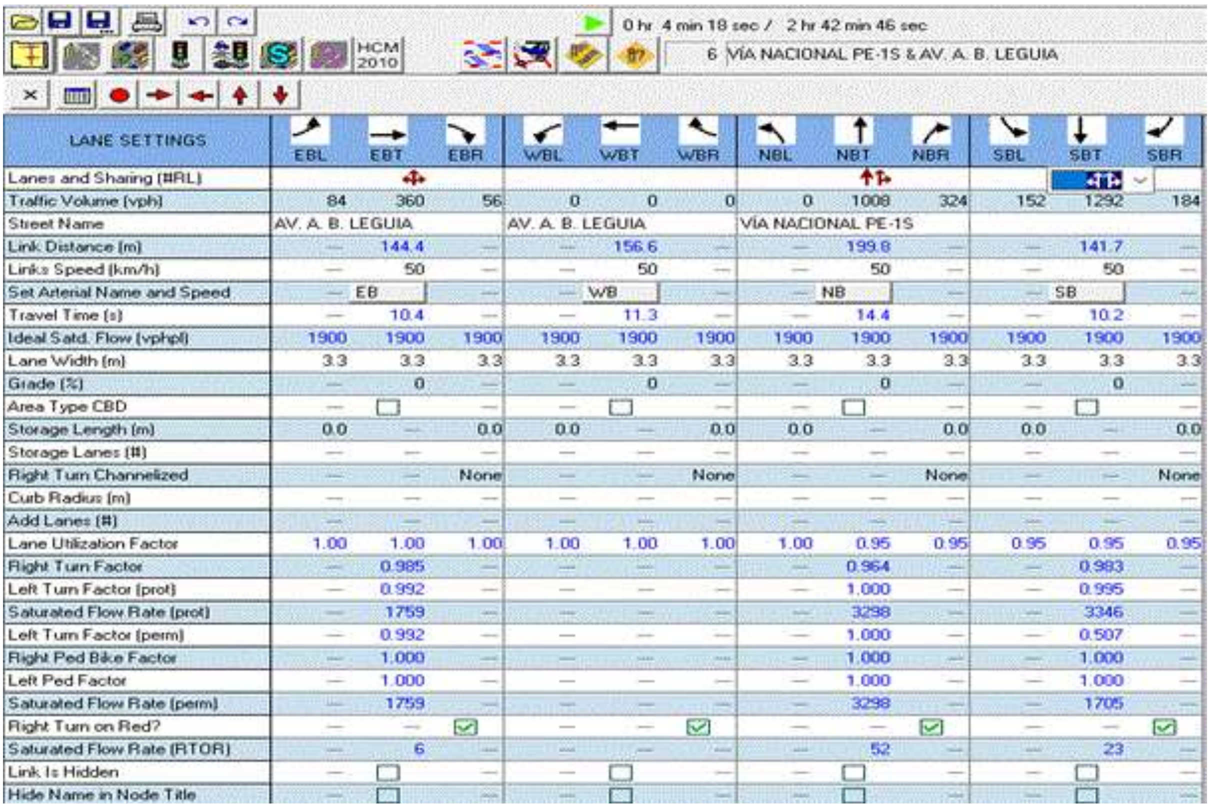
Table 6. *Hourly volume during rush hour at the intersection with Av. Augusto B. Leguía*

Av. Augusto B. Leguía	HORA DE CONTEO		VEHÍCULO LIVIANO - GIROS			VEHÍCULO PESADO - GIROS		
			1	2	3	1	2	3
	INICIO	TERMINO	IZQUIERDA	SIGUEN	DERECHA	IZQUIERDA	SIGUEN	DERECHA
DIRECCION	7:45 a. m.	8:00 a. m.	184	768	152	0	524	0
N - S	Flujo proyectado para 20 años		8941	37317	7386	0	14037	0
DIRECCION	7:45 a. m.	8:00 a. m.	164	644	0	160	364	0
S -N	Flujo proyectado para 20 años		7969	31292	0	3926	8933	0
DIRECCION	7:45 a. m.	8:00 a. m.	0	0	0	0	0	0
E - W	Flujo proyectado para 20 años		0	0	0	0	0	0
DIRECCION	7:45 a. m.	8:00 a. m.	84	340	44	0	20	12
W - E	Flujo proyectado para 20 años		4082	16521	2138	0	491	294

Note. It is the volume determined in the N-S direction, at the peak hour for the current and future scenario

Figure 3 shows the entry of the information determined by means of the directional gauging at rush hour, defined in vehicles per hour considered in Table 5 and 6, configuring the intersections Av. Gregorio Albarracín and Av. Augusto B. Leguía on the national highway, to proceed with the road analysis.

