# Transportation Research Record

## IMPACT OF WAITING TIMES ON PEDESTRIANS' AND CAR DRIVERS' BEHAVIOR AT SIGNALIZED INTERSECTIONS

--Manuscript Draft--

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| **Full Title:** | IMPACT OF WAITING TIMES ON PEDESTRIANS' AND CAR DRIVERS' BEHAVIOR AT SIGNALIZED INTERSECTIONS |
| **Abstract:** | In order to guarantee high speed and punctuality, tramways and buses are given full priority when they cross signalized intersections. The increasing number of tramway lines keep extending the waiting times for every driver, pedestrian and cyclist. French road sign regulation decrees that the waiting time at traffic lights must not exceed 120 seconds. The transport ministry has opened discussions about modifying this rule and financed research work to assess the impact of waiting times on users' behavior and safety.<br>The behavior of 44,000 drivers was observed in five cities. The rate of running red lights clearly depends on the length of waiting times. The 120 seconds maximum could be extended for drivers on tramway crossings.<br>8,000 pedestrians were also observed. Even if the waiting time is short, 64% of the pedestrians do not comply with the red light. If it is long (between 90 and 300 seconds), it rises to 80%. An acceptability and credibility threshold exists and is less than 90 seconds. The research suggests waiting time limits should not be extended for pedestrians. |
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# IMPACT OF WAITING TIMES ON PEDESTRIANS' AND CAR DRIVERS' BEHAVIOR AT SIGNALIZED INTERSECTIONS

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## ABSTRACT

In order to guarantee high speed and punctuality, tramways and buses are given full priority when they cross signalized intersections. The increasing number of tramway lines keep extending the waiting times for every driver, pedestrian and cyclist. French road sign regulation decrees that the waiting time at traffic lights must not exceed 120 seconds. The transport ministry has opened discussions about modifying this rule and financed research work to assess the impact of waiting times on users' behavior and safety.
The behavior of 44,000 drivers was observed in five cities. The rate of running red lights clearly depends on the length of waiting times. The 120 seconds maximum could be extended for drivers on tramway crossings.
8,000 pedestrians were also observed. Even if the waiting time is short, 64% of the pedestrians do not comply with the red light. If it is long (between 90 and 300 seconds), it rises to 80%. An acceptability and credibility threshold exists and is less than 90 seconds. The research suggests waiting time limits should not be extended for pedestrians.


*Keywords*: Intersection management, behavior, road safety.

## 1. INTRODUCTION

The French legislation on road signalization states that: "the waiting time imposed on road-users should never exceed two minutes under normal circumstances. However, it may be possible that the waiting time exceeds two minutes or more, in case of exceptional circumstances involving level crossing, moveable bridge, etc."

Limiting the waiting time is not a French particularity. For instance, the German traffic light guidelines *(1)* recommend that the waiting time should not exceed 120 seconds for car drivers and 60 seconds for pedestrians and cyclists. In the USA, a cycle length between 50 and 120 seconds is recommended, with an optimum of 90 seconds. But these rules are technical recommendations and not part of national legislation.

In France, in order to guarantee high speed and punctuality, tramways and buses are given full priority when they cross signalized intersections. If a junction is frequently crossed by public transport vehicles, car drivers and pedestrians have to wait a long time before getting a green light. Examples of situations like these are when two or more trams arrive in quick succession and therefore increased waiting times occur.
The increasing number of tramway lines in France, which have their own lanes and absolute priority, keep extending the waiting times for every driver, pedestrian and cyclist.

The operators have to make a difficult choice:

- If they give full priority to public transport, they risk going over 120 seconds and therefore disrespect the regulation.
- If they respect the law, they have to slow down the public transport, making them stop at crossings which could prove complicated politically.

We conducted a first study in 2015. There are 32 tramway networks in France, so the study was based on 32 interviews with all the operators. The first results indicated that the maximum waiting times in a day were regularly over 2 minutes in 12 of the networks:

- 5 networks have maximum waiting times from 2 to 3 minutes.
- 3 networks have maximum waiting times from 3 to 4 minutes.
- 4 networks have maximum waiting times of over 4 minutes.

