# The Impact of Traffic Lights on Dangerous Pedestrian Crossings and Violations: a Case Study in Montreal

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**ABSTRACT**

Pedestrian violations of signals and dangerous crossing situations at intersections are commonly observed. The objective of this study was to determine the impact of pedestrian waiting time at an intersection, due to phasing, time of arrival and the presence of a pedestrian signal on the proportion and type of pedestrian violations and dangerous crossing situations. Seven intersections with similar geometry and traffic conditions but different maximum waiting times, four of which had a pedestrian signal, were observed over at least two hours to collect crossing information. Data was collected manually for the main analysis and with a video camera for the validation of results.

Many factors were identified as having an impact on the proportion of violations. Some confirmed the literature, such as age, sex, group size, conflicting vehicle flow and pedestrian signals. New factors were identified in this research such as maximum waiting time (red phase). It was also determined that an intersection's clearing time had an impact on violations and on the proportion of dangerous crossings committed. Also, pedestrians' speeds depended on the type of crossing. The results underline the importance of providing pedestrian signals and paying particular attention to pedestrian maximum waiting time as well as clearing time.

## INTRODUCTION

In its most recent transportation plan (1), Montreal has implemented a pedestrian charter to ensure that pedestrian needs are considered and to improve their safety. Crossings are where pedestrians are exposed to motorized traffic and are most vulnerable. They are even more vulnerable when crossing outside of the crosswalk or during a conflicting phase at a signalized intersection, since other road users will not expect their encounter. Fortunately, pedestrian violations rarely lead to collisions. Nevertheless, pedestrian violations are the primary factor in 13 % of all pedestrian deaths in road accidents in Canada (2).

According to the Quebec Highway Safety Code (QHSC) (3), in the presence of a pedestrian signal, pedestrians can start crossing on the walking man silhouette. Pedestrians cannot start crossing on the flashing hand, unless there is a countdown present, in which case pedestrians can start on the flashing hand, as long as they finish crossing before the steady hand. If there is no pedestrian signal, pedestrians can only start crossing on the green light (3). Violations in the following study are crossings that started on the yellow light, red light, steady hand, or on the flashing hand (with the exception of countdown signals). Dangerous crossings are crossings performed at least partly on the red light that expose pedestrians to conflicting traffic. According to the QHSC, pedestrians have the legal right of way at an intersection at all times, meaning if a pedestrian started crossing legally but finished too late, it is not considered a violation (3).

Determining what factors influence the proportion of violations and dangerous situations will help authorities understand what can be implemented to reduce the number of violations and dangerous crossings. These include engineering countermeasures, enforcement and education actions. From this, a reduction in the number of unexpected encounters should occur on the roadway, which can only have a positive impact on safety.

This work presents an analysis of pedestrian violations and dangerous crossings at signalized intersections and their relationship with factors such as maximum waiting time (red phase) at an intersection, time of arrival, and the presence of a pedestrian signal. To our knowledge, pedestrian crossing behavior has not been studied with respect to these factors. Time of arrival is the time (phase) at which the pedestrian arrived. This research hypothesizes that time of arrival and intersection maximum waiting time are factors influencing the proportion of dangerous crossing situations and violations. This study will determine if they should be taken into consideration in future research.

The background of this work is presented in the next section. It is followed by a description of the proposed methodology, the experimental results and the conclusion.

## BACKGROUND

Factors influencing a pedestrian's decision to commit a violation have been widely studied. Some factors concern pedestrians themselves while others are linked to external factors. Studies have determined that men have a tendency to commit more violations than women (4) (5) (6) and young adults tend to violate a traffic light more often than other age groups. As people age, they are less likely to take risks while crossing the road, due in part to their declining mobility (7) (8). The people surrounding a pedestrian will also affect his crossing behavior. The larger the group of pedestrians, either travelling together or waiting at an intersection, the less likely a pedestrian will violate the traffic control (4) (7). Teenagers, however, are more likely to violate traffic control in a larger group: Rosenbloom suggests that teenagers travelling with their peers tend to take bigger risks for reasons such as social acceptance (4). The motive of travel is also likely to impact the decision to commit violations. People traveling to work or school are likely to commit more violations than people traveling leisurely (8).

A pedestrian's decision to violate traffic signalization will also be affected by the characteristics of the intersection. Factors such as the presence of a pedestrian signal have been proven to reduce the proportion of violations (9) (10). The length of the crossing will also have an impact: the longer the crossing, the less likely the violations. (9) (11). Land use and travel generators are also likely to influence the proportion of violations. At travel generators, violations have proven to be more common (7) (11). Pedestrians crossing illegally will wait for an acceptable gap between oncoming traffic to safely cross the street. When conflicting vehicle flow increases, theses gaps become smaller and rarer, making it more difficult for pedestrians to cross the street (5) (12) (13).

