Keywords: tram management; drivers' behaviors; junction; travelers; traffic congestion

Mouloud KHELF[1]*, Salim BOUKEBBAB[2], Neila BHOURI[3]

THE EFFECT OF TRAM MANAGEMENT ON ROAD TRAFFIC FLUIDITY AND ITS INFLUENCE ON DRIVERS' BEHAVIORS AT A CRITICAL JUNCTION IN ALGERIA

Summary. This research paper aims to study the effect of tram management on traffic fluidity and its impact on car drivers' behaviors at junctions crossed by trams. The methodology used in this research is based on a mathematical model and an investigation of car drivers. The first step is to analyze the data of annual travelers' attendance and assess the number of trams offered and needed in operation to respond adequately to the factual demand. The second step proceeds to show how the previous results of the trams' fleet influence traffic jams. That is, this step identifies how the number of trams used in operation blocks other motorists and reduces traffic flow capacity at junctions. Finally, the purpose of the questionnaire is to determine car drivers' opinions of the causes of traffic congestion at junctions and understand how this phenomenon affects their behaviors. The outcomes demonstrate that tram management is ineffective because there is a considerable gap between the annual offered tram fleet and the actual one needed according to the real statistical data. The high number of trams utilized is the leading cause of traffic congestion. Furthermore, this situation disturbs the control of traffic lights at common intersections. Unfortunately, this outcome is the main reason for drivers' poor behavior, as 75.20% of car drivers are always stressed. These issues have intensified traffic jams in several junctions along the tram line. The article recommends some solutions to improve tram management and traffic fluidity to avoid the substandard behavior of car drivers at junctions.

1. INTRODUCTION

In spite of the considerable evolution of road infrastructure that has been made around the world, traffic jams are still a difficult issue to resolve [1, 2]. The main solution implemented in several countries is investing in sustainable public transport [3, 4]. These modes of transportation must respond to the population demand so that they can attract them to be used as the preferred transportation means [5, 6].

The tram is one of these modern transportation modes, and it affords different advantages [7, 8]. Especially, it helps in reducing the traffic flow and minimizing road accidents on its line [9]. The benefits of trams encouraged many countries across the world to construct and develop this kind of railway [10]. The Algerian government has also Extensively financed the construction of tram networks. Many cities have benefited from tram lines, including Constantine City [11].

[1] University of Constantine 1, Department of Transport Engineering; Campus A. Hamani, route Ain El Bey, Constantine, 25000, Algeria; e-mail: mouloud.khelf@umc.edu.dz; orcid.org/0000-0001-6900-3830
[2] University of Constantine 1, Department of Transport Engineering; Campus A. Hamani, route Ain El Bey, Constantine, 25000, Algeria; e-mail: boukebbab@yahoo.fr; orcid.org/ 0000-0001-8997-989X
[3] University Gustave Eiffel, Department (COSYS), GRETTIA laboratory; 14-20 boulevard Newton 77447 Marne la Vallée, Cedex 2, Paris, France; e-mail: neila.bhouri@univ-eiffel.fr; orcid.org/0000-0003-0775-7922
* Corresponding author. E-mail: mouloud.khelf@umc.edu.dz

However, the tram has become a source of enormous traffic jams at junctions. Its frequent passage (every three minutes) during rush hour in both directions has negatively affected road traffic [11, 12]. As with other trams in many countries, the Algerian tram has priority over other motorists at junctions [13, 14]. Thus, it reduces cars' fluidity at its passage [15, 16], which can be a source of irritation.

Certainly, the establishment of traffic lights to control crossroads is very important because it organizes traffic and decreases delays for drivers [17, 18]. However, if the synchronization of lights does not respond effectively to real situations, they will increase traffic jams [15, 19].

Several previous papers have studied the impact of road accidents on congestion and the effects of drivers' behaviors on accidents [20-23], but the impact of traffic jams on the risks of accidents has been discussed relatively rarely [24, 25]. The behavior of drivers is one of the causes of accidents and congestion at the same time [26, 27]. Multiple studies have shown that changing the queue on a road is a dangerous maneuver [28, 29], which often causes accidents and aggravates traffic jams, especially in urban areas [30-32].