Everyday more than 200 tramway crossings all over France have maximum waiting times longer than 2 minutes.

On the other hand, 7 network operators decided (on approximately 100 intersections) to stop their trams at the lights to respect the regulation. When they stop the tram, if there are no pedestrians present, they give a minimum green light period to car drivers which lasts 6 seconds to relieve the immediate situation, and then give the go-ahead back to the tram driver, so they can continue without losing too much time. The issue however is that such a method has several drawbacks. Studies show that with only 6 seconds, only two or sometimes three cars have the opportunity to cross, the temptation for the third or fourth car to try and cross the intersection in-time increases dramatically and therefore the chances of further complications or even accidents rise significantly. In France, the legislation decrees that the green light periods must not be shorter than 6 seconds. In Canadian legislation *(2)*, the green light periods cannot be shorter than 4 seconds for car drivers

and 5 seconds for pedestrians. In the United States, this minimum time is calculated and depends of the geometry of the crossings *(3)*.

In this research, pedestrians, cyclists and car drivers' behavior is analysed, in order to assess the impact of waiting times on the rate of red light running. Previous research has been conducted regarding the rate of red light running. Analyses of red light running data from 19 intersections in four American states found that noncompliance rates averaged 3.2 per intersection per hour *(4)*. Similarly, a study conducted on five crossings in Fairfax City, Virginia, showed that noncompliance rates averaged 3 per intersection per hour *(5)*. Crashes resulting from red light running are frequent. An American study of 9,951 vehicles involved in fatal crashes at crossings in 1999 and 2000 estimated that 20% of the vehicles failed to obey the signals *(6)*. In 2005, more than 800 people were killed in crashes that involved red light running *(7)*. About half of the deaths in these crashes were pedestrians and occupants in other vehicles who were hit by the people who ran the red light.

As for pedestrians, the Highway Capacity Manuel *(8)* says that on signalized intersections, when pedestrians experience more than a 30 seconds delay, they become impatient, and engage in risk-taking behavior. The likelihood of noncompliance is moderate above 30 seconds, and very high above 60 seconds. Zhang et al. *(9)* showed that four variables significantly affect the probability of pedestrians' red-light running behavior, which are the trip purpose, time period in one day, pedestrian's attitude towards whether to run a red light when in hurry, and pedestrian's attitude towards whether quality of road facility affects crossing behavior. Dommes et al. *(10)* noticed that gender had no major impact on red light violations by pedestrians, but age did, with more cautious behaviors as pedestrians were older. Several factors were identified as having an impact on the proportion of pedestrian violations. In accordance with the literature, age, group size, pedestrian flow and pedestrian signals are associated to pedestrian violations. In addition, other factors were identified, such as maximum waiting time *(11)*.

Following these observations, the French transport ministry has opened discussion about modifying this regulation on tramway crossings. Before changing the maximum waiting time of 120 seconds and finding a new time limit respected by road users, we had to make sure that increasing the waiting times would not lower levels of safety for all concerned. The aim of this research is therefore to assess the impact of waiting times on behavior and safety of car drivers, cyclists and pedestrians, and to propose a new waiting time maximum for French regulation.

## 2. METHOD

Nine junctions were studied in five French cities (Lyon, Metz, Montpellier, Nantes, and Strasbourg). Waiting times and behavior were recorded by cameras over 180 hours, on Tuesdays and Thursdays, from 7 a.m. to 10 a.m. and from 4 p.m. to 7 p.m. The cameras were discreet, placed at a height of six meters, so that the people could not see them and therefore would not change their behavior. All the videos were watched and verified by real people to guarantee accuracy, no automatic software was used.