Other factors, such as the day of the week, the period of the year or the time of day also impact the proportion of violations, as they are often linked to travel motive and therefore influence pedestrian behavior (8) (12). Weather will affect the level of comfort of a pedestrian and therefore influence their travel behavior (13) (14). A study conducted in Toronto concluded that in Canada's winter conditions, people are less likely to wait at an intersection due to the cold. Other weather conditions, such as heavy rain, are also likely to shorten pedestrians' patience (14).

Research has also been undertaken on the average time pedestrians will wait, whether they commit a violation or not. People who had violated the traffic signal had a slightly smaller waiting time, people wait a very similar length of time whether or not they committed a violation (12). Only in cases where the legal crossing must be made in two phases, pedestrians would have much smaller waiting times if they committed a violation (14).

The cultural context of the pedestrian is also very important. Norms of conduct differ from one place to another, making it difficult to compare pedestrians from different cultural or social contexts (4). Most studies are done at a punctual place or a relatively small area, like cities. Results such as the proportion of violations or the average time a pedestrian will wait can rarely be applied directly elsewhere, but factors influencing the number of violations seem to be constant from one region to another.

Many factors influencing the proportion of violations have already been identified in the literature. But some factors need further study. To the extent of our knowledge, there has been no study of

- the influence of pedestrian maximum waiting time (red phase) and moment of arrival at the intersection on the number of violations

Studies on waiting time did not discuss in detail the time of arrival of a pedestrian at the intersection. Do people commit violations because they arrived at the beginning of the red and must wait the whole red phase or do they commit violations whatever their time of arrival?

- the influence of pedestrian maximum waiting time and available crossing time on the type of violations

Violations are usually not differentiated or compared with other dangerous crossing situations. Violations can be separated in different categories with different levels of risk. To these violations can also be added legal dangerous crossing situations, which expose pedestrians to vehicles as much as certain types of violations.

## METHODOLOGY

All the selected intersections are in Montreal's Plateau-Mont-Royal borough, on Sherbrooke Street, one of the most important arterials in the city. This assured that all intersections had similar conflicting vehicle flow, similar geometry and land use. Data was collected on days considered similar, either Tuesdays or Wednesdays between June 21$^{st}$ and July 5$^{th}$, 2011. The weather on the days selected for data collection was sunny in the low twenties degrees Celsius. The number of vehicles during rush hour on Sherbrooke Street is important. Therefore, during the motorized traffic peak hour, there would have been few gaps for pedestrians to cross illegally. On the other hand, collecting data only during off-peak hours would have meant fewer pedestrians. The end of the morning rush hour was therefore selected as the best time period to collect data. Data was collected for 2 hours, between 9:30AM and 11:30AM.

Intersections were also selected to have a variety of maximum waiting times (MWT) due to the red phase for people wanting to cross Sherbrooke. Seven intersections on Sherbrooke were identified. Selected intersections were divided into three categories:

1. Short MWT: when the red phase is between 40 and 45 s, it is considered short.
2. Moderate MWT: approaches with a red phase closer to 50 s are considered moderate and
3. Long MWT: approaches with a red phase closer to 60 s were considered long. In one of the cases, on the East crossing of Montcalm and Sherbrooke, MWT would vary between 55 s and 80 s, depending when the call for the pedestrian phase was made. This crossing was considered to have a long MWT.

These categories were chosen for this specific set of intersections. They do not represent the general variety of maximum wait times that can be observed, which could easily be as high as 120 s. Each MWT category has at least one intersection with a pedestrian signal, and one without. The only exception is the short category, since there was no intersection in this portion of Sherbrooke with a short MWT and a pedestrian signal. In the long category, there were 3 intersections with pedestrian signals. All three intersections were selected because they had the three main types of pedestrian signals: standard, with countdown and with a call button. The selected intersections and their characteristics are presented in TABLE 1.

