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POLYTECHNIQUE MONTRÉAL

affiliée à l'Université de Montréal

Analysing Pedestrian Safety Behavior at Urban Signalized Intersections

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Mémoire présenté en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*

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POLYTECHNIQUE MONTRÉAL

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Ce mémoire intitulé :

Analysing Pedestrian Safety Behavior at Urban Signalized Intersections

présentée par **Mohsen MILADI**

en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*

a été dûment accepté par le jury d'examen constitué de :

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DEDICATION

To my parents, who have done so much for me,

To my sister and brother.

ACKNOWLEDGEMENTS

"My desert is without end…

My soul, my heart must rend…

The world here out pictured…

In which picture I descend?"

- ***Rumi***

To My Advisors

I wanted to take this opportunity to express my heartfelt thanks to Professor Owen Waygood, Professor Marie-soleil Cloutier, and Bobin Wang for their guidance and supports throughout the course of my master at Polytechnique.

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RÉSUMÉ

Les piétons sont des usagers de la route vulnérables qui sont particulièrement sujets aux blessures graves et aux décès lorsqu'ils sont impliqués dans des accidents avec des véhicules. La sécurité routière pour les piétons au niveau des intersections continue d'être un enjeu important en Amérique du Nord et dans le monde entier.

L'objectif de cette recherche est d'examiner les facteurs qui influencent le comportement de traversée des piétons aux intersections. Nous examinerons en particulier les distractions des piétons, les mouvements de tête et les comportements de traversées à risque, C'est-à-dire selon le respect des feux de circulation.

La sécurité des piétons dépend de divers éléments de conception, mais aussi du comportement des piétons lors de la traversée d'une intersection. Ces comportements de croisement sont à leur tour influencés par les caractéristiques individuelles, la conception des intersections et l'environnement bâti entourant l'intersection. Les intersections sont une partie importante de la conception des routes car les piétons y sont exposés à diverses activités potentiellement dangereuses en lien avec la façon dont l'intersection est conçue. De plus, plusieurs facteurs de l'environnement bâti, tels que la densité de population, le type d'utilisation du sol et le nombre d'arrêts d'autobus, ont une forte relation avec les comportements des piétons.

Afin de mieux comprendre l'influence des caractéristiques des intersections et de l'environnement bâti sur le comportement des piétons, la proportion de distraction et les mouvements de la tête avant de traverser ont été étudiée et comparée entre des sites à Montréal et à Québec. Les observations de la distraction des piétons avant la traversée incluaient : utiliser des écouteurs, marcher avec un compagnon, avoir un téléphone intelligent en main, et parler au téléphone. Les observations des mouvements de tête des piétons avant et pendant (au milieu de) la traversée incluaient : regarder le feu de circulation, regarder la circulation, regarder d'autres piétons et, regarder un appareil électronique. Des analyses statistiques descriptives ont été réalisées sur les deux groupes de mesures. Enfin, des modèles de régression logistique ont été estimés afin de déterminer les facteurs d'influence sur quatre comportements dangereux : commencer à traverser sur le feu rouge, terminer sur le feu rouge, débuter la traversée sur le feu vert et finir sur le feu rouge, et traverser complètement sur le feu rouge.

Les données ont été recueillies en observant au hasard les piétons lorsqu'ils traversaient à vingt-quatre intersections à Montréal et à Québec (à parts égales). Selon les résultats, la distraction la plus courante était l'utilisation d'écouteurs (16%), et avoir un compagnon (15%). Certains piétons (13 %) ont été observés avec un téléphone en main avant de traverser et seulement quelques piétons (2-3%) ont été observés parlant au téléphone avant de traverser. En termes de mouvement de tête, les piétons des deux villes ont eu à peu près le même comportement lors de la traversée. Cependant, quelques différences ont été observées avant la traversée. À Montréal, les piétons regardent plus les feux de circulation, tandis qu'à Québec, ils regardent plus la circulation. Il se peut que les piétons de Québec recherchent un espace dans la circulation afin de pouvoir traverser avant d'avoir le droit de passage (sur le feu vert). Regarder le feu de circulation peut indiquer que les individus sont plus préoccupés par le temps de traversée que la circulation. Ainsi, ce résultat pourrait suggérer que les piétons de Montréal étaient plus préoccupés par le temps qu'il leur restait.

Plusieurs facteurs ont été pris en compte lors de l'analyse des comportements de traversée à risque tels que le départ, l'arrivée et le passage au rouge aux intersections. Les résultats démontrent l'importance du temps d'attente pour les piétons. Les temps d'attente courts (<30) diminuaient la probabilité de telles activités par un facteur de 7,7. Les résultats montrent que les piétons aux moyennes et petites intersections ont moins de chance de traverser illégalement qu'aux grandes intersections avec des terre-pleins. Pour un comportement défini comme une distraction, seul le fait d'avoir un téléphone dans une main était significatif, et cela réduisait la probabilité de commencer à traverser sur le feu rouge. Pour les mouvements de tête, le comportement de regarder le trafic était quatre fois plus associée au fait de traverser illégalement.

Les résultats montrent l'importance de la conception géométrique et de la programmation des feux de circulation, qui prennent en compte tous les groupes d'âge et tous les sexes. Le temps imparti pour traverser semble également être un problème, les piétons plus âgés et plus jeunes étant plus probables de finir au rouge tout en commençant au vert. Pour réduire les comportements dangereux des piétons, la conception des intersections, en particulier la gestion du temps de phase et la distance à traverser, sont plus importantes pour les piétons que les distractions pour les piétons, leur âge ou leur sexe.

ABSTRACT

Pedestrians are vulnerable roadway users who are particularly prone to serious road injuries and fatalities when involved in vehicle crashes. In North America and across the world, pedestrian safety at urban signalized intersections is still a major issue.

The objective of this research is to examine factors that influence pedestrian behaviour at intersection with respect to safety. In particular, these measures are examined: Pedestrian distractions, head movement, and risky crossing behavior.

Pedestrian safety depends on various design elements, but also on pedestrian behavior when crossing intersection. Those crossing behaviors are in turn influenced by individual characteristics, intersection characteristics, and built environment. Intersections are a critical part of roadway design since pedestrians are exposed to different and potentially dangerous activities due to how an intersection is designed. Furthermore, several built environment factors, such as population density, land use type, and number of bus stops, have a strong relationship with pedestrian behaviors.

In order to get a better understanding of the influence of intersection features and built environment context on pedestrian behaviour, the proportion of distraction before crossing and head movement before and during crossing were investigated. In addition, the distractions and head movement in Montreal and Quebec City were compared to find contextual differences. To do this, observations of distraction before crossing such as using headphones, travelling with a companion, having a smartphone in hand, and talking on a phone were completed in the two cities. Furthermore, head movements such as looking at traffic light, traffic, other pedestrians, and electronic devices before and during crossing were observed. Descriptive statistical analysis was performed on the two groups of measures. Finally, logistic regression models were estimated to determine the influencing factors on four dangerous behaviors: start on red, finish on red, finish on red having started on green, and cross completely on red.

The data was gathered by observing twenty-four intersections in Montreal and Quebec City (equally divided). Data was collected by randomly observing pedestrians as they crossed, and the data was statistically analyzed. According to the results, among these distractions the most common distraction was the use of headphones, after that, having a companion. Some of the pedestrians (13 %) were seen approaching with a smartphone in hand before crossing. Only a few pedestrians (2-

3%) were observed talking on their phones before crossing. In terms of head movement, pedestrians from the two cities had roughly the same behavior during crossing. However, some differences were observed before crossing. In Montreal pedestrians look at traffic lights more, while in Quebec City, they look more at traffic. It may be that pedestrians in Quebec City look for a gap in traffic so that they may cross before they have the right of way. Looking at the traffic light might indicate that individuals are more concerned about the amount of time to cross than traffic movement. As such, this result might suggest that pedestrians in Montreal were more worried about how much time was left.

Several factors were taken into account when risky crossing behaviors were analyzed such as starting, finishing, and crossing on red at intersections. Results demonstrate the importance of wait-time for pedestrians. Short waiting times (<30) decrease the likelihood of such activities by a factor of 7.7. The findings show that pedestrians at medium and small intersections are less likely to cross illegally than at large intersections with safety islands. For distractions, only having a smartphone in one's hand was significant, and it reduced the likelihood of starting to cross on red. For head movement, looking at traffic was over four times more associated to crossing illegally.

The results show the importance of geometric design and traffic signal programming, which takes into account all age groups and genders. The length of time given to cross appears to be an issue as well, with older and younger pedestrians being more likely to end on red while starting on green. To decrease pedestrian dangerous crossing behaviors, intersection characteristics, particularly phase time management and distance to cross are more important to pedestrians than distractions to pedestrians, their age or gender.

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LIST OF SYMBOLS AND ABBREVIATIONS

NHTSA	National Highway Traffic Safety Administration
VKT	Vehicle Kilometre Travel
VMT	Vehicle Mile Travel
HCM	Highway Capacity Manual
STRAPI	Le projet de Système de gestion des traversées piétonnes aux intersections.
LPI	Lead-Pedestrian Interval

LIST OF APPENDICES

CHAPTER 1 INTRODUCTION

1.1 Context

Despite the relevance and advantages of active mobility, urban road infrastructure continues to be a substantial cause of injury to pedestrians. Every year, a significant number of pedestrians are killed or badly injured in motor vehicle collisions. Pedestrians, motorcyclists, and cyclists account for about half of the estimated 1.35 million individuals killed in road traffic collisions each year, according to a worldwide review of road safety [1]. Intersections are an important aspect of roadway network design as they are points in the network where pedestrians are exposed to the dangers of traffic. In North America and across the world, pedestrian safety at intersections is still a major concern. Pedestrians were killed in 14 percent of all road collision deaths reported in the United States in 2013 [2] , and 17.3 percent of road collision deaths (332 individuals) in Canada in 2018 [3]. The majority of collisions occur at intersections. A significant percentage of vehicle–pedestrian crashes (about 60%) occur at intersections in Montreal, one of Canada's major cities [4]. This obviously highlights the need for a pedestrian crash study to determine what factors influence their safety, so that preventive steps may be done to reduce fatal pedestrian collisions.

Intersections are a critical point for pedestrian safety, but certain behaviors may increase their danger. Behaviors such as looking at a cellphone can reduce pedestrian attention to dangerous traffic, whereas looking at traffic might increase their awareness of traffic, but it could also be linked to searching for opportunities to cross on red. Pedestrians are insufficiently protected at intersections with preference often given to vehicle movement in designing intersections. Individual characteristics, intersection characteristics, and context are important factors that influence on risky crossing behavior at signalized intersections.

Individual variables such as age and gender play a varied influence in the occurrence of crossing behavior. Beyond individual variables, intersection characteristics such as the type of crosswalk and presence of a safety island, sufficient visibility for vehicles, street width, and number of lanes can influence the likelihood of collisions [5-9]. Along with traffic characteristics such as speed and traffic volume [9-11], pedestrians also play a role in their safety. This can relate to observing traffic and traffic controls (e.g., traffic signals) or relate to distractions such as using headphones or mobile phones.

At intersections, pedestrian behavior and distractions while making a crossing decision are critical variables in pedestrian safety. A variety of pedestrian behaviors can be observed at intersections, including the use of headphones, having a cellphone in hand, talking on a cellphone, walking with someone, and head movements such as looking at the pedestrian light, looking at traffic, looking at the ground, and looking at other pedestrians before and during crossing.

To gain new understanding about factors that influence crossing behavior, this study will use observational data from twelve intersections in each of Montreal and Quebec City (total: twenty-four).

1.2 Problem and Objectives

Pedestrian safety at intersections is influenced by the intersection characteristics, the context of the intersection, and individual behavior. Although all users (using vehicles or not) contribute to the safety of the intersection, this thesis will focus on pedestrian behaviour as a vulnerable user. The objective of this thesis is to explain the relationship between individual pedestrian behavior and various explanatory variables that include individual characteristics, intersection characteristics, and context. Three key behaviors will be examined:

1. Distractions such as using headphone, having companion, smartphone in hand, and talking on a phone;

- How frequent are different types of distractions?
- Does this vary by context (i.e., city)?

2. Pedestrian head movements

- Examining head movements such as looking at traffic light or traffic. Does the head movement have an effect on how pedestrians cross the street?

3. Risky crossing behaviors.

- What are the effects of distraction and head movement on four risky crossing behaviours: starting on red, finishing on red, starting on green but ending on red, crossing completely on red?

1.3 Thesis structure

This thesis is organized into six chapters, with the first chapter serving as an introduction. The remaining chapters are divided as follows:

- The second chapter is devoted to a review of the scientific literature. The purpose of this literature evaluation is to identify important publications that are related to the study goals.
- Chapter 3 concerns the methodological approach.
- Chapter 4 examines distractions and head movements.
- Chapter 5 presents the article entitled "Distractions or Long Waits? Impacts on Risky Crossing Behavior", submitted to the Transportation Research Board 2022 Annual Meeting.
- Chapter 6 includes the discussion and conclusion of the research.