In this work, we will analyze the causes of congestion in a complicated junction in the city and explore how congestion can influence drivers' behaviors. For this, we will evaluate tram management to determine its influence on traffic congestion at intersections, in addition to studying the situation of the road traffic capacity in a common junction by utilizing the results of the tram's number applied in operation. Finally, the opinions of drivers who use this mode of transportation will be analyzed to highlight the causes of traffic jams and their effects on drivers' behaviors from their perception.

The study area is Constantine City, Algeria (more precisely, at the Che Guevara junction, which is a complicated junction located on the operating line [12]. It has been chosen because of its high traffic demand and its strategic location, as it leads to several important areas (Fig. 1).

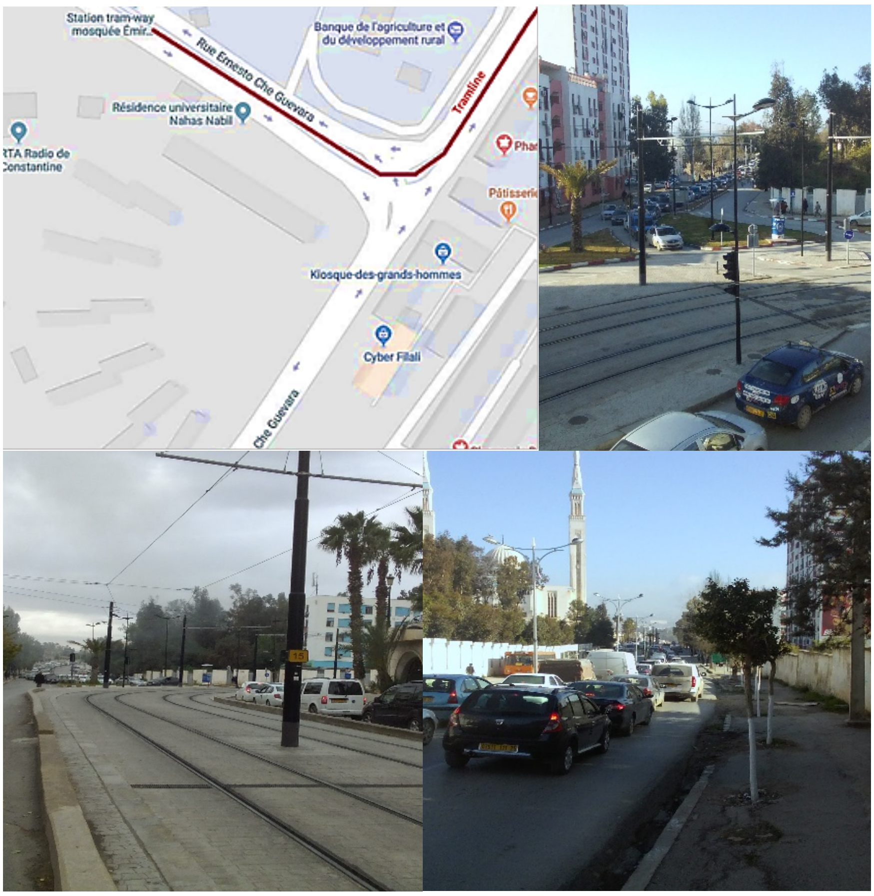

Fig. 1. Map and photos of the Che Guevara junction, Constantine City, Algeria

2. METHODOLOGY

The methodology followed in this study is divided into three sections.

2.1. Trams' management analysis

In this first part, from the tram operation data, we have made a comparison between the number of trams required to respond to the real users' attendance and the proposed number of trams offered in the year 2018. This allowed us to evaluate the tram's control and detect its impact on traffic jams.

The tram brand is a Citadis 402 range from Alstom. It is able to carry 302 users [7, 11]. The interval of time between trams is three minutes during rush hour (7:00 to 9:00 a.m. and 2:00 to 6:00 p.m.) and five minutes at other hours during weekdays [11, 33, 12]. The length of the Constantine tram network is currently 8 km, pending the opening of the next extension, which is being tested [7, 33]. Table 1 presents the offered number of trams in 2018 according to the interval of time on weekdays, Fridays and Saturdays.