Figure 3. *Configuring intersections and entering data for each access in Synchro Trafficware*



LANE SETTINGS	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	84	360	56	0	0	0	0	1008	324	152	1292	184
Street Name	AV. A. B. LEGUIA			AV. A. B. LEGUIA			VÍA NACIONAL PE-1S					
Link Distance (m)	—	144.4	—	—	156.6	—	—	199.8	—	—	141.7	—
Links Speed (km/h)	—	50	—	—	50	—	—	50	—	—	50	—
Set Arterial Name and Speed	—	EB	—	—	WB	—	—	NB	—	—	SB	—
Travel Time (s)	—	10.4	—	—	11.3	—	—	14.4	—	—	10.2	—
Ideal Satd. Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (m)	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Grade (%)	—	0	—	—	0	—	—	0	—	—	0	—
Area Type CBD	—	☐	—	—	☐	—	—	☐	—	—	☐	—
Storage Length (m)	0.0	—	0.0	0.0	—	0.0	0.0	—	0.0	0.0	—	0.0
Storage Lanes (#)	—	—	—	—	—	—	—	—	—	—	—	—
Right Turn Channelized	—	—	None	—	—	None	—	—	None	—	—	None
Curb Radius (m)	—	—	—	—	—	—	—	—	—	—	—	—
Add Lanes (#)	—	—	—	—	—	—	—	—	—	—	—	—
Lane Utilization Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.95	0.95	0.95	0.95
Right Turn Factor	—	0.985	—	—	—	—	—	0.964	—	—	0.983	—
Left Turn Factor (prot)	—	0.992	—	—	—	—	—	1.000	—	—	0.995	—
Saturated Flow Rate (prot)	—	1759	—	—	—	—	—	3298	—	—	3346	—
Left Turn Factor (perm)	—	0.992	—	—	—	—	—	1.000	—	—	0.507	—
Right Ped Bike Factor	—	1.000	—	—	—	—	—	1.000	—	—	1.000	—
Left Ped Factor	—	1.000	—	—	—	—	—	1.000	—	—	1.000	—
Saturated Flow Rate (perm)	—	1759	—	—	—	—	—	3298	—	—	1705	—
Right Turn on Red?	—	—	☑	—	—	☑	—	—	☑	—	—	☑
Saturated Flow Rate (RTOR)	—	6	—	—	—	—	—	52	—	—	23	—
Link Is Hidden	—	☐	—	—	☐	—	—	☐	—	—	☐	—
Hide Name in Node Title	—	☐	—	—	☐	—	—	☐	—	—	☐	—

Note. The configuration of the data determined in the directional gauging of turn by access, the data of traffic volume, approach speed, saturation flow, lane width and intersection nodes has been entered into the software, taken from the Synchro Trafficware.[15]

Table 7 shows the results of the determination of the service levels for each access and intersection, through the analysis of delays, **in a current scenario**, considering the traffic density for each access at times of greatest concentration.

Table 7. *Result of service levels per delay in a current scenario*

Results obtained from Synchro Trafficware					
Current scenario	Degree of saturation ratio v/c	Utilization factor	Service Level by Access	Total Intersection Delay(s)	Service Level (LOS)
Intersection Av. G. Albarracín Node N° 3	1,26	74,24%	To To C F	31,4	C
Intersection Av. A.B. Leguía Node N° 6	1,91	137%	F F C	267,5	F

Note. The results in a current scenario in the intersections by accesses to the right, to the left and those that continue straight on the road, obtain Level C and F.

Table 8 shows the results of the determination of the service levels for each access and intersection, through the analysis of delays, **in a future scenario**, considering the traffic density for each access at times of greatest concentration.