Following these chapters, this thesis includes a number of appendices that offer the reader with extra information.

CHAPTER 2 BACKGROUND

2.1 Background

2.1.1 Traditional and Vision Zero approaches to traffic safety

Vision Zero is a road safety strategy adopted by Sweden in 1997 that seeks to achieve zero fatalities or serious injuries in all forms of transportation [12]. The approach recognises risk and takes steps to prevent crashes through better design of the transportation system. There are differences between traditional traffic safety and the Vision Zero approach. Whitelegg and Haq [13] found that In the traditional approach individual road users are often given as the cause of crashes, thus it is necessary to control human behavior [12, 14]. However, in the Vision Zero approach, the issue with road safety is not simply the individual, but also the design of the transportation system. Additionally, the traditional approach focuses on merely minimizing crashes, but the Vision Zero plan aims to eliminate fatalities and injuries entirely. Street users, cars, and the transportation network must all be addressed in an integrated method in order to establish a *safe transportation system*, which requires a variety of interventions [14]. Vision Zero applies a safe system approach to the transportation network, creating a holistic view that considers individuals within the overall road infrastructure. It entails comprehending how “upstream variables” such as design principles, public engagement, legislation, and vehicle laws all have an impact on injuries and deaths [14]. To achieve such a safe system, it is necessary to understand how intersection characteristics and the built environment affect pedestrian behavior.

2.1.2 Pedestrian behavior

Various researchers have studied pedestrian behaviour at signalised intersections. Individual characteristics, intersection geometry, and the built environment were all highlighted as factors that impact pedestrian crossing behavior and their safety. This section addresses previous research that attempted to explain various pedestrian crossing behaviors and the impact of intersection characteristics and the built environment on such behaviors.

According to observational research, a significant proportion of pedestrians are distracted, with the estimates ranging from 12 to 45 percent [15]. Portable electronic devices can provide convenient access to information necessary to get around or increase enjoyment through music. However, the injury prevention community is concerned that they may cause people to get distracted from safe behavior in potentially dangerous situations [16]. According to findings from observational studies, pedestrians who are distracted by phone calls or other activities (e.g., eating, listening to music) are more likely to incur risks when crossing roadways [17-19]. Distracted pedestrians must multitask at intersections and there is a lot of burden placed on pedestrians as vulnerable users. To guarantee their crossing safety, pedestrians must carefully examine the surrounding traffic environment, including oncoming cars, traffic signs, and signals, as well as analyzing vehicle movements including their speed, distance, and arrival time [17]. To be vigilant, pedestrians must use their visual, aural, and cognitive awareness. Checking their electronic devices could cause pedestrians to overlook important traffic information, leading to more risky behavior, and be more vulnerable to collisions [17]. In one study, distracted pedestrians looked away from their street surroundings more often than undistracted pedestrians when waiting to cross the street [16]. Thompson, et al. [20] looked at how three tasks affected pedestrian crossing behaviour: chatting on the phone, sending text messages, and listening to music. They discovered that using electronic devices lengthened crossing times by 18%. When pedestrians check their phones, their crossing speed drops and their crossing duration increases, exposing a behavioral variability issue that causes unpredictability in pedestrian behavior for drivers [21]. Smartphones also impair pedestrian performance at the start of a crossing event by reducing reaction time, which may translate into a higher risk [21].

Pedestrian head movement is another factor examined in traffic safety. Bendak, et al. [22] discovered that pedestrians' head movement, such as looking to the right and left before crossing the road, is influenced by the day of the week. Significantly more pedestrians were observed looking around before crossing the road on weekdays than on weekends. They proposed that a likely reason is that on weekends, when there are more people crossing the road, pedestrians might believe that it is less important to take look around before crossing the road.

Finally, crossing with a companion at both signalised and unsignalized crossings caused people to cross more slowly [18].

2.1.2.1.1 Hypothesis

Based on the literature presented above:

Hypo. 1 People who are looking at traffic are more likely to cross on red.

For distractions, we propose that individuals using cellphones are: 1) aware that they are not fully paying attention so rely on the traffic signals more; 2) using them to make waiting time more bearable.

Hypo. 2 People holding a cellphone are less likely to cross on red.

2.1.2.2 Individual characteristics

In terms of individual characteristics, studies show that males are more prone than females to commit violations and cross on red [23-26]. With respect to age, younger adult pedestrians (aged 18–35) were found to break more traffic laws than other age groups, whereas older pedestrians (age 36-59 and age 60+) were shown to be less likely to participate in unsafe behavior [27]. Rosenbloom [24] suggested that young people (6 to 13 years) tend to do risky behavior for reasons like social acceptance. An additional human factor could relate to waiting tolerance. Using an endurance probability, Wang, et al. [28] conducted research at seven different signalized intersections in Beijing, China. At each location, video cameras were used to gather data. Peak hours (8:00 a.m.–9:00 a.m. or 5:00 p.m.–6:00 p.m.) and off-peak hours (2:00 p.m.–4:00 p.m.) were included in the survey. In this study, 1497 valid observations were collected from people of various ages. They used the exponential, Weibull, and log-logistic distributions to determine the endurance probability based on survey data. The likelihood that pedestrians will respect traffic laws as time passes is known as endurance probability [28]. Wang, et al. [28] showed that roughly half of pedestrians can tolerate a waiting time at intersection around 40 seconds. Pedestrians who committed a violation had lower waiting time thresholds, according to Wang, et al. [28].

The individual's purpose for the trip may also affect crossing behavior. Individuals who were traveling for business or school were more likely to break rules for crossing than those who were traveling for pleasure [29]. Finally, pedestrians crossing in larger groups of pedestrians walked slower than those crossing alone or in smaller groups [22]. Bendak et al. [22] suggested that the pedestrians relied on group behavior to guide them.

2.1.2.2.1 Hypothesis

Previous research found men crossed more frequently on red than women.

Hypo. 3: Men are more likely to cross on red.

Previous research found that young adults were more likely to cross on red.

Hypo. 4: Young adults are more likely to cross on red light than older pedestrians.

2.1.3 Intersection characteristics

Intersections are essential features in the road network system because they are locations where different traffic flows meet and interact [30]. Also, the role of intersection size and type in terms of signalised, unsignalized or three-way, four-way, and five-way intersections have been examined by previous research [31, 32]. Dumbaugh and Li [31] found that intersections with four-or-more-legs were associated with a significant increase in motorist crashes. This type of intersection relates to a 0.6 percent increase in vehicle crashes, almost the equivalent to adding one million miles of vehicle travel. Hadayeghi, et al. [32] found that intersections with three-legs are safer than four-leg crossroads. Separate research discovered that in urban areas having a significant number of 3-way intersection was linked to fewer pedestrian crashes [33]. Individuals readied themselves to cross on red in streets with two or three lanes, but this was not true in four-lane streets [22]. That research also observed that when roads get broader, people walk faster.

Pedestrian crash frequency was strongly associated with the number of intersections and signals. Siddiqui et al. [34] found that the number of intersections per traffic analysis zone had a positive relationship with vehicle-pedestrian crashes. As a result, pedestrians are exposed at intersections to danger, a higher number of them increases the points where pedestrians would be in a dangerous situation. In a separate study, the most risky crossing for pedestrians was found to be crossing at intersections without traffic light, where the risk of getting injury or dying was about four times higher than everywhere else on the roadway [35].

Driving speed is an important element related to crashes. In an urban road network, Zeng and Huang [36] discovered a positive relationship between increased speed limits and the chance of a crash. However, the context also plays a role. On urban roads, the crash rate rises faster with an increase in speed than on rural routes [37].

Studies have also focused on particular parts of the population. In terms of older pedestrians (above 65), several associations with an increased risk of mortality or severe injuries have been found [38]: the incidence of a crash at a crosswalk or within 15 metres of it, crashes on a road with a 50 km/h speed limit, crashes in signalised intersection, and intersections with larger sizes (two or more lanes) all increased the risk of mortality and severity of injuries.

The number of lanes has been found to have an influence on collision frequency. According to prior research, the risk of a crash increases in frequency and severity when more lanes are added to roadways [36, 39, 40].

The existence of road medians has been related to fewer collisions. Medians also reduce the danger of direct collisions between opposing vehicles and restricts the location of turning motions on the route at any one time [41].

According to Bendak et al. [22], pedestrians who were waiting at red lights for more than 40 seconds looked for other options, such as crossing the road on red. Pedestrians were more likely to cross on red at intersections with long waiting times [42, 43].

2.1.3.1.1 Hypothesis

Prior research found that people are less likely to cross on red at large intersections.

Hypo. 5: People are less likely to cross on red at large intersections.

Based on past research,

Hypo. 6: Pedestrians are more likely to cross on red if they are made to wait more than 30 seconds.

2.1.4 Built environment

The built environment has a direct influence on traffic volume, pedestrian volume, and pedestrian crossing behaviour. In terms of road network characteristics, the number of vehicle-pedestrian crashes is adversely related to the density of local streets and walkways [44]. Having sidewalks, pedestrian paths, and local streets were all associated with lower crash rates [44].

Hadayeghi et al. [45] found that the number of crashes each year increases as total Vehicle Kilometre Travel (VKT), total labour force, household population, and intersection density rise. Additionally, higher VKT were associated with larger area-wide crash frequencies [32, 45]. Zhang et al. [46] considered VKT per person as there is a link between the built environment and VKT. Zhang et al. [46] calculated weighted VKT per person by dividing total distance travelled by the number of persons in the vehicle for each reported trip. Zhang et al. indicated that more compact, mixed-use, infill projects and smaller city blocks can be successful in lowering VKT per person [46]. All else being equal, if per person VKT is reduced, the total VKT would also be reduced.

Larger shares of commercial land use and offices are linked to increased pedestrian crashes [5, 47]. Hadayeghi, et al. [32] showed that as the number of commercial locations increased, the risk of crash severity increased. However, there was no obvious link between commercial land usage and crash frequency [32]. In one study, pedestrian crashes were shown to be lower in areas with more mixed land use [44]. Related to context, Graham and Glaister [48] illustrated that in residential areas the risk of pedestrian crashes is higher than in commercial areas.

Another area in the built environment where traffic conflicts between diverse road users might occur is close to bus stops [41]. Traffic conflict is one of the environmental mediating variables that may lead road user to engage in dangerous actions and result in crashes [41]. According to [49], the number of bus stops have a positive correlation with the number of crashes. Higher numbers of pedestrian crashes have been linked to increased transit route density and better transit service [5, 33, 44].

Prior research has stressed the importance of elementary, middle, and high school students' walking safety. The number of schools (elementary and high school) and their density are critical issue in pedestrian safety. In two studies, the percentage of pedestrian crashes appears to have a positive association with schools (refers to the total number of elementary, middle and high schools) and university density [33, 47].

2.1.5 Driver distraction

Drivers while performing numerous tasks, may become distracted. Driving requires considerable attention as it is a dangerous activity and a secondary task might become distracting, thus reducing their ability to drive safely. Such distractions include using a cellphone (dialling, messaging, or chatting), talking with passengers, eating, or listening to music. Secondary tasks might consume a significant amount of the driver's attention, which has a detrimental influence on making rapid decisions. It is dangerous, especially when drivers are in urban settings that require them to respond quickly and safely when confronted with pedestrians or other vehicles. While driving, listening to music can have an impact on driving behavior which will be further discussed below.

Any activity that interferes in processes that have effects on driver awareness, vehicle control, or reaction time should be considered as a high-risk factor for driver distraction [2, 50-52]. Also, adjusting audio systems including the radio, inserting a CD, scrolling through a playlist, and so on are distractions that affect those dangerous outcomes [53-55].

Younger drivers, aged 16 to 20, are at the highest risk of mobile phone-related crashes [56]. In a meta-analysis by Klauer et al. [57], secondary task distraction was shown to be an influencing factor in at least 23 percent of all crashes. Listening to music as a secondary task for all kinds of music doesn’t have the same effect. The rhythm or beat of music has different effects on drivers. Acceleration and traffic violations can be increased by listening to rapid music [58, 59]. Young drivers show that they are more likely to engage in risky driving behavior when listening to rapid music [60].

2.1.6 Conclusion

The above is a non-exhaustive list of how individual behavior, intersection characteristics, and the built environment affect pedestrian safety. The relevance of crucial elements linked to pedestrian behavior and safety was discussed and a number of those influences are shown in Figure 2.1.