Table 1

The suggested number of trams used in operation

	Weekdays	Fridays	Saturdays
Performance (trams/day)	504	368	252

In an exceptional month of the year 2018, the number of 592 trams were used per day for 30 days (between May 16 and June 14). The theoretical number of travelers per month is calculated using Equation (1).

$$P_o = T_o * M_c \quad . \tag{1}$$

- P_o is the theoretical number of travelers per month.
- T_o is the theoretical number of trams offered per month.
- M_c is the tram's mass capacity (302 travelers per tram).

The theoretical number of trams offered per month is calculated using Equation (2).

$$T_o = (T_w + T_f + T_s) \quad . \tag{2}$$

- T_w is the theoretical number of trams offered on weekdays per month.
- T_f is the theoretical number of trams offered on Fridays per month.
- T_s is the theoretical number of trams offered on Saturdays.

The real number of trams needed per month is calculated from Equation (3).

$$T_r = \frac{D_r}{M_c} \quad . \tag{3}$$

- T_r is the real number of trams needed per month.
- D_r: is the real number of travelers per month.

The tram attendance rate per month is calculated from Equation (4).

$$A_r = \frac{T_r}{T_o} \quad . \tag{4}$$

- A_r is the tram attendance rate per month.

2.2. Evaluation of the road traffic situation

In the second part, according to the results of the tram's operation analyzed previously, the objective is to evaluate traffic flow at the intersection. We focused on the impact of tram exploitation on the traffic flow situation. This section will clearly show the estimation of the number of blocked cars due to the passage of trams at the shared signalized crossroads. A comparison between the traffic flow blocked because of the suggested and real trams' frequencies were analyzed to show their impacts on traffic fluidity.

The time headway *h* in the calculation of the traffic flow is two seconds [34]. The required time *t* for the tram to leave the Che Guevara junction is 40 seconds [12]. The estimated blocked traffic flow according to the theoretical and real number of trams is calculated from Equation (5).

$$Q_b = \frac{T_f * t}{h} \quad . \tag{5}$$

- Q_b is the estimated blocked traffic flow.
- T_f is T_o in the case of the estimated blocked traffic flow Q_{bo} according to the theoretical number of trams per month.
- T_f is T_r in the case of the estimated blocked traffic flow Q_{br} according to the real number of trams needed per month.

The estimated gained rate of traffic fluidity Q_{bg} at the Che Guevara junction is calculated from Equation (6).

$$Q_{bg} = \frac{Q_{bo} - Q_{br}}{Q_{bo}} * 100 \quad . \tag{6}$$

2.3. A survey with car drivers

In this last step of the study, 250 drivers who pass through the Che Guevara junction were interviewed in April 2019 to collect their opinions on traffic congestion. This was done to confirm, from their perspective, the existence of traffic congestion at the Che Guevara junction to understand its main causes and how it impacts their behaviors (e.g., making dangerous maneuvers and performing acts of violence against other drivers).

3. ANALYSIS AND DISCUSSION

3.1. Tram management evaluation

Comparison of the annual suggested and real travelers' frequency

The data regarding the annual frequency of tram travelers were acquired from the Enterprise Metro Algiers. Overall, the figures below show that the tram does not respond optimally to travelers' demands because it is not operated in real-time. Fig. 2 shows that the suggested users' demand is four to five times greater than the real users' attendance. This shows that the tram operation is not suitably managed in real-time.