**TABLE 1 Characteristics of selected intersections.**

| Intersection | MWT (s) | | Pedestrian Signal | Number of Observation Periods | Total Counts | | Conflicting Vehicle Flow (veh/h) | Road Width 5-10 m from intersection (m) | Crossing Length (m) | Land Use | Clearing Time (s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Amherst/ Sherbrooke | short | 42 | no | 1 | Pedestrians | 183 | 1129 | 18.1 | 25.4 | Urban / mixed | 4 |
| | | | | | Dang. legal crossings | 16 (8.7 %) | | | | | |
| | | | | | Violations | 15 (8.1 %) | | | | | |
| Fullum/ Sherbrooke | medium | 46 | no | 1 | Pedestrians | 107 | 1598 | 18.7 | 24.2 | Urban / residential | 4 |
| | | | | | Dang. legal crossings | 11 (10.3 %) | | | | | |
| | | | | | Violations | 9 (8.4 %) | | | | | |
| Iberville/ Sherbrooke | medium | 46 | yes | 2 | Pedestrians | 134 | 1812 | 18.7 | 23.7 | Urban / mixed | 15 |
| | | | | | Dang. legal crossings | 0 (0 %) | | | | | |
| | | | | | Violations | 32 (23.8 %) | | | | | |
| Montcalm/ Sherbrooke (West crossing) | long | 56 | no | 1 | Pedestrians | 38 | 1812 | 18.7 | 23.7 | Urban / mixed | 4 |
| | | | | | Dang. legal crossings | 4 (10.5 %) | | | | | |
| | | | | | Violations | 4 (10.5 %) | | | | | |
| Montcalm/ Sherbrooke (East crossing) | long | 80 | yes, on call | 1 | Pedestrians | 50 | 1574 | 18.8 | 24.4 | Urban / mixed | 12 |
| | | | | | Dang. legal crossings | 3 (6 %) | | | | | |
| | | | | | Violations | 36 (72 %) | | | | | |
| Jeanne-Mance/ Sherbrooke | long | 54 | yes | 1 | Pedestrians | 348 | 1446 | 17.9 | 20.9 | Urban / mixed | 27 |
| | | | | | Dang. legal crossings | 0 (0 %) | | | | | |
| | | | | | Violations | 88 (25.3 %) | | | | | |
| Saint-André/ Sherbrooke | long | 58 | no | 2 | Pedestrians | 159 | 1324 | 17.8 | 18.4 | Urban / residential | 4 |
| | | | | | Dang. legal crossings | 13 (8.2 %) | | | | | |
| | | | | | Violations | 53 (33.3 %) | | | | | |
| Saint-Urbain/ Sherbrooke | long | 60 | yes, countdown | 1 | Pedestrians | 355 | 1235 | 17.5 | 21.1 | Urban / mixed | 17 |
| | | | | | Dang. legal crossings | 0 (0 %) | | | | | |
| | | | | | Violations | 34 (9.6 %) | | | | | |

Counts were performed manually by teams of two people, one counting pedestrians and the other violations and dangerous situations. Pedestrians committing violations or crossing dangerously were therefore counted in both databases. Data collection was done over 4 days. The following information was collected:

- time of arrival (time at which a pedestrian arrives to the crossing)
- age group
- sex
- number of pedestrians moving together, or platoon size
- number of pedestrians waiting at the corner
- crossing used
- direction of crossing

Age was estimated in five age groups:

- child (age 0-8)
- teenager (age 9-17)
- young adult (age 18-35)
- adult (age 36-59)
- senior (age 60+)

For violations and dangerous crossings, additional information was collected:

- time of arrival at the intersection
- start time of crossing
- end time of crossing
  - walking man / green
  - flashing hand
  - steady hand / yellow
  - beginning of red
  - middle of red
  - end of red
  - anticipation of green (only start time of crossing)
- speed of crossing
  - walking
  - running
  - disabled

For the start time of crossing, “anticipation of green” category was added to distinguish people who started to cross in the last third of the red light from people starting only a few seconds before the green light.

Two intersections required a second day of counts to verify preliminary results or to complete counting when there were too few pedestrians. In one of the cases, at the intersection of Saint-André and Sherbrooke, the additional information collected for violations and dangerous crossings was collected for all crossings. This allowed a better comparison of all types of crossings. Saint-André/Sherbrooke had a lower pedestrian flow which made this detailed data collection possible.

The fusion of violations and dangerous situations database with the counts database was necessary, since they were done separately. This was done by grouping entries with identical information together. In some cases, both entries did not match exactly. When this happened, if the age group was slightly different or if the difference concerned the number of pedestrians at the corner or the group size, both entries were considered a match. If the information of both entries differed, violation or dangerous crossing situation information was considered accurate. All violations and dangerous crossing situations were matched to a pedestrian crossing.

Video data was also collected for 3.5 h at two intersections, one with a pedestrian signal (Iberville/Sherbrooke) and one without (Amherst/Sherbrooke), while manual counts were done.

Video data was collected as a means of visually verifying the observations made in the field, and to complement these observations by providing information on pedestrian crossing behavior, trajectories and position on the crosswalk. Using an automated video analysis tool (15) employed previously for pedestrian studies (16), road users' trajectories were extracted from two hours of video from 10:00AM at the two intersections. Pedestrians are identified based on their average speed, since it is smaller than cars', and a screen line orthogonal to the crosswalk, in the middle of the roadway, was used to select the trajectories relevant for the studies. The timing of the pedestrian light could be easily manually synchronized to the video and used to identify the portion of trajectories in the roadway during the yellow and red phases.