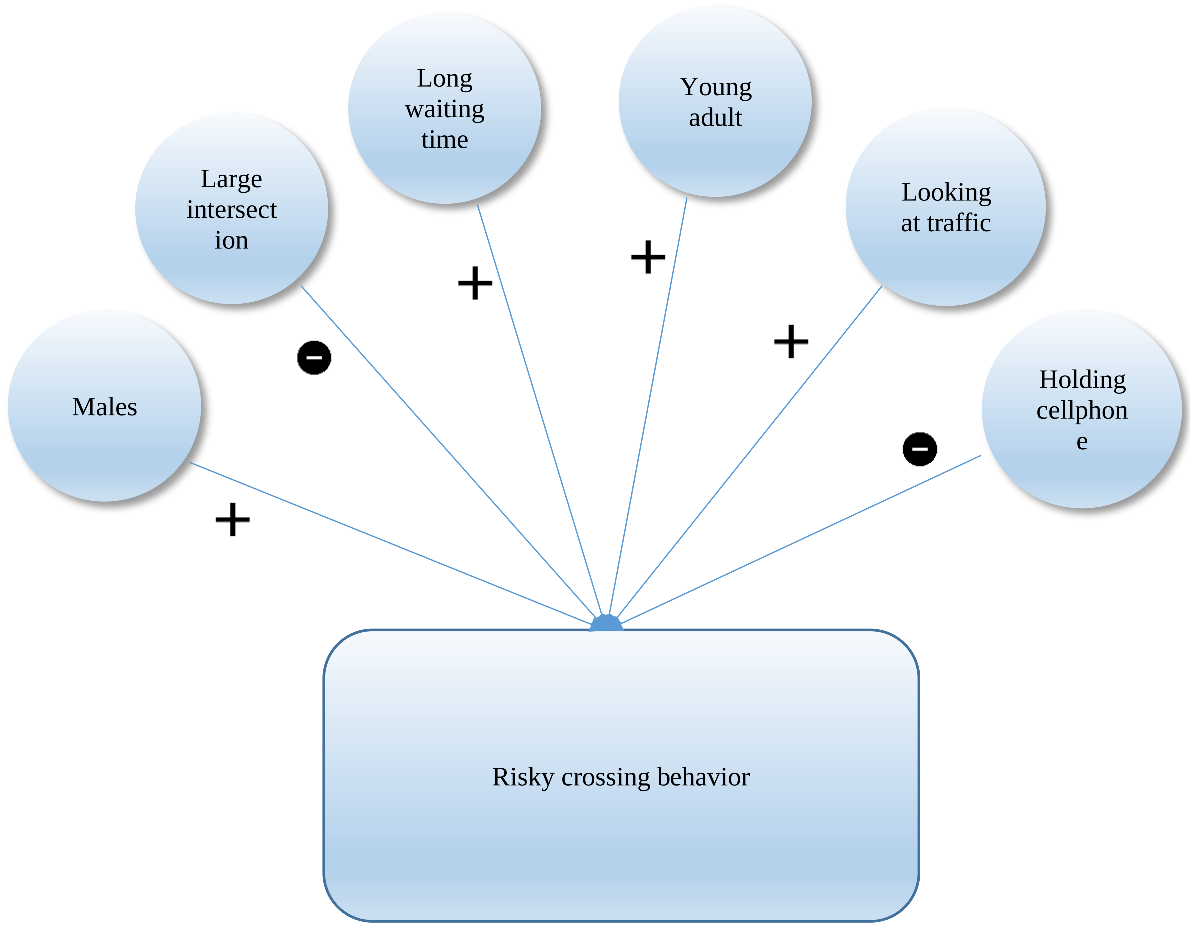

Figure 2.1Influences on pedestrian risky crossing behavior

CHAPTER 3 METHODOLOGY

The methodology relevant for this thesis is presented in its entirety here. The relevant part will be repeated in the research article that follows.

3.1 Study area

Our observation data was obtained from Montreal and Quebec City. In 2016, the city of Montreal covered an area of 367 km^2 and had a population of 1.7 million, which represented 40% of the population of the census metropolitan area. Quebec City covered an area of 428 km^2 and had a population of 532,000 (Statistics Canada. 2016). Twelve intersections were selected in each city (Figures 3.1 and 3.2) due to their geometric characteristics and their built environment (see Tables 3.1 and 3.2).

Decision criteria for choosing these intersections are common characteristics. The first element was the presence of pedestrians. Having a large mass of pedestrians in order to have sufficiently large numbers of observations in order to conduct statistical analysis. Furthermore, the higher number of pedestrians, the greater the diversity of their individual actions, and therefore the more meaningful and representative the data collected. The second necessary element for each intersection is having a location near the intersection where the observer may be positioned in such a way that pedestrians can be seen safely and discretely. It is therefore necessary to have relatively wide approaches to the intersection. Other characteristics observed at the intersections are listed below:

- Light cycles in intersections
- The width of the road, crosswalks and waiting areas
- Floor marking
- The presence of streetlights
- Visible signs at the intersection
- Speed limitation signs
- Prohibition of right or left turn
- Presence of push buttons or not

- Characterization of the pedestrian figure (white silhouette), numerical counting (pedestrian countdown), appearance of figures.

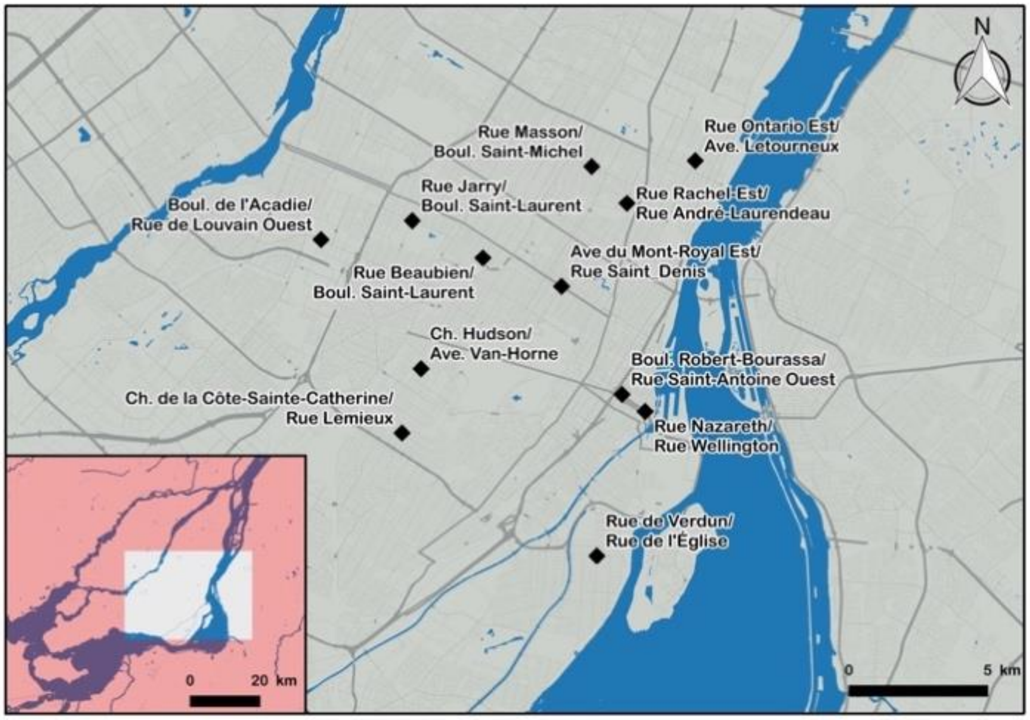

Figure 3.1 The intersection locations of this study in Montreal (Rue = street; Boul. = boulevard). Image credit: Simon Turcotte

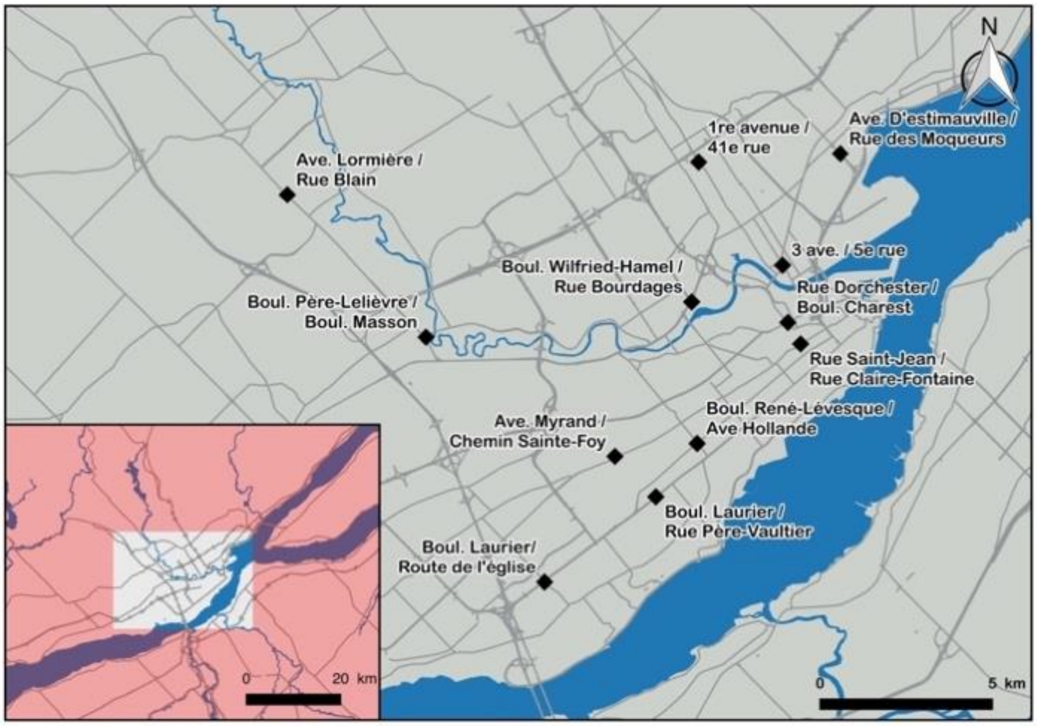

Figure 3.2 The intersection locations of this study in Quebec City (Rue = street; Boul. = boulevard). Image credit: Simon Turcotte

Table 3.1 Intersection characteristics observed in Montreal

Intersection name	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
Beaubien & Saint Laurent	3 and 4	10 & 14 m	0	T type (three ways)	yes	2	no	Most urban
Jarry & Saint Laurent	5 and 7	17 & 23 m	1.5 m	four ways	yes	4	no	Middle density urban
Acadie & Louvain	4 and 7	14 & 26 m	1.5 m	four ways	no	2	no	Most residential
Rachel & Laurendeau	3 and 5	19 & 17 m	0	four ways	yes	3	yes	Middle density urban
Cote Saint Catherin & /Lemieux	6 and 6	16 & 13 m	0	T type (three ways)	yes	2	no	Most urban
Hudson & Van_Horne	4 and 3	16 & 11 m	0	four ways	yes	2	no	Most urban
Verdun & De L'eglise	3 and 3	12 & 10 m	0	four ways	yes	3	no	Most urban
Nazareth & Wellington	2 and 5	17 & 18 m	0	four ways	no	1	no	Middle density urban
Robert Bourassa & Saint Antoine	8 and 6	31 & 22 m	3 m	four ways	no	1	no	Most urban
Mont Royal & Saint Denis	3 and 6	11 & 18 m	0	four ways	yes	4	no	Most urban
Ontario & Letourneux	4 and 4	12 & 12 m	0	four ways	yes	2	no	Most urban
Masson & Saint Michel	4 and 6	11 & 18 m	0	four ways	yes	4	no	Most urban

Table 3.2 Intersection characteristics observed in Québec City

Intersection name	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
3 me Avenue & 5 me Rrue	2 and 4	7 & 10 m	0	four ways	yes	2	yes	Middle density urban
Dorchester & Charest	6 and 4	20 & 12 m	0	four ways	no	3	no	Most urban
L'ormiere & Blain	4 and 4	15 &15 m	0	four ways	no	2	yes	Middle density urban
Pére Leliévre & Masson	4 and 4	12 & 12 m	0	four ways	no	0	yes	Most residential
René Lévesque & Hollande	4 and 4	14 & 12 m	0	four ways	yes	2	no	Most residential
Saint Jean & Claire Fontaine	2 and 3	6 & 9 m	0	T type (three ways)	no	1	no	Middle density urban
Wilfried Hamel & Bourdages	8 and 4	33 & 15 m	3.5 m	four ways	no	2	no	Most urban
Laurier & De L'Église	8 and 4	28 & 14 m	2 m	four ways	no	3	no	Most residential
Myrand &Chemin Sainte Foy	4 and 4	12 & 15 m	0	four ways	no	2	no	Most residential
1re Avenue & 41me Rue	4 and 5	14 & 19 m	0	four ways	no	4	no	Middle density urban
D'estimauville & Des Moqueurs	2 and 4	8 & 18 m	0	four ways	no	1	no	Middle density urban
Cartier & Grande Allée*	2 and 4	8 &13 m	0	four ways	no	2	no	Middle density urban
Laurier & Du Père Vaultier	4 and 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential

* This intersection was observed only in the Fall of 2019 and Spring of 2020 as it replaced another intersection where insufficient number of pedestrians were observed in the Summer of 2019.