Table 8. *Results of service levels per delay in a future scenario*

Results obtained from Synchro Trafficware					
Designed for 20 years	Degree of saturation ratio v/c	Utilization factor	Service Level by Access	Total Intersection Delay(s)	Intersection Service Level (LOS)
Intersection Av. G. Albarracín Node N° 3	1,22	109,0%	F C F B	81,7	F
Intersection Av. A.B. Leguía Node N° 6	2,00	110,3%	F F C	103,3	F

Note. The results in a projected 20-year future scenario, analyzed by directional turns, obtain critical congestion flows at the intersections of nodes 3 and 6.

Table 9 shows the results of the service levels for each access and intersection, through the analysis of delays on the national road, **modeling in an overpass**, considering the traffic density for each access at times of greatest concentration.

Table 9. *Result of the service levels due to delay on the national road modeling an Overpass*

Results obtained from Synchro Trafficware					
Overpass	Degree of saturation ratio v/c	Utilization factor	Service Level by Access	Total Intersection Delay(s)	Intersection Service Level (LOS)
Intersection Av. G. Albarracín Node 3	It does not exist	0.00%	To B To B	0	To
Intersection Av. A.B. Leguía Node 6	It does not exist	0.00%	B To To	0	To

Note. The results simulated in a future scenario, depressing the PE-1S national road, generating an overpass with the intersections of nodes 3 and 6 in the direction of N-S.

The results obtained with the Synchro software have made it possible to determine the level of service at the intersections evaluated. The results indicate that, without the implementation of an overpass, vehicular flow conditions are at critical levels, which translates into excessive delay times and a lower than desired level of service. The simulation of an overpass as an improvement alternative suggests that an A service level could be reached, which would imply a more efficient vehicular flow and less congestion at intersections.

The implementation of an overpass would not only improve traffic on the PE-1S road, but would also have a positive impact on the quality of life of users by reducing travel times and stress associated with congestion. In addition, this solution is expected to contribute to reducing vehicle wear and tear and fuel consumption, resulting in economic and environmental benefits

Figure 4 shows the road analysis carried out in a current scenario, based on the data recorded in the configuration of the lanes, traffic volume, road geometry, turns by accesses, the nodes of the intersections and as a result we show the generation of the 3D model using Synchro Trafficware. [15]

Figure 4. *Road analysis is a current scenario of intersections on the national highway*

Note. The road analysis shows the vehicular flows entered in the Synchro, in a current scenario where the flows are concentrated in the N-S and S-N direction of the national highway with the intersections Av. Gregorio Albarracín and Av. A.B. Leguía.[15]

In the same way, Figure 5 shows the road analysis for a future scenario, where we can visualize a greater concentration of flows exceeding the capacity of the national highway, so it is necessary to propose a solution that allows reducing delay times for the intersections present on the national highway.

Figure 5. *Road analysis is a future scenario of intersections on the national highway*

Note. The road analysis shows the vehicular flows entered in the Synchro in a future scenario where the flows are concentrated in the N-S and S-N direction of the national highway with the intersections Av. Gregorio Albarracín and Av. A.B. Leguía.[15]

Consequently, Figure 6 shows the road analysis in 2D incorporating an overpass, depressing the national highway in order to eliminate traffic congestion at intersections, as can be seen the free flow of vehicles on the national highway.

Figure 6. *2D road analysis of the depressed national road in the N-S direction*

Note. 2D road analysis, based on traffic variables in the Overpass scenario at the intersections of the national highway

Figure 7 shows the 3D road analysis of the national road, depressed to an overpass, where the free flows generated by eliminating the intersections considered in the research Av. Gregorio Albarracín and Av. Augusto B. Leguía are visualized.

Figure 7. *3D road analysis of the depressed national road in the N-S direction*

Note. 3D road analysis of Overpasses, positively influence the improvement of conditions, leaving the congestion conflicts generated by the intersections to create free flows on the national road.

Figure 8 shows the 3D model of the national road, depressed at an overpass, where the free flows generated by eliminating the intersection with Gregorio Albarracín Avenue are visualized.

Figure 8. *Overpass depressing the national road at the intersection Av. Gregorio Albarracín*

Note. The proposed scenario of an overpass, through road analysis, totally improves the conditions of traffic operation, generating free flows on the national road.

Figure 9 shows the 3D model of the national road, depressed at an overpass, where the free flows generated by eliminating the intersection with Augusto B. Leguía Avenue are visualized.
Figure 9. *Depressed overpass on the national road at the intersection of Av. Augusto B. Leguía*

Note. The proposed scenario of an overpass, through road analysis, totally improves the conditions of traffic operation, generating free flows on the national road.