### 2.1. Pedestrians and cyclists

Behaviors of thousands of pedestrians were observed and analysed on three signalized crossings. Every crossing is located in an urban area. When the pedestrians arrive at a pedestrian light crossing, if the light is green, they of course cross. Analysis was only conducted when the light was showing red. We have divided these behaviors into four categories:

- The pedestrians arrive, the light is red, they cross immediately. They are classified in the first category "Red".
  The pedestrians arrive, the light is red, they assess the distance/time between the passing cars. As soon as a gap is long enough for them to cross, they do, without looking at the colour of the light. They are also classified in the first category "Red".
- The pedestrians arrive, the light is red, they wait. They do not look at the gaps between the cars, they decide to wait. Some of these pedestrians may have other distractions (discussing amongst themselves, reading, looking at their phone, etc). Suddenly, they lose patience, they look at the cars coming and then cross while the light is still red. They are classified in the 2nd category "Red after waiting".
- The pedestrians arrive, the light is red, they decide to wait until the light is green, then they cross. They are classified in the 3rd category "Decide to wait green".
- The pedestrians arrive, the light is red, they keep looking impatiently at the cars to find a big enough gap to cross. The traffic is heavy, there are no gaps. Suddenly, the light turns green, they cross. We consider that they had no choice but to wait. They are classified in the 4th category "Have to wait green".

The waiting times are very different on the three crossings, so we can evaluate the rates of the four behaviors described above, depending on the length of the waiting times.

The evaluation of cyclists' behavior was conducted with the same methodology.

### 2.2. Drivers

The behavior of car drivers was studied on six signalized crossings. Every colour change of the lights was systematically noted. We calculated the average length of red periods and green periods, and the minimum/maximum red periods observed on each crossing.
We counted every car crossing both during green and red periods. During red periods, we counted every car that ran the red light.
The length of waiting times vary on the six studied crossings, so we can evaluate the influence of

the waiting times on the rate of red light runners.

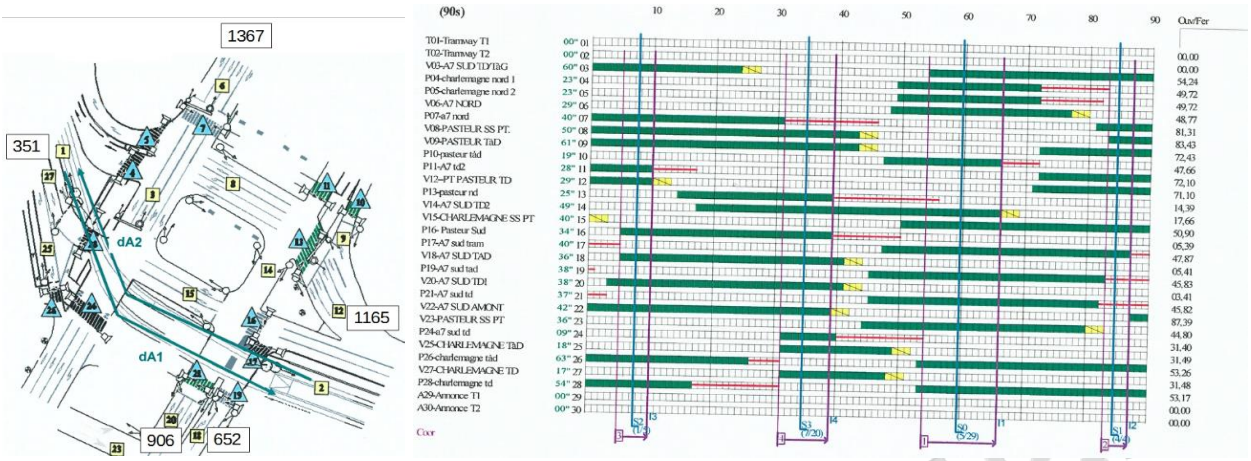


**FIGURE 1 : example of plan and diagram of a studied intersection**

## 3. RESULTS

### 3.1. Crashes

The road accidents (people injured) that occurred from 2010 to 2015 on the nine studied crossings were reviewed. Few personal accidents happened, therefore we have not been able to find a link between the waiting times and the number of accidents.