3.2 Data collection

At these 24 intersections, data was collected by randomly observing pedestrians as they crossed. The observation periods, lasting 3 hours each time, were conducted at different times throughout the year. During the Summer of 2019, each intersection was visited three times (morning, noon, and evening) for a total of 9 hours of observations and accounted for more than half of the total observations made during the project. In the Fall of 2019 and Spring 2020 (each representing about 1/4 of the observations), these were made at the end of the day, from 3 p.m. to 6 p.m. as this is the period of the day when most collisions occur [2]. Although planned, no observations were made in the Winter of 2020 due to the pandemic. There were 4711 pedestrian observations in this dataset. Pedestrian characteristics are from observation, so some errors in terms of gender or age may occur. Pedestrians were also randomly interviewed to obtain information such as perception danger. Results of that part of the study can be seen here [61].

In addition, a web survey was conducted to gather input from other road users' perspectives in Spring 2020 with around 1,200 respondents (mostly drivers) in Montreal and Quebec City. Questions included knowledge about diagonal crossing and turning at intersections, and what they focus on when turning (e.g., attention to pedestrians, oncoming traffic). General results of that survey and the project can be found here [62].

Counts of vehicles and pedestrian volume at the same time of day as the observations at the intersections are from 2018 [63] for Montreal. For Quebec City, the data were obtained through direct request to the transport engineering department of the City of Quebec.

The observation data was collected using the Survey123 software. The factors which were observed at the study locations were:

- Individual characteristics (age group, sex, mobility aid),
- Distractions before crossing,
- Head movement before and during crossing,
- Intersection characteristics (type of intersection, average waiting time (see methodology for details), number of lanes, street width, presence of refuge island, presence of bus stop),
- The pedestrian's interactions with other road users (bikes and vehicles). This observation data was used in another project by STRAPI team (see Figure 3.3),
- Built environment and land use (most urban, middle density urban, most residential).

The built environment was categorized into three groups by Non-hierarchical analysis method (K-means cluster analysis) depending on these characteristics: population density at the intersection in a buffer zone with radius of 500 meters, material deprivation index and social deprivation index [64], area of residential and commercial areas in km^2 and area of industrial and institutional zones in km^2 [65] (see Table 3.3). The latter value is not statistically different between the groups. The material deprivation index: “involves deprivation of the goods and conveniences that are part of modern life, such as adequate housing, possession of a car, access to high speed internet, or a neighbourhood with recreational areas” [64]. The social deprivation index: “is characterized by individuals living alone, being a lone parent and being separated, divorced or widowed” (*ibid*).

Table 3.3 Built environment categories and their characteristics

	Most urban ***Mean (Std. Dev.)***	***Middle density urban*** ***Mean (Std. Dev.)***	***Most residential*** ***Mean (Std. Dev.)***
Population density	20,490 (2,680)	11,742 (813)	6680 (1177)
Material deprivation index	-0.02 (0.03)	-0.04 (0.03)	0.00 (0.03)
Social deprivation index	0.05 (0.01)	0.04 (0.01)	0.02 (-0.02)
Residential and commercial areas	0.35 (0.11)	0.32 (0.08)	0.38 (0.06)
Industrial and institutional area*	0.07 (0.03)	0.07 (0.07)	0.07 (0.03)

* This variable is not statistically different between the groups based on One-way ANOVA test (Bartlett's test).

Before crossing, the following forms of distraction were observed:

- Using headphones,
- Holding a smartphone in their hand,
- Having a companion, and
- Talking on their phone.

In addition, all types of head movement before and during crossing are classified as follows:

- Looking at traffic light,
- Looking at traffic,
- Looking at the ground,
- Looking at other pedestrians,
- Looking at an electronic device.

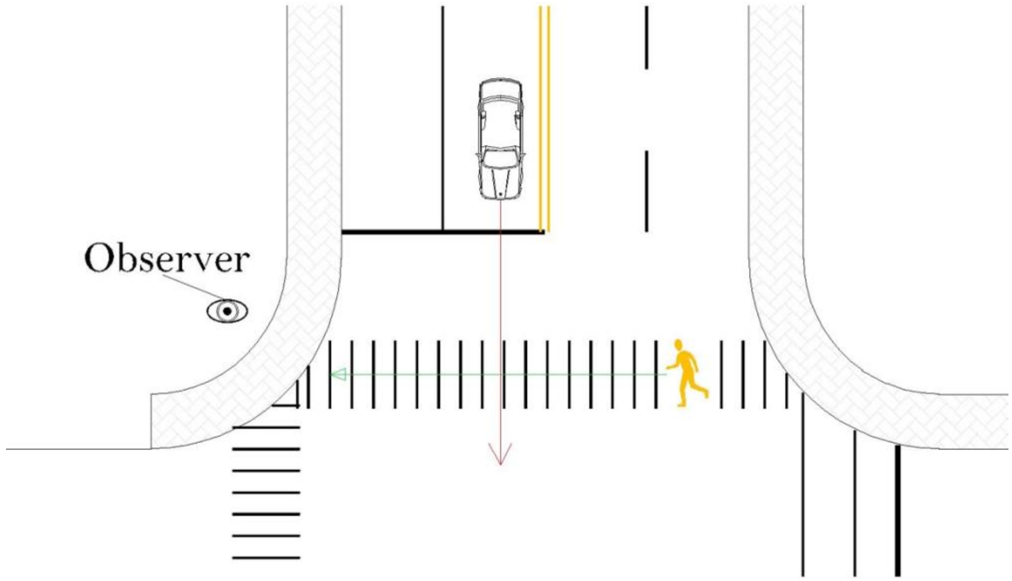

Figure 3.3 Diagram of an interaction between a pedestrian and a vehicle.

Using an observation guide and stationed at a corner of the intersection, observers would pick a random pedestrian approaching the intersection. The observers then turned their attention to the type of crossing they are making (diagonal crossing, L or one segment at a time). Their head movement during the crossing was also noted as well as their individual characteristics (age, sex, etc.).

The observation of pedestrian behavior is divided into four zones (Figure 3.4). Each zone corresponds to one part of the observation form, and each of them refers to a specific moment in space and time:

- Zone 1: approaching the crossing,
- Zone 2: at the beginning of the crossing (as soon as one foot is placed in the street),
- Zone 3: at mid-crossing, and
- Zone 4: at the end of the crossing (when the last foot is out of the street).

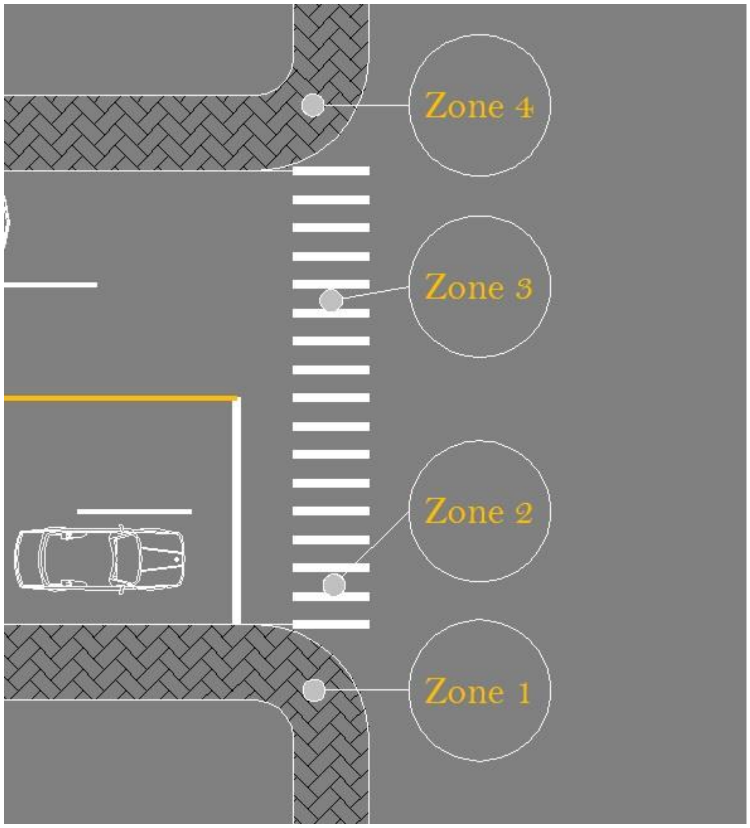

Figure 3.4 Zones for the pedestrian behavior observation.

The general statistics of the observations for this study are shown in Table 3.4.

Table 3.4 General statistics of the observations.

Variables	***Quebec***		***Montreal***
Observations	48% (2265)		52% (2446)
Female	50.3% (1140)	*	52.3% (1279)
Age groups			
Below 12	0.4% (8)	*	2.4% (59)
12 To 24	24.6% (557).	*	22% (534)
25 To 64	63% (1430)	*	65% (1578)
56 And up	12% (270)		11.3% (276)
Distraction before crossing			
Using headphones	15%		17%
Being with someone	16%	*	14%
Smartphone in hand	12%		13%
Talking with cellphone	2%		3%
Head movements before crossing			
Looking straight at traffic light	57%	*	85%
Looking at traffic	47%	*	37%
Looking at the ground	18%		20%
Looking at other pedestrians	5%		6%
Looking at electronic device	3.50%		6%
Head movement during crossing			
Looking straight at traffic light	53%	*	79%
Looking at traffic	27%		27%
Looking at the ground	31%	*	25%
Looking at other pedestrians	6%		6%
Looking at electronic device	2%		3%
Crossing violation			
Start on red	29%	*	8%
Finish on red	32%	*	12%
Start on green finish on red	1%	*	6%
Cross on red (start and finish on red)	26%	*	4%

* Statistical difference between cities by Pearson Chi-squared test.

3.3 Analysis Modeling

Chi-squared analysis using STATA v. 13 was performed to determine whether statistical differences exist in the frequency of such behaviors across the intersections. Then, intersections are identified that have behaviors that fall outside the average plus or minus one standard deviation (i.e., those at the extreme upper and lower). The context and characteristics of these intersections are examined for differences. To determine influences on risky crossing behavior, logistic regression models using STATA v.13 were performed. In the analysis, the independent variables are pedestrian characteristics, behavior (distractions and head movement), intersection characteristics, and built environment context. Risky crossing behaviors were considered as dependent variables. The relationship of each independent variable was calculated with respect to each of the four dependent variables.

CHAPTER 4 DISTRACTIONS AND HEAD MOVEMENT

Finding the proportion of distraction before crossing and head movement before and during crossing is important for gaining a better understanding of the effect of intersection characteristics and built environment context on pedestrian behavior.

Chi-squared analysis using STATA v. 13 was performed to determine whether statistical differences exist in the frequency of the observed behaviors (distractions: using headphones, holding a smartphone in their hand, having a companion, and talking on their phone. And head movements: looking at traffic light, looking at traffic, looking at the ground, looking at other pedestrians, looking at an electronic device) across the intersections. Then, intersections are identified that have behaviors that fall outside the average plus standard deviation (both more and less). The context and characteristics of these intersections are examined for differences.

Pedestrian distraction may reduce their ability to react to dangerous traffic. It relates primarily to personal safety, as opposed to danger imposed on others, as is the case with driver distraction

Intersections were divided into three groups to make it easier to determine relationships (Table 4.1): large, medium, and small. These clusters were created based on street crossing width, number of lanes, presence of bus stop, and small refuge islands. A new variable was created for the presence of small refuge islands (rather than using the size of the island).

Table 4.1 Intersection categories

Intersection categories	*Number of intersections (mean)*	*Number of lanes (mean)*	*Width of street (mean)*	*Number of bus stops (mean)*	*Presence of small refuge island (mean)*
Large intersections	6	7.3	27.5 m	2.3	1
Medium intersections	9	5.2	18 m	2.7	0.1
Small intersections	10	3.8	12.6 m	1.8	0

4.1 Distractions before crossing

The frequency of four distractions is shown in Figure 4.1. As can be seen, the percentage of observed pedestrians who used headphones, had a smartphone in hand, or talked on a cellphone in Montreal was more than in Quebec City. However, they are not statistically different (Table 3.4). According to the Figure 4.1 having a companion in Quebec City is more likely than in Montreal and this is statistically significant based on Pearson Chi-squared test.

