Understanding pedestrian red light violation: Exploration of the impact of traffic engineering and traffic conditions

Luc Pellecuer[1], Aurélien Chusseau[2]

[1] University of the West of England, Frenchay Campus, Coldharbour Ln, Bristol BS16 1QY
[2] Île-de-France Mobilités, 39-41 rue de Chateaudun, 75009, Paris, France

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Abstract
The design of the geometry and traffic controls at signalised junctions is often focused on the level of service offered to drivers and rarely takes into consideration the level of service offered to pedestrians. This results in pedestrian adopting illegal and unsafe behaviours – e.g. red light violation. This study aimed to identify the elements of signalised junction design that are critical in pedestrian safety by analysing how they affect pedestrian behaviour. Both traffic engineering design (e.g. junction geometry) and associated traffic conditions (e.g. traffic speed) were investigated. Over 6500 observations had been made at 10 signalised junctions in the city centre of Montreal, Canada. The 10 junctions were selected to ensure that a variety of environments, road users and junction designs were covered. Results show that the presence of a countdown display has the most significant and positive impact on pedestrian behaviour. Results also suggest that pedestrians cross at the red light when they feel confident about their ability to judge whether they can use the available traffic gaps to cross safely the street.

1. INTRODUCTION

The design of the geometry and traffic controls at signalised junctions is mostly focused on the level of service offered to drivers and rarely takes into consideration the level of service offered to pedestrians (Cohen and Almarwani, 2021). This often leads to poorly designed junction and to pedestrians waiting longer at signalised junctions. As a consequence, pedestrians are more prone to unsafe behaviours, such as red light crossing (Brosseau et al., 2013; Chen et al., 2017).

As the number of pedestrians in the streets keeps increasing, pedestrian behaviour has been extensively studied over the last decades (Feng et al., 2021). In particular, because of their relative vulnerability, the behaviour of pedestrians at signalised junctions and pedestrian red light violations have been the focus of many research projects. Dommes et al. (2015) reported the literature frequently associates pedestrian crossing at red light with vehicular traffic conditions, waiting time and length of crossing.

Understanding why pedestrians cross during the red phase is crucial for traffic engineers so they can design junctions that provide a level of service that is acceptable to every type of users and to ultimately improve the safety at the junctions.

This study aims to explore the impact of traffic engineering and traffic conditions on pedestrian red light violation and to identify elements that need special attention when designing the junction. It is anticipated that the results of this study will help improve the level of service offered to pedestrian and thus limit pedestrian risky behaviours.

2. LITERATURE REVIEW

Pedestrian behaviour is complex and depends on a variety of factors that can be categorised as individual-related (e.g. demographics), junction-related (e.g. junction layout, traffic light cycle characteristics), and environmental-related factors (e.g. vehicle traffic characteristics, weather).

The individual related factors that are considered in the literature are often limited to gender and/or age – e.g., Brosseaud et al. (2013), Guo et al. (2011), Raoniar and Maurya (2022), and Zhu et al. (2021). Young people and men are generally found to be more likely to cross at the red light (Bendak et al. (2021); Brosseaud et al. 2013, Guo et al., 2011). However, differences of behaviour were not observed between genders by Raoniar and Maurya (2022) or Dommes et al. (2015). Zhu et al. (2021) also found that men are generally found to be more likely to cross at the red light, but reported that younger people were less likely to cross at the red light than older people. The authors suggest this might be explained by younger people in Hong Kong having a relatively higher level of education. In addition to gender and age, Zhu et al. (2021) included in their study other personal characteristics, namely if the individual carried a baggage, walked with children or a companion. The first two factors were not statistically significantly associated with a higher rate of red light violation. The presence of a companion was shown to reduce the risk of red light violation though.