### 3.2. Pedestrians

8,000 pedestrians were observed at crossings with different lengths of red light waiting time (referred to as 'red time'). P1, P2 and P3 are three individual crossings located in three different cities, where pedestrians' and cyclists' behaviour was analysed.

**TABLE 1 Waiting times on crossings P1, P2 and P3**

| Name of the crossing | Average green time | Average red time | Maximum red time | Number of red time over 120 seconds per hour |
|---|---|---|---|---|
| Crossing P1 | 17 | 42 | 99 | 0 |
| Crossing P2 | 9 | 88 | 112 | 0 |
| Crossing P3 | 17 | 113 | 302 | 11 |

At crossing P1 with an average red time of 42 seconds and a maximum red time of 99 seconds, 36% of pedestrians will wait for the green light before crossing. At crossing P2 with an average red time of 88 seconds and a maximum red time of 112 seconds, 20% of pedestrians wait. At crossing P3 with an average red time of 113 seconds and a maximum red time of 302 seconds, 20% of pedestrians wait.

**TABLE 2 Behavior of pedestrians on crossings P1, P2 and P3**

| Name of the crossing | Number of observed pedestrians | Behavior "Red" | Behavior "Red after waiting" | Behavior "Decide to wait green" | Behavior "Have to wait green" |
|---|---|---|---|---|---|
| Crossing P1 | 753 | 57.6 % | 6.1 % | 27.2 % | 9.0 % |
| Crossing P2 | 4347 | 78.2 % | 2.0 % | 10.9 % | 8.9 % |
| Crossing P3 | 3052 | 74.0 % | 6.5 % | 14.5 % | 5.0 % |

Even if the waiting time is short, up to 64% of the pedestrians do not respect the red light. When the waiting time is long, this percentage of pedestrians rises to 80%. The remaining 20% are captive pedestrians, mostly children (alone or with their parents), elderly and disabled people. We can conclude that a waiting time from 90 to 300 seconds is too long for the pedestrian to wait. An acceptability threshold and credibility threshold exists and is less than 90 seconds.

### 3.3. Cyclists

On the three same crossings, the behavior of cyclists was studied too. However, the sample is smaller for cyclists than for pedestrians.
When the waiting time is short, about 60 % of cyclists run the red light.
When it is long, from 90 to 300 seconds, 85 % of cyclists run the red light.

**TABLE 3 Behavior of cyclists on crossings P1, P2 and P3**

| Name of the crossing | Number of observed cyclists | Behavior "Red" | Behavior "Red after waiting" | Behavior "Decide to wait green" | Behavior "Have to wait green" |
|---|---|---|---|---|---|
| Crossing P1 | 200 | 54.5 % | 6.0 % | 20.0 % | 19.5 % |
| Crossing P2 | 53 | 86.8 % | 1.9 % | 7.5 % | 3.8 % |
| Crossing P3 | 1006 | 81.0 % | 5.0 % | 10.0 % | 4.0 % |

Cyclists respect the lights even less than pedestrians. The conclusion for cyclists is the same as that of the pedestrians: 120 seconds is already beyond the acceptability threshold. If they can physically cross the road, and if the traffic is not too heavy, most cyclists will not wait at signalized intersections. The waiting times should ideally be below 90 seconds so that it remains credible.

### 3.4. Drivers

#### *3.4.1. Long red light periods*

D1, D2, D3, D4, D5 and D6 are six individual crossings located in different cities, where drivers' behaviour was analysed.
When the red light waiting time is short (referred to as 'red time'), with a maximum of 60 to 100 seconds (crossings D1, D2, D3), the rate of running red light ranges from 0.3% to 1% of car drivers.
If the red time is longer, with maximums between 140 to 300 seconds (crossings D4, D5), the rate is between 1.2% and 1.3%.