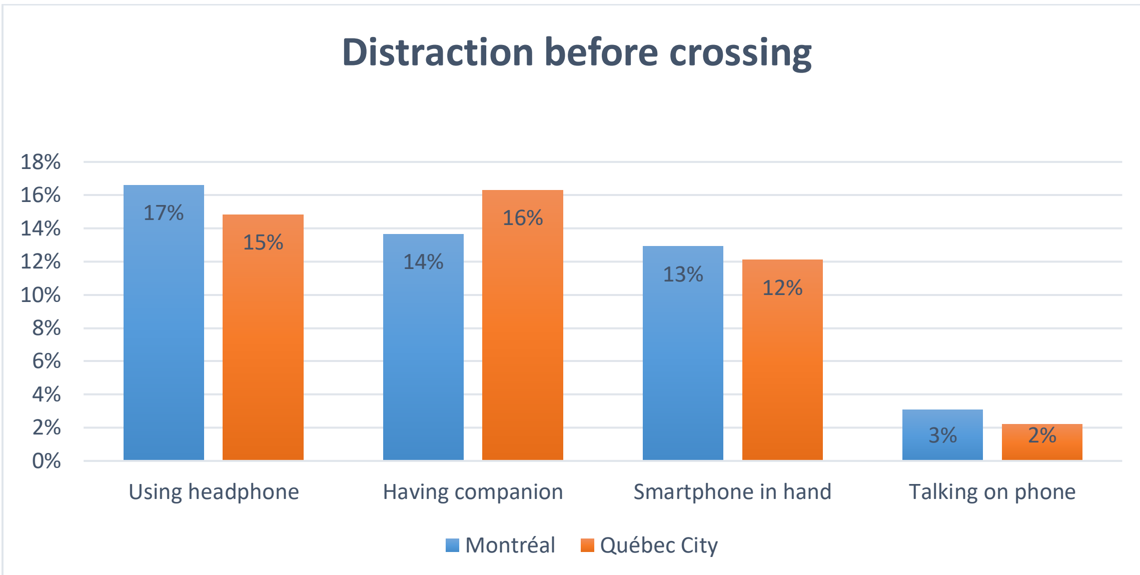

Figure 4.1 Distraction before crossing in Montreal and Quebec City

Now, relationships with intersections are examined. To begin, the variable "using headphones" was used in this analysis. A difference was found between different intersections (Table 4.2). One intersection in Quebec City stands out as its percentage of using headphones (24%) is considerably more than the average (16%) plus one standard deviation (4%). From looking at the diagram of the intersection design, it has four lanes for one axis and five lanes for the other. For the geographic location, this intersection is located in an area with a high population density. In Montreal, there are two intersections with high percentages: 25% and 22%. These two intersections have similar built environment types, since they are both in a "middle density urban area". There are six intersections which are lower than average (16%) minus one standard deviation (4%): One in Montreal and five in Quebec City. The common point in these six is that most of the intersections are in an area with lower density. The majority of those intersections have between two and four lanes. Another characteristic might be related to wearing headphones is the kind of pedestrian who use headphones more often. As such, proximity to university or schools might result in a large proportion of students who are more likely to use headphones.

There are no clear design features associated with wearing headphones. In terms of the built environment, it's possible that areas that aren't particularly residential have fewer people (as a percentage) using headphones. Whether this relates to the type of pedestrians, or the location is not clear. In Montreal it may be that in non-residential or commercial areas individuals may feel that traffic is more dangerous, so they do not want such distractions. It could also be that the people observed are different; perhaps young people are more likely to have headphones on and are more likely to be found in more residential areas.

Table 4.2 Comparing proportion of variable "using headphones" among the critical intersections

City	*Intersection Name*	*Percentage*	*Number of lanes*	*Width of street*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
Mtl	*Jarry & Saint Laurent*	25% *	5 and 7	17 & 23 m	1.5 m	four ways	yes	4	no	Middle density urban
QC	*Myrand &Chemin Sainte Foy.*	24% *	4 and 4	12 & 15 m	0	four ways	no	2	no	Most residential
Mtl	*Nazareth & Wellington.*	22% *	2 and 5	17 & 18 m	0	four ways	no	1	no	Middle density urban
Mtl	*Ontario & Letourneux*	11%	4 and 4	12 & 12 m	0	four ways	yes	2	no	Most urban
QC	*3 me Avenue & 5 me Rrue*	11%	2 and 4	7 & 10 m	0	four ways	yes	2	yes	Middle density urban
QC	*Cartier & Grande Allée*	11%	2 and 4	8 &13 m	0	four ways	no	2	no	Middle density urban
QC	*Laurier & De L'Église*	11%	8 and 4	28 & 14 m	2 m	four ways	no	3	no	Most residential
QC	*Laurier & Du Père Vaultier*	9%	4 and 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential
QC	*D'estimauville & Des Moqueurs*	6%	2 and 4	8 & 18 m	0	four ways	no	1	no	Middle density urban

* Intersection with the percentage of using headphone more than the average plus standard deviation across all intersections in the study.

For the variable of "having a companion", we can see the differences in Table 4.3:

There is one intersection in Montreal with percentages higher than the average (14%) plus standard deviation (3%) and three in Quebec (21%, 22%, and 26%). The number of lanes for the Montreal intersection are between four and seven, and the mean of street width is between nineteen and twenty. These features are those found in the medium group of intersections. In Quebec City the intersections of interest have two to four lanes and street width are all 13 meters, which places these intersections in the small intersection category. In Montreal the highest percentage are in locations classified as the most urban areas, but in Quebec City the pattern is different with the intersections found in middle density urban areas. We find out the main common factor in this variable is that these intersections are located in areas with higher population density (most urban area). It appears that in such locations, pedestrians are more likely to cross with a companion.

Table 4.3 Comparing proportion of variable "having a companion" among the critical intersections

City	*Intersection name*	*Percentage*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stop (#)*	*Bike lane (yes, no)*	*Built environment type*
Mtl	*Robert bourassa/Saint antoine*	19% *	8 and 6	31 & 22 m	3 m	four ways	no	1	no	Most urban
Qc	*3 me Avenue & 5 me Rrue*	21% *	2 and 4	7 & 10 m	0	four ways	yes	2	yes	Middle density urban
Qc	*Saint Jean & Claire Fontaine*	22% *	2 and 3	6 & 9 m	0	T type (three ways)	no	1	no	Middle density urban
Qc	*D'estimauville & Des Moqueurs*	26% *	2 and 4	8 & 18 m	0	four ways	no	1	no	Middle density urban
Mtl	*Rachel & Laurendeau*	10%	3 and 5	19 & 17 m	0	four ways	yes	3	yes	Middle density urban
Mtl	*Cote Saint Catherin & /Lemieux*	10%	6 and 6	16 & 13 m	0	T type (three ways)	yes	2	no	Most urban
Mtl	*Verdun & De L'eglise*	6%	3 and 3	12 & 10 m	0	four ways	yes	3	no	Most urban

* Intersection with the percentage of having companion more the average plus standard deviation across all intersections in the study.

For the variable of "smartphone in hand", the results are presented in Table 4.4:

The average was 13% and the standard deviation was 4%. For Quebec City there are two intersections above the threshold being used (with 18% and 20%). There is one intersection in Montreal (24%) that is more than average (13%) plus standard deviation (4%). The Montreal intersection is in the medium intersection category and located in a middle density area. Intersections related to Quebec City are in the large intersection category and one is located in a most urban area, while the other is in a most residential area. These results suggest that people may be more likely to hold a smartphone in their hand at large and medium intersections with longer crossing duration than small intersections. No relationship with the context was found.

Table 4.4 Comparing proportion of variable "smartphone in hand" among the critical intersections

City	*Intersection name*	*Percentage*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
Mtl	*Nazareth & Wellington*	24% *	2 & 5	17 & 18 m	0	four ways	no	1	no	Middle density urban
QC	*Dorchester & Charest*	18% *	6 & 4	20 & 12 m	0	four ways	no	3	no	Most urban
QC	*Laurier & De L'Église*	20% *	8 & 4	28 & 14 m	2 m	four ways	no	3	no	Most residential
Mtl	*Cote Saint Catherin & /Lemieux*	8%	6 & 6	16 & 13 m	0	T type (three ways)	yes	2	no	Most urban
Mtl	*Ontario & Letourneux*	8%	4 & 4	12 & 12 m	0	four ways	yes	2	no	Most urban
QC	*3 me Avenue & 5 me Rrue*	7%	2 & 4	7 & 10 m	0	four ways	yes	2	yes	Middle density urban
QC	*Laurier & Du Père Vaultier*	6%	4 & 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential

* Intersection with the percentage of smartphone in hand more than the average plus standard deviation across all intersections in the study.

For the variable of "talking on a cellphone", the results are shown in Table 4.5:

The average was 3% and the standard deviation was 2%. There are two intersections in Montreal that lie outside the upper range (5%), and two in Quebec City (5%). The intersections of interest in both cities have almost the same number of lanes. The two intersections in Montreal are located in most urban areas (high density). For Quebec City, the intersection is found in a middle density urban area.

Table 4.5 Comparing proportion of variable “talking on a cellphone” among the critical intersections

city	*Intersection name*	*(%)*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
Mtl	*Hudson & Van_Horne*	5% *	4 & 3	16 & 11 m	0	four ways	yes	2	no	Most urban
Mtl	*Robert Bourassa & Saint Antoine*	5%*	8 & 6	31 & 22 m	3 m	four ways	no	1	no	Most urban
QC	*L'ormiere & Blain*	5% *	4 & 4	15 &15 m	0	four ways	no	2	yes	Middle density urban
QC	*Myrand &Chemin Sainte Foy*	5% *	4 & 4	12 & 15 m	0	four ways	no	2	no	Most residential
QC	*3 me Avenue & 5 me Rrue*	1%	2 & 4	7 & 10 m	0	four ways	yes	2	yes	Middle density urban
QC	*Cartier & Grande Allée**	0%	2 & 4	8 &13 m	0	four ways	no	2	no	Middle density urban
QC	*Wilfried Hamel & Bourdages*	1%	8 & 4	33 & 15 m	3.5 m	four ways	no	2	no	Most urban
QC	*Laurier & Du Père Vaultier*	0%	4 & 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential
QC	*D’estimauville & Des Moqueurs*	1%	2 & 4	8 & 18 m	0	four ways	no	1	no	Middle density urban

* Intersection with the percentage of talking cellphone more than the average plus standard deviation across all intersections in the study.

4.2 Head movement before crossing

The previous section examined potential distractions to pedestrians that may increase their risk to dangerous traffic. In this section, a behavior that may demonstrate how much attention or worry a pedestrian is giving to traffic danger is examined: head movement before the crossing were observed for Montreal and Quebec. The percentages of each head movement are in shown in Figure 4.2.

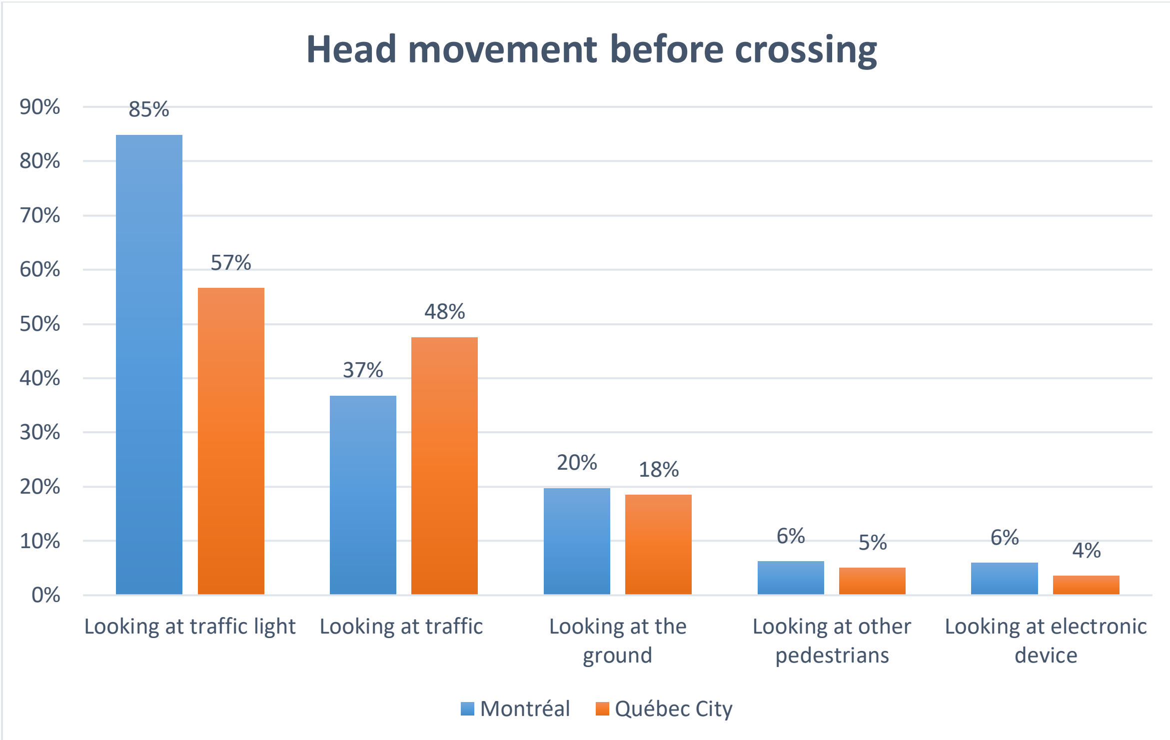

Figure 4.2 Head movement before crossing in Montreal and Quebec City

Results of Chi-Squared analysis show that differences in looking at the traffic light before crossing are statistically significant in Montreal (85%) compared to Quebec City (57%). Another statistical difference is the percentage of pedestrians who look at traffic; the percentage of pedestrians who look at traffic in Quebec City (48%) was higher than in Montreal. The percentage of people look at "the ground," "other pedestrians," and "electronic gadgets" in Montreal was greater than in Quebec City, but not statistically significant.