Junction-related factors are associated with the design of the junction and the traffic engineering facilities in place. Longer crossings are consistently shown to reduce the likelihood of red light violation (Afshari et al., 2021). Pedestrian behaviour is shown to vary depending on the number of lanes crossed. Bendak et al. (2021) observed that 13.9% of pedestrians crossed at the red light at two-lane junctions, 19% at three-lane junctions and 0% at four lane junctions. Zhu et al. (2021) found that an increase in the number of lanes is significantly correlated with a decrease in red light violation. In the research published by Marisamynathan & Vedagiri (2018), 46% of pedestrians report that they do not comply with red lights to save time and for convenience. This is in line with the observations made by Bendak et al. (2021) Brosseau et al. (2013), Chen et al. (2017), and Raonar and Maurya (2022) that pedestrian violations are associated with longer waiting time. The presence of a countdown is found to reduce the probability of red light violation by Brosseaud et al (2013) and Lipovac et al. (2013). The impact of dedicated road marking was reported by Koepsell et al. (2002) to be minimal for older pedestrians in the U.S. More recently, Mukherjee and Mitra (2020) observed in Kolkata city (India) that the absence of marking was associated with relatively higher pedestrian violations.

The environmental-related factors that are very often considered in the literature are vehicle traffic characteristics. Zhu et al. (2021) and Afshari et al. (2021) found that red light violations are less likely when the traffic volume. Zhu et al. (2021) also found that red light violations are less likely when percentage of heavy vehicles increase. Weather is also proven to affect pedestrian behaviour, with more pedestrians adopting non-compliant behaviour in cold weather and when it is snowing (Li & Fernie, 2010). Bendak et al. (2021) reported that in Sharjah (UAE) pedestrians are more likely to cross at the red light in hot weather. The impact of the presence and behaviour of other pedestrians on pedestrian behaviour has also been investigated. Raoniar and Maurya (2022) found that pedestrians in Kolkata city (India) tend to reproduce the behaviour of others. Pedestrians are less prone to cross when the light is red if other people wait at the curb, but are more likely to violate the signal if a significant number of pedestrians successfully cross the roads. Zhu et al. found similar results from their study of junctions in Hong Kong.

3. RESEARCH DESIGN AND METHODOLOGY

This study hypothesises that pedestrian behaviour at signalised junction is the result of the interactions between the pedestrians, the junction, and external factors – i.e. environmental factors. Figure 1 briefly describes the main factors associated with those three elements.

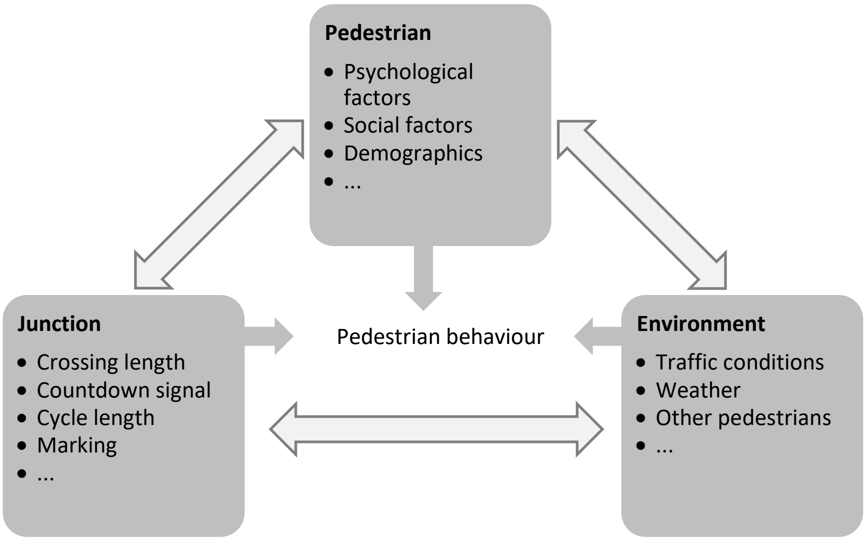

Figure 1: Interactions affecting the pedestrian's behaviour.