**TABLE 4 Waiting times on crossings D1 to D6**

| Name of the crossing | Average green time | Average red time | Maximum red time | Number of red time over 120" per hour |
|---|---|---|---|---|
| Crossing D1 | 79 | 24 | 87 | 0 |
| Crossing D2 | 87 | 21 | 58 | 0 |
| Crossing D3 | 53 | 41 | 105 | 0 |
| Crossing D4 | 32 | 87 | 143 | 3.8 |
| Crossing D5 | 41 | 82 | 298 | 4.5 |
| Crossing D6 | 14 | 162 | 758 | 11 |

On crossing D6 with an average red time of 162 seconds, and a maximum red time of about 12 minutes, the acceptability threshold is exceeded. 25.6% of car drivers run the red light. Moreover, if a driver accepts it and waits for the green light, they block the other drivers behind them and prevents them from potentially running the red light. Therefore, 25.6 % of drivers ran the red light, but the rate of drivers who wanted to do so could have been even higher.

**TABLE 5 Behavior of car drivers on crossings D1 to D6**

| Name of the crossing | Number of observed cars | Number of red light runners | Percentage |
|---|---|---|---|
| Crossing D1 | 16755 | 134 | 0.80 % |
| Crossing D2 | 1036 | 11 | 1.06 % |
| Crossing D3 | 9590 | 28 | 0.29 % |
| Crossing D4 | 11280 | 145 | 1.29 % |
| Crossing D5 | 4923 | 58 | 1.18 % |
| Crossing D6 | 687 | 176 | 25.6 % |

*3.4.2. Short green light periods*

We saw that too long red time periods can cause an increase of red light runnings. But too short green time can have the same effect because it creates a frustration effect on drivers. We have therefore added a specific study of those short green periods.
Those short time green periods cause a very high rate of red light running. When those periods last 6 or 7 seconds, 32 % of drivers crossed during red times. It is 3 times more than for periods of 8 to 10 seconds, and about 10 times more than for periods of 11 to 15 seconds.

**TABLE 6 Behavior of car drivers on crossing D1 depending on the green period length**

| Green light period length | Number of studied periods | Traffic (vehicles) | Number of red light runners | Percentage |
|---|---|---|---|---|
| 6 - 7 seconds | 24 | 60 | 19 | 32 % |
| 8 - 10 seconds | 15 | 63 | 8 | 13 % |
| 11 - 15 seconds | 36 | 154 | 5 | 3 % |

However, it is difficult to compare those figures to the previous ones, for this reason. During a 6 second green period, two drivers can cross, the third and fourth ones have to make a choice of stopping or running the red light. During a fifty second green period, 25 drivers can cross during this green time. The $26^{th}$ and $27^{th}$ drivers arrive during this critical moment, when the light turns yellow and then red. They now have to make a choice whether to stop or to accelerate. It is obvious that the percentage of drivers who run the red light will be far higher during very short green periods. If we want to compare the figures precisely, we have to compare the rate of signalling cycles during which a driver ran the red light.

*3.4.3. Rate of signalling cycles with a red light infringement*

To be able to compare the figures, it is important to study the infringements per lane. On a four-lane-road, 4 drivers potentially arrive during the critical moment when the light turns red. Statistically, it is 4 times more probable to observe a red light infringement on a four-lane-road than on a single-lane-road.

On crossings D2 and D3 (waiting time from 60 to 100 seconds), only 3 to 4% of cycles have a red light infringements.

On crossings D4 and D5 with a long waiting time, between 10 and 11% of cycles are concerned by a red light infringement. We can conclude that the waiting time has an impact on the rate of infringements. But this rate is similar on D4 (maximum waiting time of 140 seconds) and on D5 (maximum waiting time of 300 seconds).
On crossing D6, where waiting times can reach 8 to 12 minutes, 36% of signal cycles have a red light infringement.

It is hard to compare precisely a red light infringement rate on short green periods and on long red periods. However, we can conclude that six-second-long green periods cause five times more infringements than 11-15 second-long green periods.