# RESULTS

The focus of this study was on two crossing categories: dangerous crossing (dang.) situations and crossing violations (viol.). The two categories can be further divided into three crossing types:

- *Dangerous violations* (dang. viol.): Pedestrians commit a dangerous violation when crossing during the red phase. They could either have started too early (beginning of crossing on "Anticipation" phase) or crossed during the red phase.
- *Non-dangerous violations* (non-dang. viol.): Certain violations do not expose pedestrians to conflicting vehicles. They occur when pedestrians start to cross too late (on the yellow light, flashing hand (unless there is a countdown) or full hand) but still manage to finish before the red light.
- *Dangerous legal crossings* (dang. leg.): If pedestrians start to cross on the walking man or on the green light, the crossing is legal, even if the end of the crossing is under the red light. While pedestrians have the right of way, the situation can be dangerous due to conflicting traffic.

Results are presented in three parts: exploratory analysis, video-based validation and trajectory visualization and statistical regression modeling results.

## Exploratory Analysis

After preliminary analysis, the data from Montcalm/Sherbrooke's East crossing was removed from the main dataset and analyzed separately. The analysis is presented later in a separate sub-section.

The main dataset is presented in FIGURE 1. Since intersections did not have the same number of pedestrians, the proportions of violations among all crossing events were used so every intersection would have the same weight in the average. For every type of violation, the presence of a pedestrian signal with countdown reduces the proportion of violations. A standard pedestrian signal increases the proportion of violations, but more than half were non-dangerous violations. All types of pedestrian signals reduce the proportion of dangerous crossings, which is consistent with the literature (9) (10). For all types of violations, the longer the MWT, the higher the proportion of violations. The opposite result is observed for dangerous legal crossings, but this may be explained by the repartition of intersections with a pedestrian signal, which reduces the proportion of dangerous crossings. There are two intersections with pedestrian signals in the long MWT category, one in the medium category and none in the short category. Results could therefore be influenced only by the intersection sample.

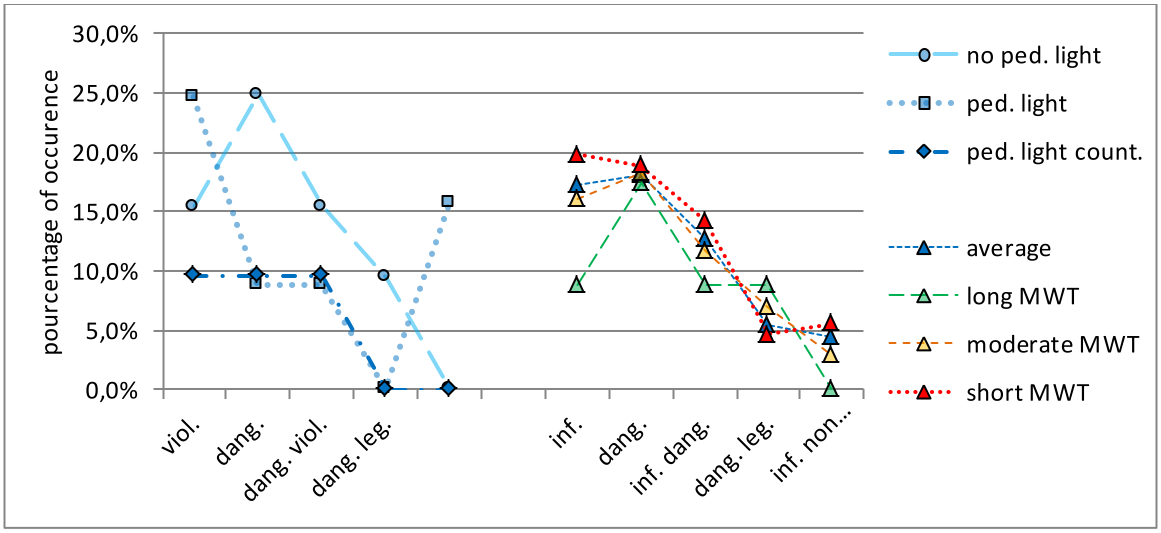


**FIGURE 1 Overview of data, showing average proportions of various types of violations per crossing event per group of intersections, based on the presence of pedestrian light and the length of the MWT.**

The relation between intersection clearing time and type of crossing is presented in TABLE 2. All intersections without a pedestrian signal had a yellow time of 4 s. The time necessary to cross the street was calculated with a fixed walking speed of 1.1 m/s and the length of the crossing to explore trends. On Jeanne-Mance/Sherbrooke, people walking normally can start crossing 8 s after the beginning of the flashing hand and still finish crossing the street in time. This leads to a high percentage of pedestrians crossing completely on the flashing hand. As the length of the flashing hand decreases, this type of violation becomes less important. On Iberville/Sherbrooke, where the length of the flashing hand is 7 s shorter than the time needed to cross, very few people were able to do a complete crossing during the flashing hand. Many more people finished crossing on the steady hand.