Although considering the three elements would lead to a better understanding of pedestrian behaviour, this study focused on the factors associated with the junction and environment. Following a review of the literature (Brosseau et al., 2013; Marisamynathan & Vedagiri, 2018), ten factors associated with the junction and environment were considered in this study. Most of them are regularly reported as significantly affecting the pedestrians' behaviour, while the others were choices made by the authors. Amongst the ten factors, eight were directly obtained from the collected data:

- motorised vehicle flow at the junction;
- motorised vehicle speed in the junction;
- pedestrian flow;
- length of pedestrian crossing;
- presence of countdown for pedestrian crossing;
- presence of pedestrian crossing marking;

- type of approach crossed;
- maximum waiting time for pedestrians.

The remaining two, namely pedestrian character of the junction and pedestrian group effect, were estimated based on calculations and observations, respectively.

3.1 Data collection

In this study, data was collected through field observations in the city centre of Montreal, Canada. Field observations allows the observers to study pedestrian behaviour in their natural environment as unobtrusively as possible (Feng et al., 2021). In addition to pedestrian observations and manual counts, appropriate data was collected to be able to investigate the factors listed above.

Pedestrian data

A total of 6623 pedestrians had been observed at ten junctions over ten observation sessions.

To maximise the possible number of observations, the study sites were chosen in the centre of the city. The location of observation sites was selected ensure that a variety of junctions and neighbourhood types were included in order to avoid any bias due to the location of the study sites. A total of ten junctions were selected in the central boroughs of Ville-Marie (6 sites – see Figure 2) and Plateau-Mont-Royal (4 sites – see Figure 3). Table 1 shows the key characteristics of each site.

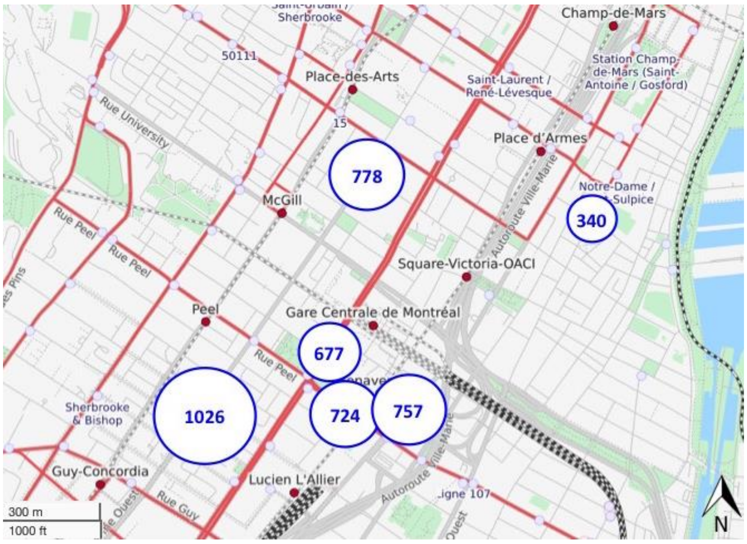

Figure 2: Distribution of the number of pedestrians observed in Ville-Marie borough.

Figure 3: Distribution of the number of pedestrians observed in Plateau Mont-Royal borough.

Table 1: Key characteristics of Montreal boroughs where observations were made

Borough	Neighborhood	Number of pedestrians observed	Neighborhood description		
			Characteristic activities	Buildings	Space: roads and sidewalks
Ville-Marie	Ville-Marie	3184	• Business district (important home-work flow) • Montreal shopping hotspot (Sainte-Catherine Street) • University area (McGill University and Concordia University)	• High concentration of skyscrapers	• Wide avenues • Standard sidewalks
	Old Montreal	340	• One of the most touristic areas of the city • Many places of entertainment	• Old quarter with buildings that rarely exceed 5 floors	• Narrow roads with paved sections • Narrow sidewalks
	Quartier des Spectacles	1257	• Arts and entertainment district • Nightlife • University area (UQAM University)	• High buildings	• Standard roads • Large pedestrian spaces (esplanades, cut off road traffic on several sections of St. Catherine Street)
	Gay Village	525	• Predominantly residential neighborhood • Nightlife • University area (UQAM University)	• Buildings rarely exceed 5 floors	• Standard roads • Large pedestrian spaces (cut off road traffic on St. Catherine Street)
Plateau Mont-Royal	Plateau Mont-Royal	1317	• Predominantly residential neighborhood • Presence of many places of entertainment	• Buildings rarely exceed 5 floors	• Narrow roads • Standard sidewalks