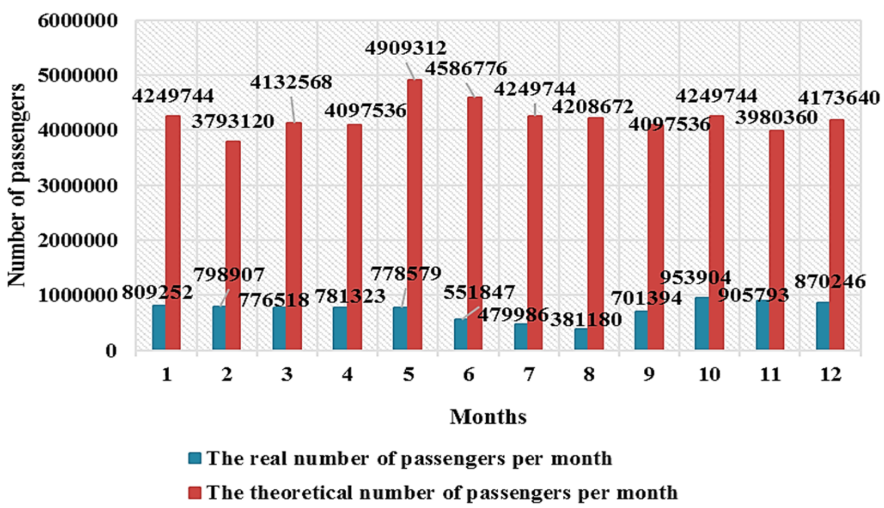

Fig. 2. Comparison of the annual suggested and the real travelers' demand

Estimation of the suggested and real number of trams

Fig. 3 represents a comparison between the suggested number of trams used and the real number needed to satisfy the real traveler attendance in the year 2018. Of note, the actual number of trams that could meet travelers' demand does not exceed 3500 trams per month. The rate of trams needed to respond to the real users' demand is between 9.06% and 22.76% of the offered suggested trams.

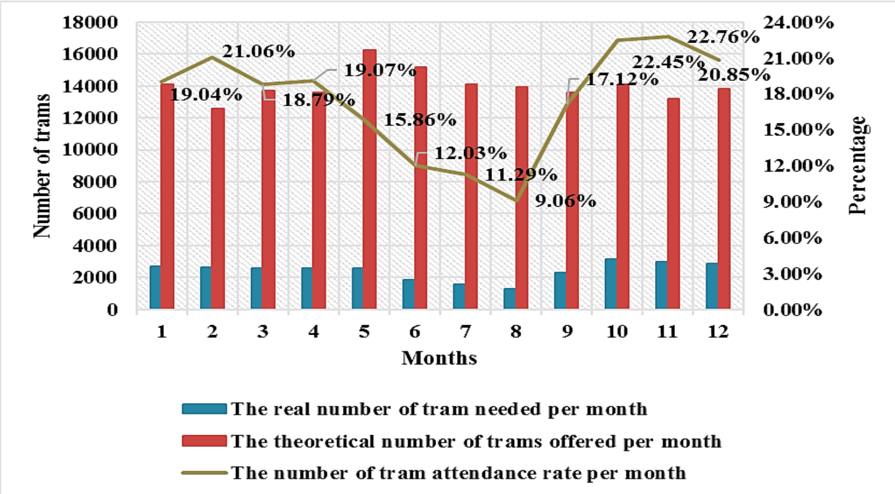

Fig. 3. Estimation of the real number of trams needed and the suggested number offered

3.2. Evaluation of traffic flow at the Che Guevara junction

Fig. 4 illustrates the estimated blocked traffic flow due to the passage of the suggested and real number of trams needed at the Che Guevara junction. This estimation of the blocked traffic flow is calculated for cars that cross the tram line to go to their destinations.

The results show that the traffic flow could have been improved if the number of trams had responded optimally to the tram travelers' attendance. Specifically, the intersection could have gained between 77.24% and 90.94% fluidity compared to the applied proposed number of trams. This contributes efficiently to reducing congestion at the Che Guevara intersection and all the other junctions located on the lane of the tram. This situation has persisted until now, and it is necessary to reduce the number of trams to be more efficient in reducing traffic jams.