There is also a relation between the difference between the time required to cross and the time offered, and the proportion of dangerous crossings ending on the red light. The bigger the difference, the higher the share of dangerous crossings ending on the red light. Amherst/Sherbrooke has the biggest difference and the highest proportion of dangerous crossings ending on the red light. A standard pedestrian signal (Iberville/Sherbrooke and Jeanne-Mance/Sherbrooke), which has a longer clearing time, seems to lower even more the proportion of people ending their crossings en the red light.

The countdown on Saint-Urbain/Sherbrooke seems to have an impact on crossing behavior since none of the 355 pedestrians finished their crossing on the steady hand, while many people finished on the red light. This result seems to support the findings of Wanty, who suggested that when a countdown is present, people tend to cross according to the time remaining, but often underestimate their crossing time (17). People therefore probably either made sure to complete their crossing before the end of the countdown or underestimated their crossing time and finished too late, on the red light.

**TABLE 2 Effect of clearing time on violation type.**

| Intersection | Clearing time $t_{cl}$ (s) | Necessary time to cross $t_{cr}$ (s) | Difference $t_{cl}$- $t_{cr}$ (s) | % observed out of all crossings | | % observed out of dang. crossings |
|---|---|---|---|---|---|---|
| | | | | Beginning and end of crossing on the flashing hand | End of crossing on the steady hand | End of crossing on the red light |
| Amherst/Sherbrooke | 4 | 23 | -19 | - | | 75 |
| Fullum/Sherbrooke | 4 | 22 | -18 | - | | 70 |
| Montcalm/Sherbrooke W | 4 | 22 | -18 | - | | 50 |
| Saint-André/Sherbrooke | 4 | 17 | -13 | - | | 30 |
| Iberville/Sherbrooke | 15 | 22 | -7 | 2 | 8 | 0 |
| Saint-Urbain/Sherbrooke | 17 | 19 | -2 | 6 | 0 | 76 |
| Jeanne-Mance/Sherbrooke | 27 | 19 | 8 | 18 | 5 | 10 |

The number of pedestrians travelling together or waiting at the corner also seems to have an influence on the number of violations. A clear tendency can be observed in FIGURE 2. As the group size increases, the proportion of violations decreases. This is consistent with the findings of Rosenbloom and Zhang (4) (7).

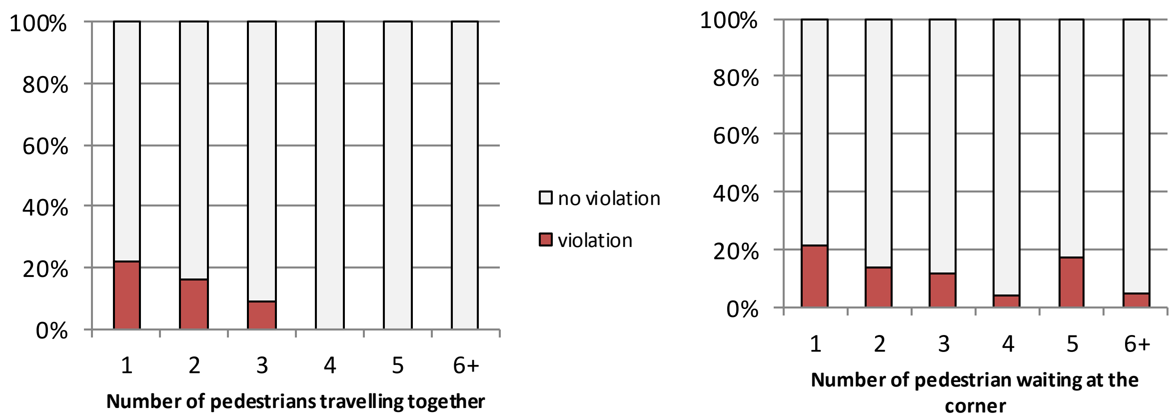


**FIGURE 2 Proportion of violations as a function of the number of pedestrians waiting at corner and group size.**

The relation between speed of crossing and crossing type was also studied. Out of the observed dangerous and violation data, three types of crossing situations have a higher occurrence of people running: end of crossing on the red light (44 % running), end on the steady hand (14 %) and crossing on the red light (16 %). Other types of situations have a lower running occurrence (7 %). The same tendency can be observed with the complete data of Saint-André/Sherbrooke, where people ran 33 % of the time when ending on the red light, 10 % of the time when crossing on the red light, but only 4 % of the time while crossing completely on the green light or starting by anticipation. This seems to support the findings of Zhuang who claimed that people run for two reasons: either to complete their crossing or to avoid vehicles (7).