To make a maximum of observations, the data collection was initially planned to take place during peak hours. However, a pre-study test session showed that the high volume of pedestrians during morning peak hour would make it impracticable to manually record the observations. As a result, observations were made around the lunch time and the end of business, and the ten observation sessions took place between 10:30 and 18:30 from 03/07/2018 to 06/07/2018. Each session lasted 65 minutes on average**.** Table 2 shows the distribution of the number of observations according to the time and date and site of observations.

Table 2: Count of pedestrians observed according to the day, time, and observation site.

Observation time and date	Junction									
	Mont-Royal/ Rivard	Notre-Dame/ Saint-François Xavier	Peel/ Canadiens-de-Montréal	René-Levesque/ Metcalfe	Saint-Antoine/ Cathédrale	Saint-Laurent/ Rachel	Sainte-Catherine/ Berri	Sainte-Catherine/ Crescent	Sainte-Catherine/ Hôtel-de-Ville	Sainte-Catherine/ Saint-Alexandre
03/07/2018	0	0	724	0	0	0	0	1026	0	0
14:00-15:00			133							
15:00-16:00			333							
16:00-17:00			258							
17:00-18:00								755		
18:00-19:00								271		
04/07/2018	0	340	0	0	757	0	525	0	479	0
10:00-11:00							396			
11:00-12:00							129		286	
12:00-13:00									193	
15:00-16:00					285					
16:00-17:00					472					
17:00-18:00		249								
18:00-19:00		91								
05/07/2018	885	0	0	0	0	432	0	0	0	0
14:00-15:00	639									
15:00-16:00	246									
16:00-17:00						240				
17:00-18:00						192				
06/07/2018	0	0	0	677	0	0	0	0	0	778
16:00-17:00				476						
17:00-18:00				201						
18:00-19:00										778
Total	**885**	**340**	**724**	**677**	**757**	**432**	**525**	**1026**	**479**	**778**

Pedestrian were counted manually using a digital counting system with digital clickers developed in MS Excel. The choice of this system was made to minimise the influence of human bias observed in traditional manual methods – i.e. with sheets or clickers.

Other data collected

Traffic signal being dynamically controlled, traffic signal timings were measured manually. To ensure any disruption to traffic and avoid any safety issue, crossing lengths were measured in Google Maps. Motorised traffic speeds were measured with the *Traffic Advisor Radar™* radar gun. Pedestrian and motorised traffic flows were obtained from the *Données ouvertes* website of the city of Montreal. Data was not available for the Mont-Royal/Rivard and Saint-Laurent/Rachel junctions. Therefore, flows were inferred from those of Mont-Royal/Berri and Saint-Laurent/Mont-Royal.

3.2 Derived data

The pedestrian character of a junction is an indicator that was developed for this study that aims to represent the friendliness of the junction to pedestrians. It basically accounts for the relative flows of pedestrians and motorised vehicles and is computed as follows:

$$PC = \frac{Vol_{ped}}{Vol_{mot}}$$

where Vol_{ped} is the average daily volume of pedestrians at the junction between 06:00 and 18:00

Vol_{mot} is the average daily volume of motorised vehicle at the junction between 06:00 and 18:00

The pedestrian group effect was monitored using the counting system described above. This factor represents the number of pedestrian crossings during the red phase that were initiated by one or more pedestrians. The number was directly estimated by the observer. It was the number of pedestrians who visibly changed their behaviour and followed one or more pedestrians who crossed the junction during the red phase.

3.3 Data analysis

Data was analysed differently depending on the nature of the variable observed – see Table 3. Correlation coefficients were computed for continuous variables. On the other hand, categorical variables were simply analysed from the graphic representation of the observations.