For the variable “looking at traffic light” we can find these results in Table 4.6:

All of the intersections which are higher than the average (72 %) plus one standard deviation (18%) are in Montreal. The intersection characteristics show that they are all in the small intersection category and located in areas classified as middle or more urban (high density). Looking at the traffic light may indicate that the pedestrian is simply waiting their turn. It may indicate also that the time allocated to cross is limited (in small intersections) and they do not want to miss their chance.

Table 4.6 Comparing proportion of variable "looking at traffic light" among the critical intersections

City	*Intersection name*	*(%)*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
MTL	*Rachel & Laurendeau*	94% *	3 & 5	19 & 17 m	0	four ways	yes	3	yes	Middle density urban
MTL	*Mont Royal & Saint Denis*	90% *	3 & 6	11 & 18 m	0	four ways	yes	4	no	Most urban
MTL	*Masson & Saint Michel*	91% *	4 & 6	11 & 18 m	0	four ways	yes	4	no	Most urban
QC	*3 me Avenue & 5 me Rrue*	49%	2 & 4	7 & 10 m	0	four ways	yes	2	yes	Middle density urban
QC	*Saint Jean & Claire Fontaine*	36%	2 & 3	6 & 9 m	0	T type (three ways)	no	1	no	Middle density urban
QC	*Laurier & Du Père Vaultier*	26%	4 & 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential
QC	*D'estimauville & Des Moqueurs*	42%	2 & 4	8 & 18 m	0	four ways	no	1	no	Middle density urban

* Intersection with the percentage of looking at traffic light before crossing more than the average plus standard deviation across all intersections in the study.

For the variable "looking at traffic" we can find these results as the Table 4.7:

All of the intersections which have proportions that are more than the average (40%) plus one standard deviation (12%) is located in Quebec City and are in the small intersection category. The built environment type is almost always the same, in residential area. In Quebec City more pedestrians were observed to look at the traffic before crossing. It is related to the small number of lanes (small intersections) and location, middle density urban area. Individuals who are looking at traffic may be judging whether or not there is a sufficient gap for them to cross before their light turns. This may be more likely in a situation where the wait time is judged to be too long.

Table 4.7 Comparing proportion of variable "looking at traffic" among the critical intersections

City	*Intersection name*	*(%)*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*street parking*	*bus stops (#)*	*bike lane (yes, no)*	*built environment type*
QC	*3 me Avenue & 5 me Rrue*	72% *	2 & 4	7 & 10 m	0	four ways	yes	2	yes	Middle density urban
QC	*René Lévesque & Hollande*	53% *	4 & 4	14 & 12 m	0	four ways	yes	2	no	Most residential
QC	*Saint Jean & Claire Fontaine*	73% *	2 & 3	6 & 9 m	0	T type (three ways)	no	1	no	Middle density urban
QC	*D'estimauville & Des Moqueurs*	76% *	2 & 4	8 & 18 m	0	four ways	no	1	no	Middle density urban
MTL	*Nazareth & Wellington*	26%	2 & 5	17 & 18 m	0	four ways	no	1	no	Middle density urban
MTL	*Robert Bourassa & Saint Antoine*	27%	8 & 6	31 & 22 m	3 m	four ways	no	1	no	Most urban
QC	*Laurier & De L'Église*	25%	8 & 4	28 & 14 m	2 m	four ways	no	3	no	Most residential

* Intersection with the percentage of looking at traffic before crossing more than the average plus standard deviation across all intersections in the study.

For the variable "looking at the ground" we can find these results in Table 4.8:

There are two intersections where pedestrians were observed looking at the ground more than the average (20 %) plus standard deviation (12%). Both are located in Quebec City and are classified in the small intersection category and in most urban area. Individuals may look to the sidewalk if they are confident to cross when it is their turn whether they are watching for the light to change or not. A likely factor that may influence this behavior could be age group (e.g., older people).

Table 4.8 Comparing proportion of variable "looking at the ground" among the critical intersections

City	*Intersection name*	*(%)*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
QC	*1re Avenue & 41me Rue*	40% *	4 & 5	14 & 19 m	0	four ways	no	4	no	Middle density urban
QC	*Laurier & Du Père Vaultier*	59% *	4 & 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential
QC	*L'ormiere & Blain*	3%	4 & 4	15 &15 m	0	four ways	no	2	yes	Middle density urban
QC	*Pére Leliévre & Masson*	1%	4 & 4	12 & 12 m	0	four ways	no	0	yes	Most residential
QC	*Myrand &Chemin Sainte Foy*	4%	4 & 4	12 & 15 m	0	four ways	no	2	no	Most residential
QC	*D'estimauville & Des Moqueurs*	7%	2 & 4	8 & 18 m	0	four ways	no	1	no	Middle density urban

* Intersection with the percentage of looking at ground before crossing more than the average plus standard deviation across all intersections in the study.

For the variable "looking at other pedestrians" we can find these results in Table 4.9:

We can see five intersections where more people were observed looking at other pedestrians than the average (6%) plus one standard deviation (2%): one in Quebec City and four in Montreal. The intersection characteristics are similar, and they are categorized in either the medium or small intersections categories. All these intersections are frequently located in the most urban areas (high population density).

Table 4.9 Comparing proportion of variable "looking at other pedestrian" among the critical intersections

City	*Intersection name*	*(%)*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
MTL	*Robert Bourassa & Saint Antoine*	9% *	8 & 6	31 & 22 m	3 m	four ways	no	1	no	Most urban
MTL	*Mont Royal & Saint Denis*	9% *	3 & 6	11 & 18 m	0	four ways	yes	4	no	Most urban
MTL	*Ontario & Letourneux*	9% *	4 & 4	12 & 12 m	0	four ways	yes	2	no	Most urban
MTL	*Masson & Saint Michel*	8% *	4 & 6	11 & 18 m	0	four ways	yes	4	no	Most urban
QC	*Dorchester & Charest*	9% *	6 & 4	20 & 12 m	0	four ways	no	3	no	Most urban
MTL	*Verdun & De L'eglise*	0%	3 & 3	12 & 10 m	0	four ways	yes	3	no	Most urban
QC	*Pére Leliévre & Masson*	2%	4 & 4	12 & 12 m	0	four ways	no	0	yes	Most residential
QC	*René Lévesque & Hollande*	2%	4 & 4	14 & 12 m	0	four ways	yes	2	no	Most residential

* Intersection with the percentage of looking at other pedestrian before crossing more than the average plus standard deviation across all intersections in the study.

For the variable "looking at electronic device" we can find these results in Table 4.10:

There are two intersections where pedestrian looking at the electronic device more than the average (5%) plus one standard deviation (3%). These intersections are located in Montreal and are classified in the medium intersection category. Both of intersections have population densities that are higher than those in the lower density areas. Thus, the common point among them is similarity of intersection characteristics and that they are located in neighborhoods that are classified as the most urban areas.

Table 4.10 Comparing proportion of variable "looking at electronic device" among the critical intersections

city	*Intersection name*	*(%)*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
MTL	*Nazareth & Wellington*	13% *	2 & 5	17 & 18 m	0	four ways	no	1	no	Middle density urban
MTL	*Robert Bourassa & Saint Antoine*	9% *	8 & 6	31 & 22 m	3 m	four ways	no	1	no	Most urban
QC	*René Lévesque & Hollande*	2% *	4 & 4	14 & 12 m	0	four ways	yes	2	no	Most residential
QC	*Saint Jean & Claire Fontaine*	1%	2 & 3	6 & 9 m	0	T type (three ways)	no	1	no	Middle density urban
QC	*Laurier & Du Père Vaultier*	0%	4 & 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential
QC	*D'estimauville & Des Moqueurs*	1%	2 & 4	8 & 18 m	0	four ways	no	1	no	Middle density urban

* Intersection with the percentage of looking at electronic device before crossing more than the average plus standard deviation across all intersections in the study.

Head movement during crossing

Head movement during crossing were observed in Montreal and Quebec. The percentages of each head movement are shown in Figure 4.3.

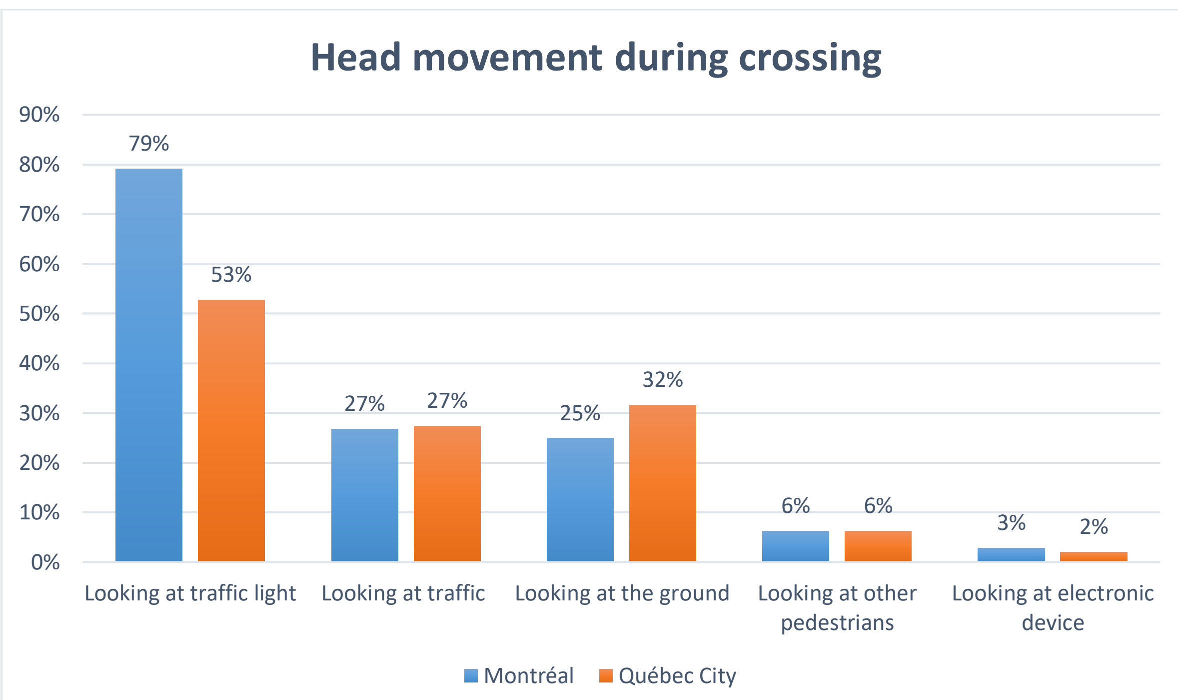

Figure 4.3 Head movement during crossing in Montreal and Quebec City

Looking at traffic light during crossing in Montreal (79%) is statistically more than Quebec City (53%) (Figure 4.3). However, the percentage of pedestrians looking at traffic during crossing in

Quebec City was the same as in Montreal (27%). Pedestrians in Quebec City (32%) look at "the ground" statistically more than those in Montreal (25%). Both cities have the same results regarding looking at "other pedestrians" (6%) and "electronic devices" (2-3%) during crossing.

For the variable “looking at the traffic light” several results can be seen in Table 4.11. This behavior might indicate that individuals are more concerned about the amount of time to cross than traffic movement. For looking at the traffic light there are four intersections which have the highest occurrence of this behavior. All these intersections are in Montreal, the maximum range of this variable is 91% that is more than average (66%) plus one standard deviation (17%). These four intersections are all classified as small intersections in our study. As well, they are located in areas with high population densities in Montreal. In contrast, we can see that the intersections where the minimum number of pedestrians who looked at the traffic light during crossing were in Quebec City. These results might suggest that people in Montreal were more worried about how much time was left, while people in Quebec City were more likely to look elsewhere, whether to watch for dangerous traffic or some other point.