The characteristics of the pedestrians committing violations are represented on FIGURE 3. On average, men seem to commit more violations of both types (dang. viol. or non-dang. viol.) than women, and young adults seem to commit more violations than other age groups. These findings confirm what can be found in literature (4) (5) (6) (7) (8). Types of crossings also differ with age. Almost half (44 % versus 29 % on average) of seniors' dangerous crossing situations (dang.) are people ending on the red light (dang. leg.). This would be consistent with decreasing mobility due to age. Children were not represented on this figure because of the limited number of observations.


1 **FIGURE 3 Number of violations for 100 pedestrians for each age and sex category.**

FIGURE 4 illustrates the moment of arrival of pedestrians and the moment they decide to cross. Only the average was presented for dangerous crossings and violations because all crossings had a very similar pattern of arrival and departure. There are two darker zones, the diagonal and the first and last columns. The diagonal represents people arriving and starting to cross almost instantly. The second darker zone can be observed on the anticipation column and the green column of the Saint-André/Sherbrooke data which also shows legal crossings. This group represents the people who waited for the green light. The two groups correspond to the groups described by Yang (13) and Tiwari (6). These findings may explain why previous studies have observed similar waiting times whether people commit violations or not (12). Some pedestrians will cross shortly after they arrive, whether the light is green or red. Only their moment of arrival will determine if they commit a violation or not. The second category, people who will wait for the green light, will also be divided between violations and non-violations. If people wait during the red light but start to cross seconds before the green light ("anticipation"), it is still a violation. This means that time of arrival at the intersection has little impact on the behavior of people. The proportion of illegal crossings will be influenced by factors concerning pedestrians themselves or external factors.

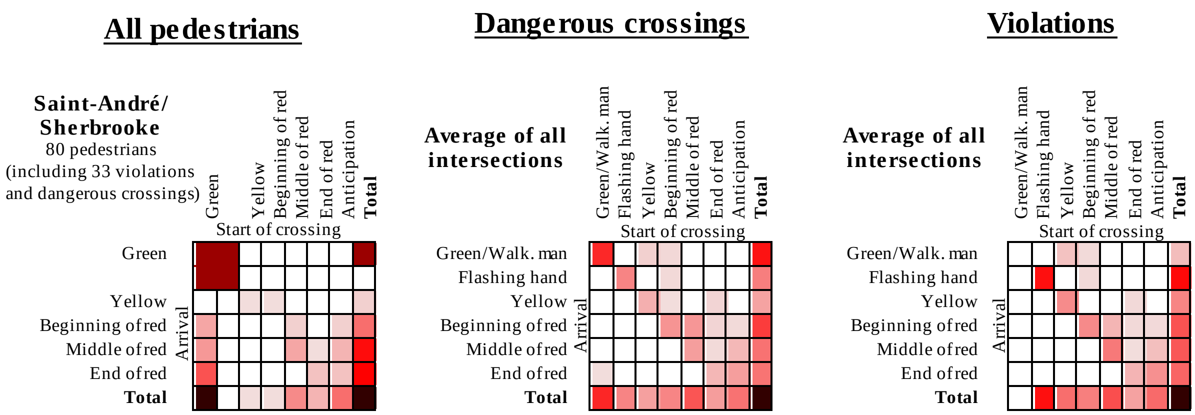


**FIGURE 4 Cross tabulation of the times of arrival and of start of crossing (the darker the color, the higher the proportion of observations with respect to the total number of observations).**

## Video-based Validation and Trajectory Visualization

The validation was made on the basis of groups of pedestrians and not individual pedestrians, which cannot be distinguished by the automated tracking system. All three "anticipation" violations were detected, one of the two "on red" violation was correctly detected and 7 "end on red" crossings out of 8 were detected correctly. There was only one false detection, which was a cyclist riding his bike on the crosswalk and finishing his crossing on the red light. The 2 missed detections happened when the pedestrians were not tracked at all. Although the count of crossings is small, this result is on par with previous evaluations (15) and confirms the potential of video-based technologies for pedestrian behavior analysis.