Table 3: Nature of the factors studied.

Factor studied	Nature
Motorised vehicle flow at the junction	Continuous variable
Pedestrian character of the junction	
Pedestrian group effect	
Motorised vehicle speed in the junction	
Pedestrian flow	
Length of pedestrian crossing	
Presence of countdown for pedestrian crossing	Categorical variable
Type of approach crossed	
Presence of pedestrian crossing marking	
Maximum waiting time for pedestrians	

4. RESULTS AND DISCUSSION

Out of the six continuous factors investigated, five were found to be correlated with the number of red light crossings – statistically significant at 5% level. The Pearson correlation coefficients for the six factors are presented in Table 4.

Table 4: Pearson's relations between studied factors and pedestrian crossings during the red phase.

Factor	R	R^2
Motorised vehicle flow	-0.880	0.775
Pedestrian character of the junction	0.841	0.707
Motorised vehicle speed	-0.745	0.555
Group effect	0.594	0.353
Length of the pedestrian crossing	-0.548	0.300
Pedestrian flow	0.128*	0.016*

* not statistically significant

The pedestrian flow is the only factor considered not to be significantly correlated with violation behaviours. Interestingly, Ashfari et al. (2021) came to the same conclusion. However, other authors reported that the pedestrian flow decreases the probability of violations (Brosseaud et al., 2013).

Figures 4-8 show the distribution of the frequency of pedestrian crossings at the red light according to the motorised vehicle flow, pedestrian character of the junction, motorised vehicle speed, group effect, and length of the pedestrian crossing, respectively.

Figure 4 shows that the motorised vehicle flow is negatively correlated with the number of violation behaviours. This confirms the findings from Ashfari et al. (2021). Looking at this factor in more detail, the observations show that pedestrian behaviour is highly correlated with the motorised vehicle flow – R^2 value of 0.775. This is in contradiction with Zhu et al. (2021) who showed that traffic volume only marginally impacts pedestrian behaviour. This difference may be due to the value of traffic flow used in this study that was not necessarily representative of the traffic conditions at the time of the observations as only average daily traffic data was available.

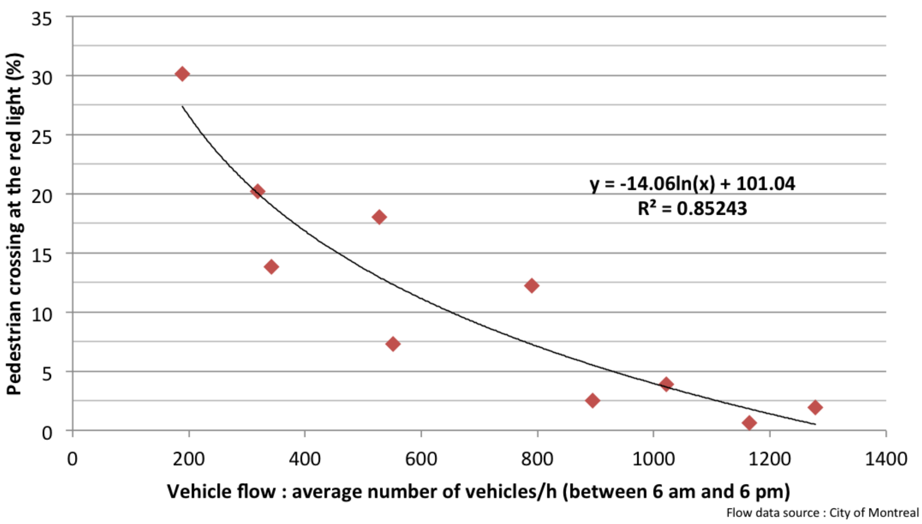

Figure 4: Relation between vehicle flow and pedestrian crossing during the red phase.

Figure 5 shows that violation behaviours are highly correlated with the pedestrian character of the intersection. This may be explained by the pedestrian's perception of the environment. They may feel safer in an environment predominantly pedestrian and thus more prone to risk crossing at the red light.