**TABLE 7 Percentage of cycles with a red light infringement on crossings D1 to D6**

| Name of the crossing | Green period length | Maximum red period length | Number of studied cycles | Percentage of cycles with a red light infringement |
|---|---|---|---|---|
| Crossing D1 | All green periods | 90 | 839 | 8 % |
| Crossing D1 | 6 - 7 seconds | 90 | 24 | 40 % |
| Crossing D1 | 8 - 10 seconds | 90 | 15 | 27 % |
| Crossing D1 | 11 - 15 seconds | 90 | 36 | 7 % |
| Crossing D2 | | 60 | 400 | 3 % |
| Crossing D3 | | 100 | 689 | 4 % |
| Crossing D4 | | 140 | 363 | 10 % |
| Crossing D5 | | 300 | 527 | 11 % |
| Crossing D6 | | 750 | 244 | 36 % |

We can conclude that very long red periods (more than 6 minutes) and very short green periods (less than 10 seconds) cause many more infringements than normal periods.

The diagram below summarises the impact of waiting times on drivers' behavior. It shows the rate of infringement as a function of the length of green periods (on the left) and red periods (on the right).

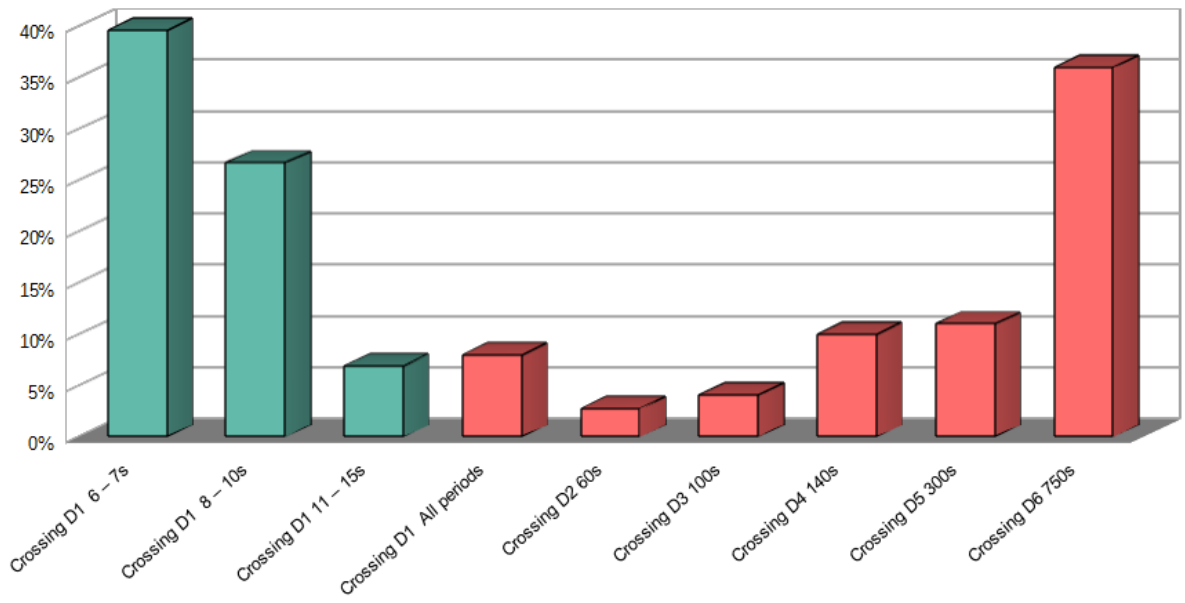


**FIGURE 2 : Rate of infringements in relation to green and red times**

## 4. DISCUSSION

Wang et al. *(12)* showed that increasing red light time would increase the likelihood of violation because pedestrians become more impatient and aggressive as the waiting time increases. The cycle time also plays an important role in crossing behavior long with green ratio.
Yang et al. *(13)* have collected pedestrian red-time crossing, signal control, crossing facility design and vehicle traffic flow data with field observation, and pedestrian's decision-making psychology data was collected with questionnaire after the crossing. The duration of red signal time was found to be the biggest influence on pedestrian red-time crossing. Red signal time is the factor of greatest influence in models based on both integrated field observation and questionnaire data and single observation data. They proved that the longer red signal is, pedestrian are more likely to perform red-time behavior. Therefore, long red signal time is the biggest reason of pedestrian red-time crossing in China. They concluded that it is most urgent to reduce pedestrian waiting time at intersections to reduce pedestrian red-time crossing. The results also show that pedestrian red-time crossing are more likely to happen where crossing distance is short. Considering the influence of red signal time, this means that pedestrian red signal time should be reduced at intersections where pedestrian crossing distance is short to reduce pedestrian red-time crossing.