Table 4.11 Comparing proportion of variable “looking at traffic light during crossing” among the critical intersections

city	*Intersection name*	*(%)*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
Mtl	*Beaubien & Saint Laurent*	84% *	3 & 4	10 & 14 m	0	T type (three ways)	yes	2	no	Most urban
Mtl	*Rachel & Laurendeau*	91% *	3 & 5	19 & 17 m	0	four ways	yes	3	yes	Middle density urban
Mtl	*Mont Royal & Saint Denis*	86% *	3 & 6	11 & 18 m	0	four ways	yes	4	no	Most urban
Mtl	*Masson & Saint Michel*	88% *	4 & 6	11 & 18 m	0	four ways	yes	4	no	Most urban
QC	*Dorchester & Charest*	46%	6 & 4	20 & 12 m	0	four ways	no	3	no	Most urban
QC	*Pére Leliévre & Masson*	47%	4 & 4	12 & 12 m	0	four ways	no	0	yes	Most residential
QC	*1re Avenue & 41me Rue*	48%	4 & 5	14 & 19 m	0	four ways	no	4	no	Middle density urban
QC	*Laurier & Du Père Vaultier*	21%	4 & 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential
QC	*D’estimauville & Des Moqueurs*	33%	2 & 4	8 & 18 m	0	four ways	no	1	no	Middle density urban

* Intersection with the percentage of looking at traffic light during crossing more than the average plus standard deviation across all intersections in the study.

For the variable “looking at traffic” relationships with the intersections can be seen in Table 4.12. This behavior might suggest that people are worried about the traffic and want to continue observing it so that they could react if necessary. There are five intersections which have the highest percentage of pedestrian who looked at traffic more than the average (26%) plus one standard deviation (6%). One such intersection in Montreal belongs to the large intersection category and is located in an area with a high population density. Four intersections in Quebec City are in small intersection category and are located in areas with middle population density. As such, it would seem that people might be more worried about traffic in Quebec City intersections with only one intersection in Montreal in the high frequency group.

Table 4.12 Comparing proportion of variable "looking at traffic during crossing" among the critical intersections

City	*Intersection name*	*(%)*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
Mtl	*Cote Saint Catherin & /Lemieux*	38% *	6 & 6	16 & 13 m	0	T type (three ways)	yes	2	no	Most urban
QC	*3 me Avenue & 5 me Rrue*	35% *	2 & 4	7 & 10 m	0	four ways	yes	2	yes	Middle density urban
QC	*René Lévesque & Hollande*	33% *	4 & 4	14 & 12 m	0	four ways	yes	2	no	Most residential
QC	*Laurier & Du Père Vaultier*	32% *	4 & 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential
QC	*D'estimauville & Des Moqueurs*	61% *	2 & 4	8 & 18 m	0	four ways	no	1	no	Middle density urban
MTL	*Beaubien & Saint Laurent*	19%	3 & 4	10 & 14 m	0	T type (three ways)	yes	2	no	Most urban
QC	*Dorchester & Charest*	17%	6 & 4	20 & 12 m	0	four ways	no	3	no	Most urban
QC	*1re Avenue & 41me Rue*	16%	4 & 5	14 & 19 m	0	four ways	no	4	no	Middle density urban

* Intersection with the percentage of looking at traffic during crossing more than the average plus standard deviation across all intersections in the study.

For the variable "looking at the ground" several results can be found in Table 4.13. This variable may indicate that the individual is not concerned about traffic, the time to cross, or does not want to make eye contact with others. It could also indicate that the quality of the road is low, requiring that the individual pay attention to cracks or such (this, however, was not observed and should be in the future). For this variable we have four intersections with a higher than average (29%) plus one standard deviation percentage (12%) of pedestrians who did it. All these intersections located in Quebec City, are in the medium intersection category (Table 4.13), with two intersections in high population density areas and two are found in middle population areas. For the least frequent, all such intersections are located in Montreal. The results suggest that whatever the reason, it is more common to look at the ground in Quebec City than in Montreal.

Table 4.13 Comparing proportion of variable “looking at the ground” among the critical intersections

City	*Intersection name*	*(%)*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
QC	*Dorchester & Charest*	47% *	6 & 4	20 & 12 m	0	four ways	no	3	no	Most urban
QC	*Wilfried Hamel & Bourdages*	43% *	8 & 4	33 & 15 m	3.5 m	four ways	no	2	no	Most urban
QC	*1re Avenue & 41me Rue*	50% *	4 & 5	14 & 19 m	0	four ways	no	4	no	Middle density urban
QC	*Laurier & Du Père Vaultier*	62% *	4 & 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential
Mtl	*Beaubien & Saint Laurent*	15%	3 & 4	10 & 14 m	0	T type (three ways)	yes	2	no	Most urban
Mtl	*Acadie & Louvain*	27%	4 & 7	14 & 26 m	1.5 m	four ways	no	2	no	Most residential
Mtl	*Mont Royal & Saint Denis*	15%	3 & 6	11 & 18 m	0	four ways	yes	4	no	Most urban

* Intersection with the percentage of looking at ground during crossing more than the average plus standard deviation across all intersections in the study.

For the variable “looking at other pedestrians” we can find these results in Table 4.14. Looking at other pedestrians could indicate that the people crossing are trying to “negotiate” their movement with the other pedestrians, perhaps indicating that the space is congested. There are five intersections where pedestrians looked at other pedestrian more than the average (6%) plus standard deviation (2%). Two intersections in Montreal are in the same intersection type (small) and are in densely populated areas. Three of the intersections are in Quebec City in medium intersections category and located in residential areas with lower population density.

Table 4.14 Comparing proportion of variable "looking at other pedestrian" among the critical intersections

City	*Intersection name*	*(%)*	*Number of lanes*	*Width of streets*	*Refuge island size*	*Intersection type*	*Street parking*	*Bus stops (#)*	*Bike lane (yes, no)*	*Built environment type*
Mtl	*Beaubien & Saint Laurent*	10% *	3 & 4	10 & 14 m	0	T type (three ways)	yes	2	no	Most urban
Mtl	*Mont Royal & Saint Denis*	9% *	3 & 6	11 & 18 m	0	four ways	yes	4	no	Most urban
QC	*Laurier & De L'Église*	9% *	8 & 4	28 & 14 m	2 m	four ways	no	3	no	Most residential
QC	*Myrand &Chemin Sainte Foy*	9% *	4 & 4	12 & 15 m	0	four ways	no	2	no	Most residential
QC	*Laurier & Du Père Vaultier*	9% *	4 & 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential
Mtl	*Cote Saint Catherin & /Lemieux*	2%	6 & 6	16 & 13 m	0	T type (three ways)	yes	2	no	Most urban
Mtl	*Hudson & Van_Horne*	3%	4 & 3	16 & 11 m	0	four ways	yes	2	no	Most urban
Mtl	*Verdun & De L'eglise*	2%	3 & 3	12 & 10 m	0	four ways	yes	3	no	Most urban
QC	*René Lévesque & Hollande*	3%	4 & 4	14 & 12 m	0	four ways	yes	2	no	Most residential
QC	*1re Avenue & 41me Rue*	3%	4 & 5	14 & 19 m	0	four ways	no	4	no	Middle density urban

* Intersection with the percentage of looking at other pedestrians during crossing more than the average plus standard deviation across all intersections in the study.

4.3 Conclusion

The findings of this section examined intersection characteristics and the built environment with respect to distractions before crossing and head movement before and during crossing in Montreal and Quebec City. The analysis suggests that some distractions and head movements may be influenced by intersection characteristics and the built environment, but it is not possible to say definitively.

CHAPTER 5 ARTICLE 1: DISTRACTIONS OR LONG WAITS? IMPACTS ON RISKY CROSSING BEHAVIOR

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Abstract

Pedestrian-vehicle conflicts at intersections are considered as a major source of injuries and fatalities. Intersections are a critical part of roadway network since pedestrians are exposed to different and potentially dangerous situation such as crossing with vehicles turning left. The risk relates to how an intersection is designed, but also what the pedestrian is doing and where in the city they are. In this study we examine various influences on risky crossing behavior. At the individual level, we examine the influence of distractions and where people are looking before crossing. We also consider various intersection characteristics including wait time, intersection size and speed limits and contextual variables such as the built environment nearby and traffic flow. The data was gathered by observing pedestrians at 24 intersections in Montreal and Quebec City (12 each). Logistic regression models were estimated to determine the influencing variables on four dangerous behaviors: a) start on red, b) finish on red, c) finish on red having started on green, and d) cross completely on red. Results demonstrate the importance of wait time on risky crossing behavior with short wait times (< 30s) decreasing the likelihood of such activities by a factor of 7.7. The findings show that pedestrians at medium and small intersections are less likely to cross illegally than at large intersections. For individual behavior, having a cellphone in one's hand reduces the likelihood of starting to cross on red while looking at traffic was over four times more associated to crossing illegally.

Keyword: Distraction, head movement, waiting time, cellphone, illegal crossing, intersection

5.1 Introduction

Crash data reveal that numerous dangerous situations exist for pedestrians as vulnerable road users, owing to the fact that cities were (and still are) primarily designed for vehicles for nearly a century [66-68]. In 2013, pedestrians represented 14% of road crash fatalities reported in the US [2], and 17.3% of road crash fatalities (332 people) in 2018 in Canada [3]. In Montreal, Canada, the majority (approximately 60%) of vehicle–pedestrian collisions occur at intersections [4]. As such, intersections continue to be an important consideration for pedestrian’s road safety.

Pedestrians are often insufficiently protected at intersections with preference typically given to vehicle movement in designing intersections and traffic signals programming. Various design variables are known to influence the likelihood of collisions such as: the absence of a safety island, the intersection size, and the number of lanes [69, 70]. As well, the length of time pedestrians must wait has an impact on whether they risk crossing on red [8, 27, 71].

At intersections, distractions when crossing may influence risky crossing behavior. A variety of distractions can be observed at intersections including talking to friends, use of headphones or cellphone. In contrast, head movement may indicate what individuals are paying attention to, such as looking at traffic, the ground, or traffic signal. However, how these behaviors relate to risky crossing behaviors and to safety is not well known.

To gain new understanding about variables influencing crossing behavior, this study used observational data from twelve intersections in each of Montreal and Quebec City, Canada.

5.2 Background

Studies have shown that various factors influence crossing behavior. These factors include individual characteristics, intersection characteristics, traffic volume, socio-demographic characteristics and other road user behaviors. In this study, a focus is given to crossing on red as a risky behavior.

In terms of individual characteristics, some research has revealed that men are more likely than women to commit violations and cross on red [23-26]. For age, young pedestrians (aged 18-30) were found to commit more violations of traffic rules than other age groups, whereas senior pedestrians were shown to be less prone to engage in unsafe behavior [27]. An additional human factor could relate to waiting tolerance. Pedestrians who committed a violation had lower waiting time thresholds, according to Wang, et al. [28].

Intersection characteristics affect pedestrian violations such as crossing on red. The presence [6, 72] and the design of the pedestrian signal itself has been shown to influence behavior, with one study suggesting that a countdown display can minimize violations in specific situations [43]. One study has demonstrated that waiting times at intersections influenced pedestrian decisions. For example, pedestrians were more likely to cross on red at intersections with long waiting times [42]. Road design can reduce risky pedestrian behaviors. Some examples include raised medians or pedestrian refuge islands [5]. Studies show that the length of crossing can influence risky behavior: longer crossings were found to contribute to fewer violations [6, 7], which may be related to the risk of being exposed to danger for longer. As well, the distance pedestrians must cross has a substantial effect on pedestrian speed, according to Iryo-Asano, et al. [8]. They found that longer crossings resulted in pedestrians walking faster.

The context of the crossing can influence behavior. The environment at intersections along with traffic conditions have a direct impact on pedestrian behavior [73, 74]. Kooij et al. [74] suggested three influences on a pedestrian's choice to cross a road or pause before crossing: the presence of oncoming cars, the pedestrian's awareness of them, and the spatial layout of the surrounding environment. Furthermore, Ukkusuri et al. [33] discovered that areas with a larger proportion of industrial, commercial, and open land-use categories had a higher risk of crashes, whereas the ones with a considerably larger residential land-use fraction had a lower risk of collisions. The human context of the intersection can also influence behavior. For example, a larger group of people waiting to cross an intersection may be less likely to do a risky behavior like crossing on red [24, 75].