Figure 6 shows the exponential relation between the percentage of crossings at the red light and the motorised vehicle speed. This may be explained by the pedestrians less wanting to cross the street when vehicles move at higher speed as they are less able to evaluate whether gaps in the motorised traffic are safe for them to cross (Kadali and Vedagiri, 2016).

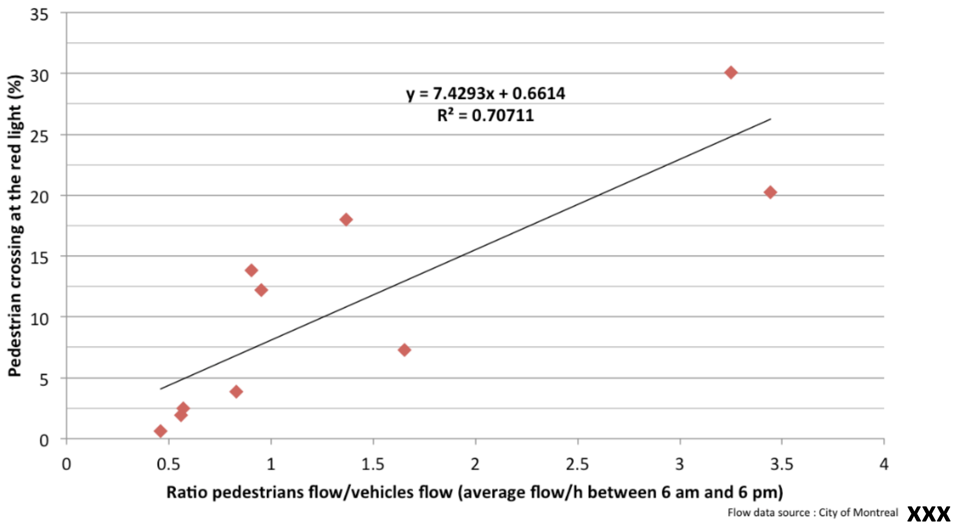

Figure 5: Relation between the pedestrian character of an intersection and pedestrian crossing during the red phase.

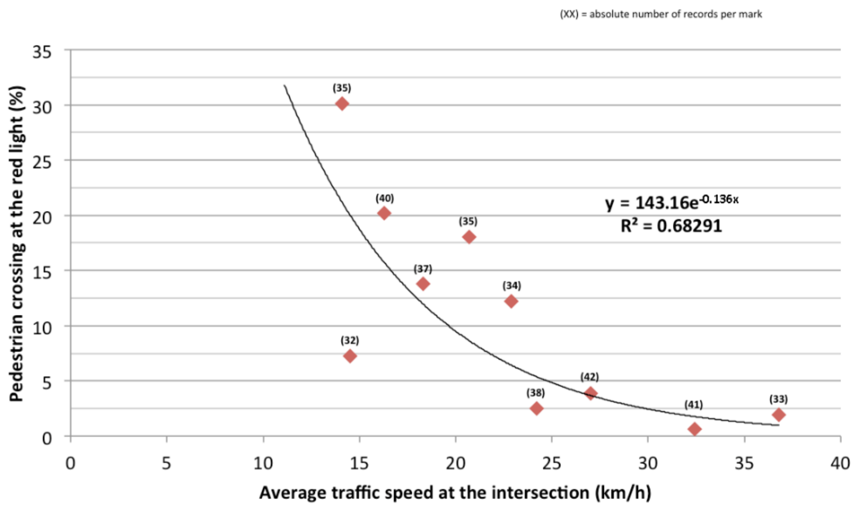

Figure 6: Relation between traffic speed and pedestrian crossing during the red phase.

Figure 7 shows that the number of pedestrian crossings during the red phase is correlated with the number of group effects observed. Similarly, Zhu et al. (2021) and Ashfari et al. (2021) estimated that pedestrians were impacted by the behaviour of the other pedestrians around them and would more often cross during the red phase if others did it during the same cycle.