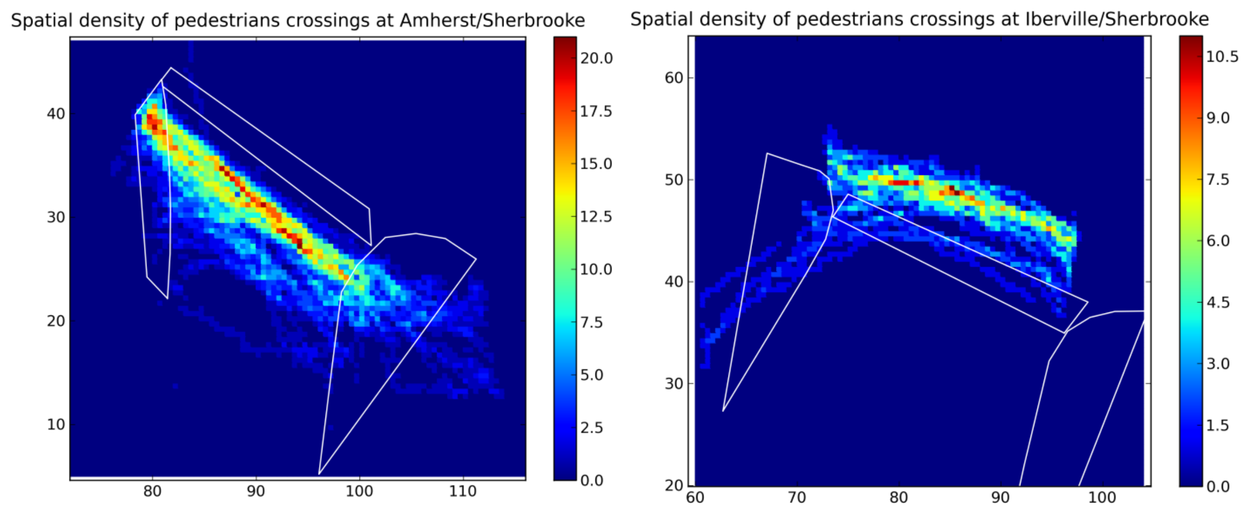


**FIGURE 5 Spatial density of pedestrian crossings for two hours (10:00AM to 12:00PM) for the west crosswalks at Amherst/Sherbrooke (left) and Iberville/Sherbrooke (right) (in white are overlaid the crosswalk and the corresponding sidewalks; the unit of the axes is meter, and the color of each cell represents the number of pedestrians)**

A preliminary analysis of the pedestrian trajectories was done by visualizing in FIGURE 5 the spatial density of the pedestrian crossings for the two intersections where video was collected. The first observation is that the perspective and the tracking of pedestrian typically at mid height cause most pedestrians to be located beside the crosswalk. This makes spatial violations difficult to detect automatically. It is nevertheless clear that there is a fair share of pedestrians walking outside of the crosswalk, in particular taking shortcuts at the beginning or the end of their crossing. It seems that the spatial density is more diffuse at Amherst/Sherbrooke, which could indicate more spatial violations in the absence of a pedestrian light, but more work is needed to draw any conclusion.

## Statistical Modeling Results

This section presents the logistic regression analysis that was carried out in order to identify the factors that influenced the proportion of types of crossings and the magnitude of their effects. All models were estimated with the open source econometrics software Gretl (18). Variables tested included information on intersection characteristics, such as crossing length, but these characteristics were not significant in the models, which confirmed that the selected intersections had similar configurations. Different models were estimated with logistic regression. Model 1 predicts violations (viol.) from the crossing data. Model 2 and 3 are similar to model 1, but Model 2 predicted dangerous violations (dang. viol.) and Model 3 dangerous crossing situations (dang.). The results obtained are presented in TABLE 3. Elasticities were calculated at the mean values. For continuous variables, the reported elasticities are for an increase of 10 %.

**TABLE 3 Logistic prediction models.**

| | Model 1 : Prediction of viol. | | | Model 2 : prediction of dang. viol. | | | Model 3 : prediction of dang. | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Coef.* | *elasticity* | *p. value* | *Coef.* | *elasticity* | *p. value* | *Coef.* | *elasticity* | *p. value* |
| Constant | -6.822 | - | 0.000 | -5.891 | - | 0.000 | -2.434 | - | 0.004 |
| Standard Ped. Signal | 0.787 | 6.1% | 0.000 | -1.054 | -4.4% | 0.000 | -1.072 | -5.7% | 0.000 |
| Count. Ped. Signal | -1.041 | -3.6% | 0.000 | -0.988 | -4.2% | 0.000 | -0.931 | -5.2% | 0.001 |
| Group size | -0.799 | -0.7% | 0.000 | -0.622 | -0.7% | 0.000 | -0.623 | -0.9% | 0.000 |
| Sex (M=1) | 0.509 | 3.5% | 0.002 | 0.520 | 4.2% | 0.008 | 0.378 | 3.6% | 0.032 |
| Age : 18-35 | 1.037 | 8.9% | 0.000 | 0.940 | 9.0% | 0.000 | 0.805 | 9.1% | 0.000 |
| Ped. flow (in hundreds) | | | | | | | -0.00135 | -1.0% | 0.002 |
| MWT | 0.103 | 3.8% | 0.000 | 0.0828 | 3.4% | 0.000 | 0.0486 | 2.4% | 0.000 |