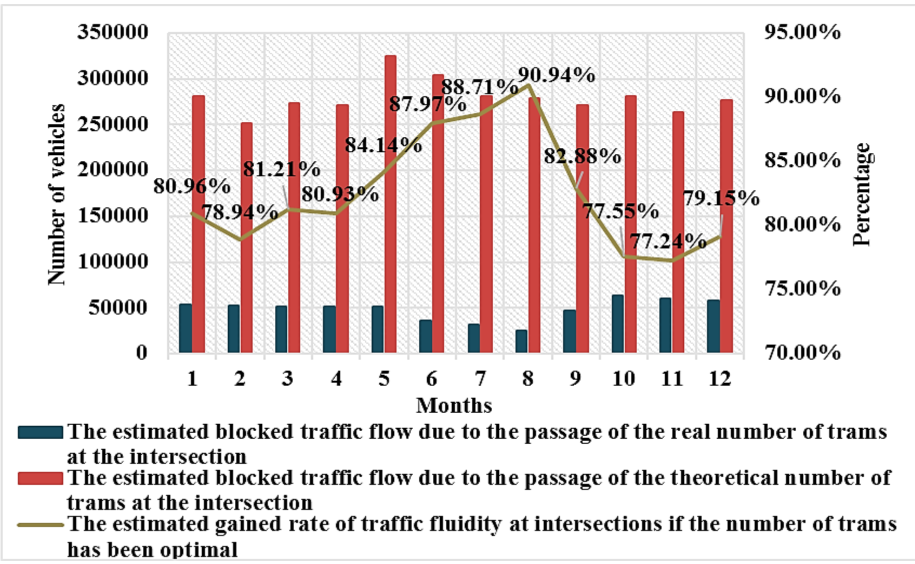

Fig. 4. Estimation of the blocked traffic flow due to the passage of trams at the Che Guevara junction

3.3. Survey analysis

Respondents' characteristics

The first part of the sample in table 2 represents the respondents' characteristics. The sample comprised 68% men and 32% women. Furthermore, 83.60% of motorists were in the age ranges of 18-36 and 37-55 years. The main reason drivers travel through this junction is for work (66.40%). Moreover, 66.40% of them use this route every day, and 15.20% use it between three and four times per week. Thus, the selected drivers know this route well.

Table 2

Respondents' characteristics [35]

		Number of drivers	Percent
Gender	Female	80	32.00%
	Male	170	68.00%
	Sum	250	100%
Age	18-36 years	75	30.00%
	37-55 years	134	53.60%
	56-75 years	41	16.40%
	Sum	250	100%
Activity	Student	10	4.00%
	Worker	216	86.40%
	Retired	17	6.80%
	Jobless	7	2.80%
	Sum	250	100%
Intersection usage reason	School/University	6	2.40%
	Job	166	66.40%
	Shopping	40	16.00%
	Other uses	38	15.20%
	Sum	250	100%
Intersection usage frequency	Every day	166	66.40%
	3-4 uses per week	38	15.20%
	1-2 uses per week	13	5.20%
	Time to time	33	13.20%
	Sum	250	100%

The traffic congestion problem

Table 3 presents the problem of traffic congestion and its causes at intersections. Specifically, 87.60% of respondents agree that traffic jams at signalized crossroads have always caused them delays; no participants denied this claim. According to the data in Table 3, it is apparent that 45.20% of drivers find that the minimum time needed to cross the intersection between 7:30 a.m. and 06:00 p.m. is 16 minutes, 32.40% say 11-15 minutes, and 22.40% of drivers find it is 5-10 minutes.

The main cause of this problem at the Che Guevara junction is the tram operation, as 63.60% of car drivers claim that the Constantine tram is weakly exploited because its passage is not regular at the Che Guevara junction; this is one of the causes of traffic congestion. Furthermore, the synchronization of the traffic lights is a cause of this issue because the signal timing is not consistent with the operation of the tram. The passage of this last causes a distribution in the traffic lights.

Table 3

Traffic congestion problems and causes at the intersection [35]

		Number of drivers	Percent
Delay caused by traffic congestion	Always	219	87.60%
	Sometimes	31	12.40%
	Never	0	0.00%
	Sum	250	100%
Time needed to cross the intersection (minutes)	5-10	56	22.40%
	11-15	81	32.40%
	16-20	67	26.80%
	21-25	22	8.80%
	26-30	24	9.60%
	Sum	250	100%
Tram operation causes congestion at intersections	Always	159	63.60%
	Sometimes	51	20.40%
	Never	40	16.00%
	Sum	250	100%
The synchronization of the traffic lights causes congestion	Always	179	71.60%
	Sometimes	42	16.80%
	Never	29	11.60%
	Sum	250	100%

Impact of traffic congestion on drivers' behaviors

This section presents the results of the impact of traffic congestion on drivers' behaviors. It is divided into three parts.