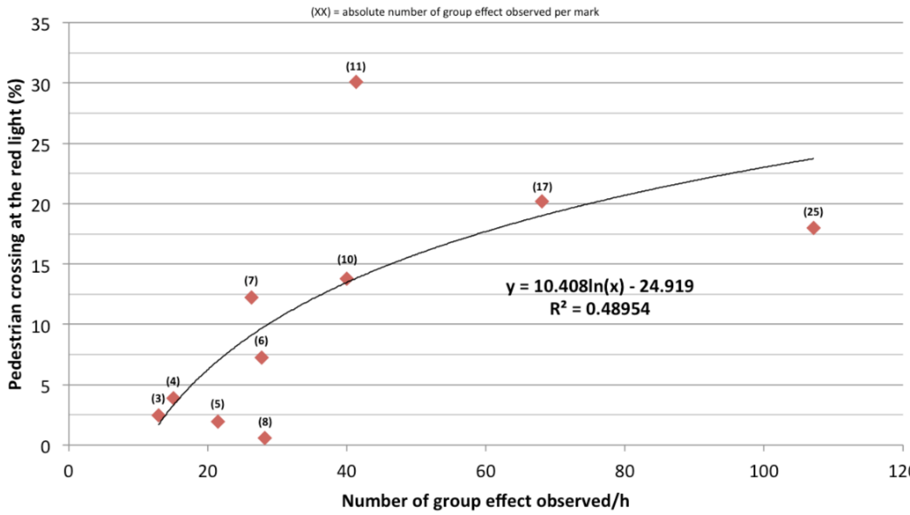

Figure 7: Relation between the number of group effect observed and pedestrian crossing during the red phase.

Figure 8 shows that the length of the pedestrian crossing is negatively correlated with the number of violation behaviours. This confirms findings from Ashfari et al. (2021). Similarly to the effect of motorised vehicle speed, this may be explained by the pedestrians less wanting to cross the street as the longer distance to cover make them less able to assess whether gaps in the traffic would give them enough time to cross safely the street.

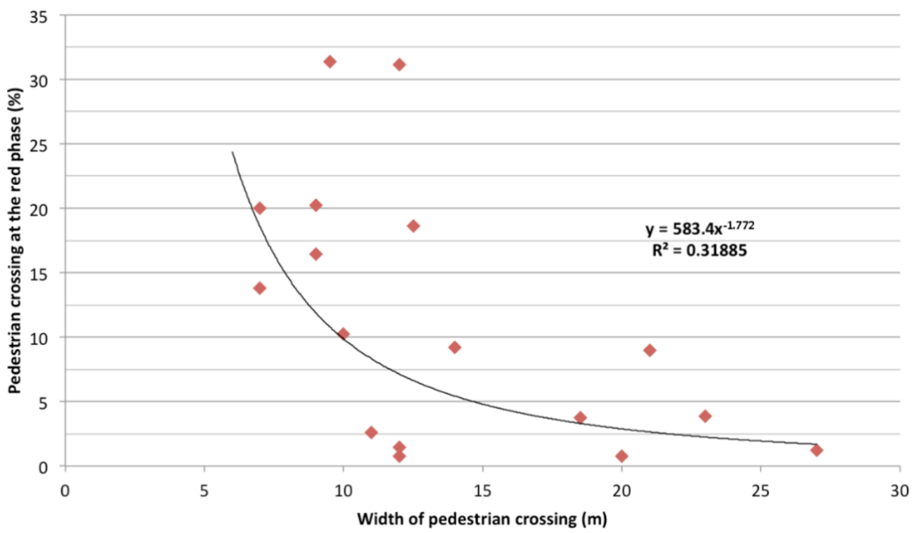

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Figure 8: Relation between length of pedestrian crossing and pedestrian crossing during the red phase.