The results show that:

- The probability of committing a violation is higher for men.
- Being a young adult has the highest impact on a person's probability of committing a violation or a dangerous crossing.
- The total number of pedestrians at the intersection and pedestrian flow decrease the probability of violations being committed; a 10 % augmentation will decrease the probability of violations by a maximum of 1 %. These first three results are in accordance with previous works which found that young adults, men and smaller groups all increased the probability of violations (4) (5) (7) (8) (6).
- The presence of a pedestrian signal (of any type) decreases the probability of dangerous crossings and violations, which is consistent with past studies (9) (10). Standard pedestrian signals increase the probability of violations, but decrease the probability of dangerous ones, meaning many of these violations will be of the non-dangerous type.
- MWT also appears to have an impact on violations. A 10 % increase in MWT will increase probability of violation and dangerous violations by 4 %.

No study has directly studied the impact of MWT at an intersection, which has proven to be statistically significant on the probability of violations or dangerous crossings.

### The Special Case of Call Buttons (Montcalm/Sherbrooke)

Montcalm/Sherbrooke's East crossing was removed from the main dataset. At this intersection, the phasing on the West crossing is not the same as the East crossing. On the West crossing, there is no pedestrian light: people must cross during the vehicle phase. On the East crossing, there is an exclusive pedestrian phase activated on call. The fact that the two crossings are different seems to create confusion among pedestrians since 72 % of pedestrians on the East crossing did not cross legally. 66 % crossed on the green vehicle light, and therefore committed a violation. Of the 50 people who used the East crossing, only 11 used the call button and crossed legally. The MWT is 80 s on the East crossing. This might explain why 3 people used the call button but crossed on the West crossing. On the West crossing, results were similar to other intersections, with 89 % of crossings being legal (compared to 80 % in average). This demonstrates the importance of clear and consistent signalization.

## CONCLUSION

This study was conducted to evaluate the impact of pedestrian waiting time, due to phasing length and time of arrival, and the presence of a pedestrian signal on the proportion of pedestrian violations and dangerous situations. Variables such as being male, being a young adult, and intersection MWT increased the proportion of violations. Other variables decreased the probability of violations, such as the presence of a pedestrian signal or a higher number of people surrounding the pedestrian. This study highlights the importance of engineering countermeasures as part of the solution to pedestrian violations. When designing the cycle length and effective green/red times for each phase, particular attention should be paid to pedestrian waiting times. Some variables will influence the type of violations. If the clearing time is longer than the time needed to cross the street, people are likely to start crossing during this period and therefore commit a violation. On the other hand, especially on intersections without pedestrian signals where the clearing time is always shorter than the time needed to cross, the higher the difference between the time given and needed, the more people will cross dangerously by finishing their crossing on the red phase. These results show the importance of properly timing pedestrian signals. To reduce violations and dangerous crossing situations, the clearing time should be as close as possible to the required time of crossing. A shorter clearing time endangers pedestrians who will have to finish on the red light and all extra time available should be given in the walking man phase.

The moment of arrival at the intersection seems to have little impact on people's crossing behavior. Pedestrians can be classified in two types: people who will start crossing almost immediately after they arrive and people who will wait for the green light (even if they often commit a violation by anticipating it by a few seconds). This may explain why other studies have found similar time waited by pedestrians before crossing (12).

In future research, these findings could be validated by collecting data from a larger sample size as well as using a more precise way of collecting data, such as video analysis. The data used in the analysis was collected manually, which may lead to errors by people collecting data such as missing pedestrians, age being wrongly evaluated or errors in transcription. This study focused on a small sample of Plateau Mont-Royal intersections. In most of the cases, there was only one intersection of each type for each MWT category. Results could therefore be specific to these specific intersections. A larger scale study with more intersections could confirm findings. A study done with complete data, like the one collected at Saint-André/Sherbrooke, would allow a better comparison of all types of crossings. Video analysis, as demonstrated in this work, will be further developed to provide a more detailed analysis and a validation procedure, and to carry out an analysis of pedestrian-vehicle conflicts (16). This type of analysis would provide insight on interactions between pedestrians and cars, and the respective influence of traffic conditions and signal timings. It would also be interesting to compare the results presented here with crash records to examine the relationship of dangerous situations, conflicts and crashes.

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