Considering that the red signal time was the factor of greatest influence, our research contributed to quantify the rates of red light running in accordance to the length of waiting time. The research also estimated the duration of an acceptability threshold for pedestrians, cyclists and car drivers.
It was well-known in the literature that longer red time periods would increase the rate of infringement, but it was not expected that short green time periods would have such a negative impact on the behavior of car drivers.

The results of the research should be useful for the engineering teams responsible for the traffic signal controls. The results can also help to modify national regulations about red light maximum time or green light minimum time.

## 5. CONCLUSION

This research studied the behavior of thousands of pedestrians, cyclists and car drivers on nine crossings. The first result shows that few pedestrians respect the red light overall. When the red light waiting time is short (about 40 seconds), 64% of pedestrians do not respect the red light. When it is longer (between 90 and 300 seconds), about 80% of pedestrians cross during red time. An acceptability and credibility threshold exists, above which pedestrians try to cross as soon as possible, regardless of the colour of the light. A waiting time of 120 seconds is already beyond this threshold. The pedestrians who respect meticulously the lights are more than often children, elderly or disabled people. Pedestrians are vulnerable. Making them wait for a long time incites them to cross when the red light is on and they care more about the gaps between cars than the colour of the light. The analysis is the same for cyclists. In the current context, we are trying to give more space to pedestrians and cyclists and improve their level of safety. It is inadvisable to extend the maximum waiting time of 120 seconds for pedestrian crossings. According to the evidence, the waiting times should last less than 90 seconds.

As for car drivers, the results of this study show that the rate of red lights running is low if the

waiting time is less than 100 seconds, with only one instance in 4% of signalling cycles. This rises to 10% when waiting times are between 100 and 300 seconds. A waiting time between three and five minutes does not cause more drivers to run the red light than a waiting time of two minutes if the car driver sees the tram and thus understands why he has to wait. A waiting time from three to five minutes is accepted and therefore respected by car drivers. A threshold does in fact exist, above which car drivers do not respect the waiting time and will run a red light, even if a tramway is coming. A waiting time of between six and twelve minutes exceeds this threshold. Beyond this threshold rates of 35% of signalling cycles with instances of drivers running the red light were observed. On a normal crossing, the maximum of 120 seconds should be respected. On tramway crossings, when several trams arrive in quick succession and cause increased waiting times, the waiting time could be extended to a maximum of three to five minutes without lowering levels of safety. But red periods longer than five minutes must be avoided at all costs.

Extended red time periods cause an increase of red light running, but too short green time periods have an effect that can be even worse. When the tram is stopped in order to respect the 120 second rule, the operators give a minimum green light period to car drivers which lasts 6 seconds to relieve the immediate situation, and then give the go-ahead back to the tram driver, so they can continue without losing too much time. Traffic light cycles with shorter green intervals, from six to seven seconds, show five times more instances of drivers running the red light than those with green intervals of 11 to 15 seconds. A very long red time seems to have less impact on behavior than a too short green time whose only aim was to prevent exceeding the maximum waiting time. The green periods of 6 or 7 seconds should be avoided to keep the lights' credibility and maintain the users' safety.

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## Author Contribution Statement

The authors confirm contribution to the paper as follows:
study conception and design: N. Speisser, C. Damas, S. Lab ;
data collection: N. Speisser, S. Lab;
analysis and interpretation of results: N. Speisser, S. Lab;
draft manuscript preparation: N. Speisser.
All authors reviewed the results and approved the final version of the manuscript.

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