Figure 9 shows the how the frequency of crossings during the red phase varies according to the factors of categorical nature. According to the observations, pedestrians tend to cross during the red phase relatively less frequently when a countdown is present (11% against 24%). This is in accordance with Chen et al. (2007) and Brosseaud et al. (2013) who reported a 15% decrease of violation behaviour when a countdown is present. This is also in agreement with Lipovac et al. (2013) who stated that “pedestrians cross the road statistically significantly less at the red light after the installation of countdown displays”.

Results also show that pedestrians tend to cross more frequently when crossing a one-way approach. The relatively reduced task complexity of crossing a one-way street (Cambon de Lavalette et al., 2009) is likely to explain this result as pedestrian would be able to assess more easily whether it is safe to cross.

The effects of the marking and of the maximum waiting time on pedestrian behaviour are not clear. The absence of clear relation is likely to be due to the specific characteristics of the site selected or to the low number of observations. Therefore, including a greater number of observation sites and more observations would allow to further investigates the impact of those two factors on pedestrians’ behaviour.

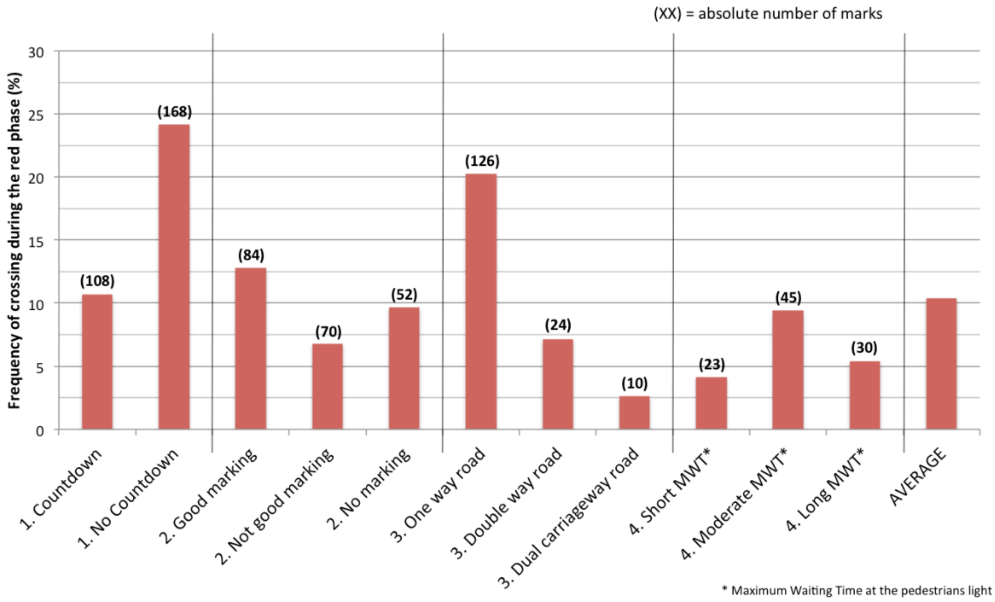

Figure 9: Frequency of crossings during the red phase (in %) according to the factors studied.

5. CONCLUSIONS

It is crucial to understand why pedestrians cross during the red phase to be able to design junctions that are safe for them. This study aimed to identify the elements of signalised junction design that are critical in pedestrian safety by analysing how they affect pedestrian behaviour. Over 6500 observations have been made at 10 signalised junctions in the city centre of Montreal, Canada. The 10 junctions were selected to ensure that a variety of environments, road users and junction designs were covered.

Results show that, amongst the design elements covered by the study, the presence of a countdown has the most significant and positive impact on pedestrian behaviour. Results also suggest that pedestrians cross at the red light when they feel confident about their ability to judge whether they can use the available traffic gaps to cross safely the street.

This contribution of this study is naturally limited by the methodology employed. A greater number of observations at more sites and during other time periods and a finer analysis of the observations would help confirm whether the results presented here are valid in other circumstances. Moreover, to be able to help traffic engineers design safer junctions, further research is needed to investigate the impact of other elements of junction design on pedestrian behaviour.

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