Discussion

The results of this research highlight the complexity and severity of traffic congestion at the intersection of the PE-1S national highway with the urban roads of Tacna. Analysis of vehicular flows reveals that the intersection experiences significant disruptions, resulting in congestion and inconvenience for users. In particular, the registration of 30,011 vehicles on the busiest day highlights the pressure facing road infrastructure. This phenomenon is not unique to Tacna, as many cities in Latin America face similar challenges due to the growth of the vehicle fleet and the inadequacy of the existing infrastructure.

The identification of peak hours, especially between 7:00 AM and 8:00 AM, provides valuable information for the planning of road interventions. During this period, a notable increase in vehicular flow was observed, suggesting that traffic management strategies should focus on these critical moments. The implementation of an overpass at the intersection could be an effective solution to improve circulation during these hours, thus relieving congestion and reducing waiting times for drivers.

The analysis carried out with the Synchro software has made it possible to evaluate the level of service at the intersections, showing that, without the proposed intervention, the vehicular flow conditions are unsatisfactory. The results indicate that the current congestion translates into long delay times and a lower than desired level of service. The simulation of an overpass suggests that this alternative could raise the service level to A, implying more efficient vehicular flow and less congestion at intersections. This finding highlights the importance of using simulation tools to assess the impact of road infrastructure improvements.

In addition to improving circulation, the proposal for an overpass has positive implications in terms of sustainability and quality of life. By reducing travel times and minimizing the stress associated with congestion, this intervention is expected to contribute to lower fuel consumption and emissions of polluting gases. This would not only benefit drivers, but would also have a positive impact on the environment and public health.

The analysis of the results is related to what was determined by , who classified a service level C with a delay of 33 seconds, which is very close to being considered with a Service Level D, so it is recommended to apply traffic correction measures. Our research determined a Service Level F, which defines improvement alternatives to determine free flows or Service Level A.[2]

Similarly, there is agreement with the results determined by , who concludes that the degree of saturation is 1 900 vehicles/hour. The generation of volumes and their assignment to the simulation mesh is uniformly assigned to the different lanes according to the directional movement scheme defined in the volume matrix, as evidenced in Figure 3.[20]

There is also agreement with the results obtained by , who determines the visualization of the road analysis of vehicular traffic in 3D, using Synchro Trafficware [9], in a similar way to what is presented in Figure 7 of our research.[21]

Our results in Table 9 agree with the results achieved by , who concludes that the introduction of an overpass rationalizes vehicular flows by improving speeds from 13.11 km/h to 46.04 km/h, which means an improvement of 251%.[4]

The results of this research support the need to carry out interventions on the PE-1S national highway to improve vehicular circulation and the quality of life of users. The implementation of an overpass is presented as a viable and effective solution to mitigate current and future congestion problems in Tacna.

Conclusions

The results of this research strongly support the need to carry out interventions on the PE-1S national highway to improve vehicular circulation and the quality of life of users in Tacna. Exhaustive road analysis, based on vehicle capacity and simulations with Synchro, has shown that the current situation at critical intersections is unsustainable. Congestion leads to excessive delay times, frustrations for drivers, and an unacceptable level of service.

However, this research also offers a viable and effective solution to address the problem: the implementation of an overpass, where the simulation of this scenario in Synchro suggests that an A service level could be reached, which would imply a smooth and efficient vehicular flow at intersections. This finding is particularly encouraging, as it demonstrates that it is possible to significantly improve traffic conditions through strategic interventions in road infrastructure.

Beyond the benefits in mobility, the proposal for an overpass also has positive implications in terms of sustainability and quality of life. By reducing travel times and stress associated with congestion, it is expected to decrease fuel consumption and pollutant emissions, contributing to a healthier and friendlier urban environment. In addition, the improvement in vehicular circulation will result in time and money savings for users, which in turn will promote the economic and social development of the city.

In conclusion, this research provides a solid and convincing basis for decision-making in road infrastructure planning in Tacna. The implementation of an overpass on the PE-1S national highway is emerging as a comprehensive solution that addresses current and future congestion problems, improving the quality of life of citizens and laying the foundations for sustainable urban development. Authorities and planners should seize this opportunity to transform mobility in Tacna, setting a precedent for other cities facing similar challenges in the region.

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