- Stress due to traffic congestion

Fig. 5 demonstrates that 75.20% of drivers are always stressed due to congestion at the intersection. This result is so high because stress is a type of annoyance that negatively impacts the behavior of drivers, which complicates the state of road traffic at the intersection. This led us to discover the severe consequences of this problem on their behaviors.

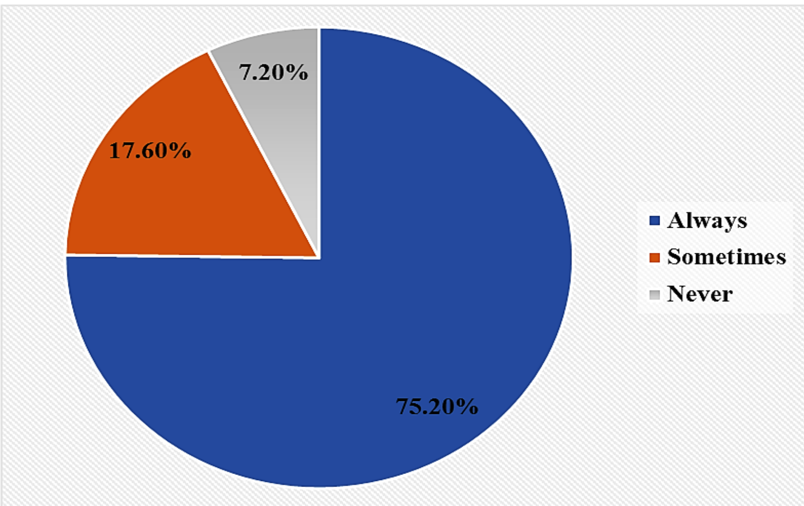

Fig. 5. Stress due to traffic congestion

- Violence due to stress

Fig. 6 illustrates the amount of violence due to the stress caused by traffic congestion. As the figure shows, 44.80% of drivers are sometimes or always violent. Many drivers commit verbal abuse, honk, tailgate cars, and cut off other drivers.

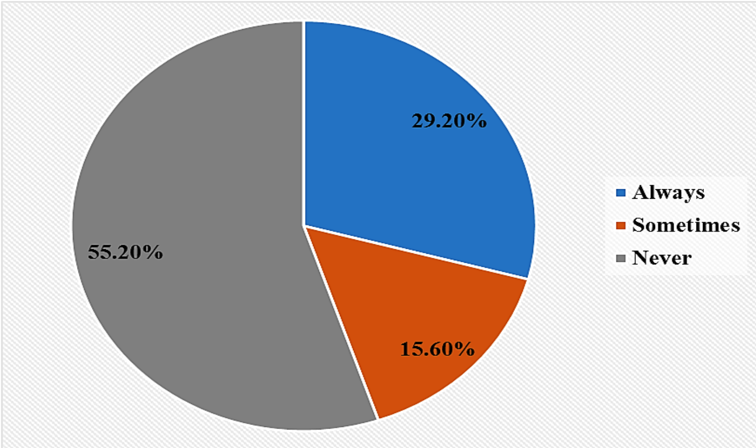

Fig. 6. Violence due to stress

- Dangerous maneuvers due to stress

Fig. 7 represents the dangerous maneuvers made by drivers due to stress. As the figure shows, 49.60% of them 49.60% change lanes and make dangerous maneuvers because of stress and impatience, and they take the risk of crossing the intersection before the tram's arrival. They also use their horn to incite other drivers to cross the intersection after the lights have already turned red.

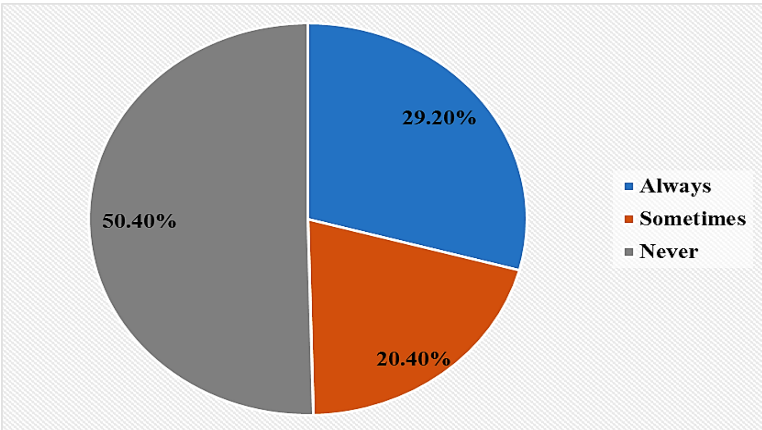

Fig. 7. Dangerous maneuvers made by drivers due to stress (ignoring red lights and changing lanes)

Sometimes, trams pass into the intersection when the light is green for motorists who traverse the line of the tram, which is very dangerous (Fig. 8). This mismanagement of the multimodal traffic system negatively influences drivers' behaviors at the intersection. For almost three years, this problem has existed, and it is time to resolve it and ameliorate the traffic control mechanisms at intersections that include tramlines. Finally, Fig. 9 shows that 90% of drivers are not satisfied with the current multimodal traffic management system because of all the causes cited previously.

Fig. 8. A disturbance in traffic light synchronization (the light is green for those crossing the tramline while the tram passes) [35]

Fig. 9. Users' satisfaction with the current multimodal traffic management at intersections

4. DISCUSSION AND CONCLUSION

The purpose of this article was to identify the real causes of congestion at intersections that contain a tramline and to explore its influneces on drivers' behaviors. The results show that at the Che Guevara junction, it is impossible to modify the geometry or expand the roads because of several constraints. Hence, it is necessary to optimize the existing infrastructure.

Unlike other articles, this paper analyzed both tram exploitation and its effect on the traffic flow situation at the same time. It also contributes to the literature by examining the opinions of road users about congestion at this intersection and how it affects their behaviors.

This study included a detailed analysis of the real and suggested travelers' demand, in addition to a comparison between a calculated proposed and real number of trams to determine whether the Constantine tram is performing well.

It has been shown that the real demand of travelers is significantly less than the proposed demand, as the number of trams applied in operation throughout the year 2018 greatly exceeded the number that could have responded to the real attendance. This poor performance caused a high traffic flow to block the intersection because of the considerable number of trams that cross it.

The high frequency of trams is not the only source of traffic jams; the inconsistency between traffic lights and the tram operation system is another main cause, as it leads to disturbances in signal timing when the rail vehicle passes through the intersection. The results show that 87.6% of drivers always get stuck in congestion at this intersection. The non-optimal multimodal traffic control has a negative impact on drivers' behaviors because it makes them stressed. Almost 50% would opt to make a dangerous decision to change lanes or cross the intersection when the tram is near the intersection.

These issues can be extra causes of congestion and can further complicate the problem, especially because they make accidents more likely. Therefore, traffic jams can be a source of accidents because of drivers' behaviors, especially those induced by stress.

5. RECOMMENDATIONS

Multiple recommendations should be implemented in order to lessen the impact of the tram fleet used in operation on other motorists and to increase traffic fluidity. This would prevent the adverse behaviors of drivers at intersections.

The establishment of an efficient timetable is necessary to ensure better management of the tram fleet and to guarantee sustainable mobility. This solution cannot be realized without an equilibrium between the tram supply (capacity or number of trams offered) and travelers' demands. Furthermore, an extensive study of tram exploitation during previous years is imperative to finding the optimal interval of time, especially during rush hour. Therefore, the increase in the time interval between trams for the optimal management of the fleet will not influence the work appointments of travelers, as it will be done according to the data in real-time to guarantee the regularity of trams, especially during rush hour.

Furthermore, the optimization of the tram's operation is an important factor in increasing fluidity for motorists. That is, when the tram interval time increases, motorists will have more time to cross junctions. Therefore, this solution can reduce the delays faced by motorists at junctions.

The optimal management of the multimodal traffic system is among the chief solutions to decrease traffic jams at junctions. The optimization of the traffic light system according to the tram control system will reduce traffic jams and limit their negative impact on drivers' behaviors. In addition, it will reduce stress among drivers, which will subsequently reduce their urge to take risks (either by changing lanes or crossing the tramline when it is dangerous to do so).

This article can serve as a reference for other papers on traffic jam problems, tram operation, and drivers' behaviors at critical junctions.

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