Distractions such as using headphones or a cellphone could influence behavior. Basch, et al. [76] found that using headphones was the most common distraction for pedestrians in New York. Such behaviors could lower a person's capacity to hear or be aware of their surrounds and avoid vehicles that are causing danger (e.g., rushing a red light, conducting a turn without properly looking for pedestrians). However, this could also be applied to people who are hard of hearing, such as older people, and the assumption of good hearing in design could create dangerous conditions. Hatfield and Murphy [18] found that females who were talking on a cellphone crossed slower, which is not a violation but could increase danger by exposing them for longer periods of time. As well, they were less likely to look at traffic before crossing which could be risky if a driver is wanting to cross the same space at the same time (legally or illegally). However, people may also adjust their risky behavior when conducting such activities that are considered distractions as they may be aware that their capacity to watch for dangerous vehicle behavior is reduced. Further, if a system is to accommodate people with different abilities, and not only those with all their faculties (e.g., a system should not be built that would exclude people with hearing or visual impairments), then “distractions” that limit their mobility (e.g., slowing them down) should never be a legitimate reason for suffering a collision with a motorized vehicle.

Risky behavior could also be linked to head movement. One could argue that not looking at traffic is risky because the individual would be less aware of risks posed by vehicles. On the other hand, an individual checking traffic may be observing general traffic conditions, but they may also be looking for an opportunity to cross outside of the green traffic signal. Hashimoto, et al. [73] assumed that pedestrians' intentions and actions vary in response to changing traffic conditions, such as facing turning automobiles. Another example would be an individual looking at the ground (and not at the traffic), who may be doing so because they are not confident of their footing and fear falling [77].

Another element that might influence dangerous behavior is traffic volume. Normally pedestrians do not tend to cross on red on streets with higher traffic volumes because of the danger imposed. Duduta, et al. [42] found that traffic volume was negatively associated with people crossing illegally. This means that higher traffic decreases the probability of crossing on red, again likely related to the situation being too dangerous. In addition, they found that gaps which provide a few seconds break in traffic could be a key predictor of the likelihood to cross on red. Essentially, people do not like to wait, and they search for opportunities, such as a gap between vehicles, to cross the road.

Thus, many individual and environmental characteristics can influence risky behavior such as crossing on red. The purpose of this study is to explore the role of several variables such as age, gender, distractions, and head movement as well as intersection characteristics and traffic levels on risky crossing behavior. This study adds empirical evidence related to risky behavior at intersections.

5.3 Methodology

5.3.1 Observation location

Our data was obtained from Montreal and Quebec City. In 2016, the city of Montreal covered an area of 366 km^2 and had a population of 1.7 million, which represented 40% of the population of the census metropolitan area. Quebec City covered an area of 428 km^2 and had a population of 532,000 (Statistics Canada. 2016). Twelve intersections were selected in each city (Figure 5.1) based on their geometric characteristics and the surrounding built environment (see Table 5.1).

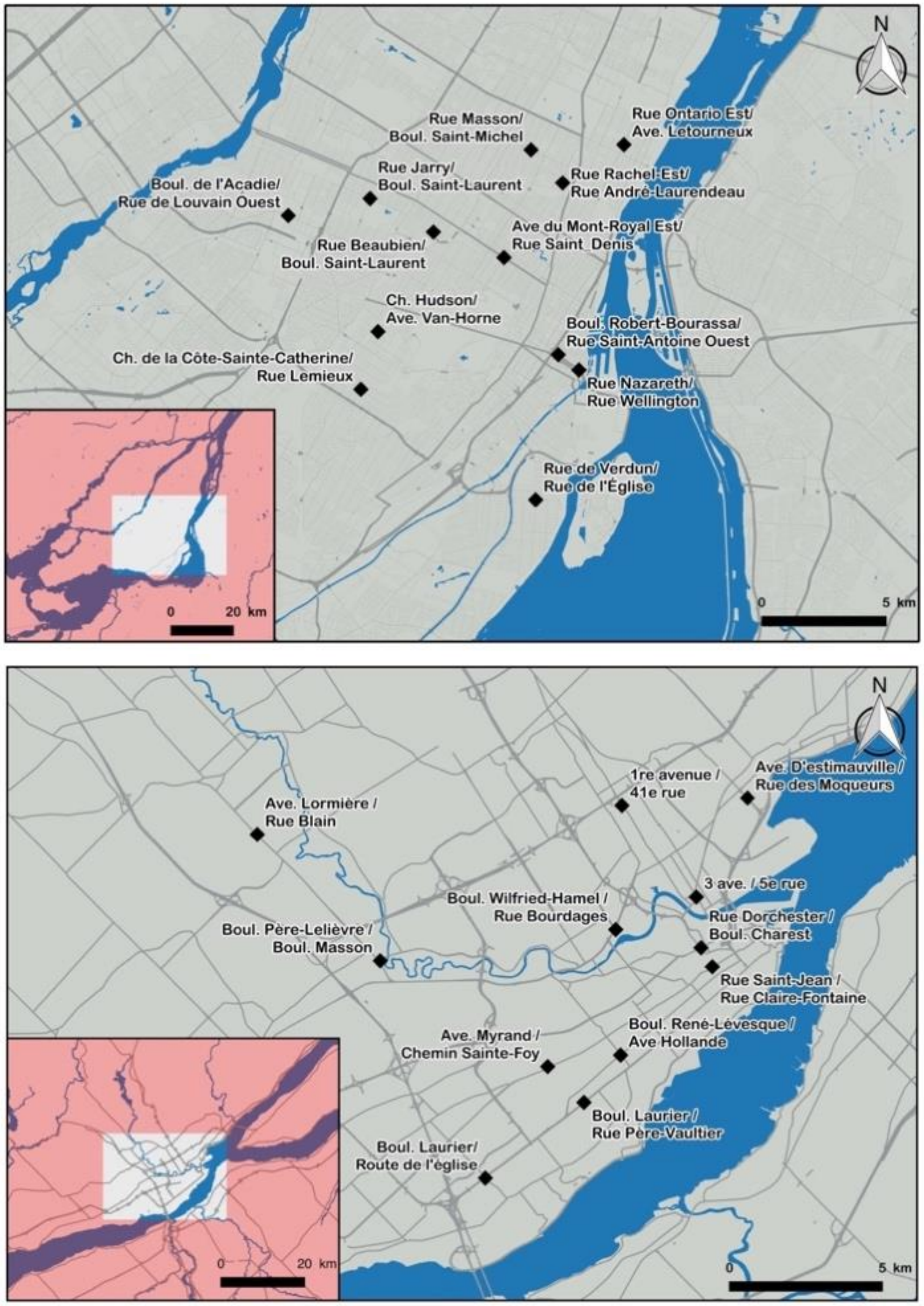

Figure 5.1 The intersections location in Montreal (top) and Quebec City (bottom) (Rue = street; Boul. = boulevard). Image credit: Simon Turcotte

Table 5.1 Intersection characteristics observed in Montreal

Intersection name	NUMBER OF LANES	WIDTH OF STREET	REFUGE ISLAND SIZE	INTERSECTION TYPE	STREET PARKING	BUS STOP (#)	BIKE LANE (YES, NO)	BUILT ENVIRONMENT TYPE
MONTREAL								
Beaubien & Saint Laurent	3 and 4	10 & 14 m	0	T type (three ways)	yes	2	no	Most urban
Jarry & Saint Laurent	5 and 7	17 & 23 m	1.5 m	four ways	yes	4	no	Middle density urban
Acadie & Louvain	4 and 7	14 & 26 m	1.5 m	four ways	no	2	no	Most residential
Rachel & Laurendeau	3 and 5	19 & 17 m	0	four ways	yes	3	yes	Middle density urban
Cote Saint Catherin & /Lemieux	6 and 6	16 & 13 m	0	T type (three ways)	yes	2	no	Most urban
Hudson & Van_Horne	4 and 3	16 & 11 m	0	four ways	yes	2	no	Most urban
Verdun & De L'eglise	3 and 3	12 & 10 m	0	four ways	yes	3	no	Most urban
Nazareth & Wellington	2 and 5	17 & 18 m	0	four ways	no	1	no	Middle density urban
Robert Bourassa & Saint Antoine	8 and 6	31 & 22 m	3 m	four ways	no	1	no	Most urban
Mont Royal & Saint Denis	3 and 6	11 & 18 m	0	four ways	yes	4	no	Most urban
Ontario & Letourneux	4 and 4	12 & 12 m	0	four ways	yes	2	no	Most urban
Masson & Saint Michel	4 and 6	11 & 18 m	0	four ways	yes	4	no	Most urban
QUEBEC CITY								
3 me Avenue & 5 me Rrue	2 and 4	7 & 10 m	0	four ways	yes	2	yes	Middle density urban
Dorchester & Charest	6 and 4	20 & 12 m	0	four ways	no	3	no	Most urban
L'ormiere & Blain	4 and 4	15 &15 m	0	four ways	no	2	yes	Middle density urban
Pére Leliévre & Masson	4 and 4	12 & 12 m	0	four ways	no	0	yes	Most residential
René Lévesque & Hollande	4 and 4	14 & 12 m	0	four ways	yes	2	no	Most residential
Saint Jean & Claire Fontaine	2 and 3	6 & 9 m	0	T type (three ways)	no	1	no	Middle density urban
Wilfried Hamel & Bourdages	8 and 4	33 & 15 m	3.5 m	four ways	no	2	no	Most urban
Laurier & De L'Église	8 and 4	28 & 14 m	2 m	four ways	no	3	no	Most residential
Myrand &Chemin Sainte Foy	4 and 4	12 & 15 m	0	four ways	no	2	no	Most residential
1re Avenue & 41me Rue	4 and 5	14 & 19 m	0	four ways	no	4	no	Middle density urban
D'estimauville & Des Moqueurs	2 and 4	8 & 18 m	0	four ways	no	1	no	Middle density urban
Cartier & Grande Allée*	2 and 4	8 &13 m	0	four ways	no	2	no	Middle density urban
Laurier & Du Père Vaultier	4 and 2	24 & 9 m	0	T type (three ways)	no	2	0	Most residential

* This intersection was observed only in the Fall of 2019 and Spring of 2020 as it replaced another intersection where insufficient number of pedestrians were observed in the Summer of 2019.

With respect to pedestrian phases at traffic-light-controlled intersections, Montreal and Quebec City have different management systems. While the Ministry of Transportation of Quebec issues universal rules across the province of Quebec for pedestrian lights (white silhouette, flashing hand, etc.), municipalities are responsible for how these systems are integrated with automobile traffic. Quebec City uses a "protected mode" also known as "exclusive phasing" or "all-red phase” [78]. However, it is not a true protected phase as the City allows vehicles to turn right on red at most intersections (all of the Quebec City intersections in the dataset). As well, nearly all pedestrian phases are requested at the end of the traffic cycle by call buttons. This means, an individual has to push a button to request the pedestrian phase that follows after all phases for vehicle movement have completed. Finally, although it is an all-red system for vehicles, it is illegal for pedestrians to cross diagonally (though in practice many do). In Montreal, some intersections give pedestrians a few seconds to begin crossing before permitting vehicle movements, called the lead-pedestrian interval (LPI) [79]. Right turns on red are forbidden on the Island of Montreal and most pedestrian phases occur automatically. One final difference between the cities is the assumption of pedestrian speed. Montreal uses 1.1 m/s and in certain cases reduce it to 1.0 m/s or 0.9 near schools, retirement homes, medical clinics, or hospitals. In Montreal, as the pedestrians cross concurrently with the traffic, they have more than the minimum time necessary to cross in many cases. Quebec City broadly uses 1.2 m/s and, as it is a pedestrian-only phase, the given number of seconds is based on the minimum time needed to cross at this speed, excluding the time necessary to cross diagonally. In certain cases, the timing may be extended due to complaints from citizens. Finally, both cities have upgraded most of their pedestrian traffic signals to use pedestrian count-downs which have been shown to improve safety behavior [43].

5.3.2 Data collection: observation protocol and variables

At these 24 intersections, data was collected by randomly observing pedestrians as they crossed towards the observers. The observation periods, lasting 3 hours each time, were conducted at different periods throughout the year. During the Summer of 2019, each intersection was visited three times (morning, noon, evening) for a total of 9 hours of observations and accounted for more than half of the total observations made during the project. In the Fall of 2019 and Spring of 2020 (each representing about 1/4 of the observations), observations were made at the end of the afternoon, from 3 p.m. to 6 p.m. as this is the period of the day when most collisions occur [2, 80]. Although planned, no observations were made in the Winter of 2020 due to the Covid-19 pandemic lockdown measures in Quebec.

Observations of pedestrian behaviors were done using a previously validated method [77, 81], which divides their crossing into four “zones”, each of them refers to a specific moment in space and time and to specific variables to observe. The fours zones are:

- Zone 1: approaching the crossing,
- Zone 2: at the beginning of the crossing (as soon as one foot is placed in the street),
- Zone 3: at mid-crossing, and
- Zone 4: at the end of the crossing (when the last foot is out of the street).

All measures used in this study were observed in Zone 1 and the pedestrian light when the pedestrian started crossing (zone 2) and when he reached the other side (Zone 4). Please refer to [77, 81] for further details. Waiting time was observed using another protocol by randomly choosing a pedestrian and recording the time spent waiting within the intersection (at 1 or 2 corners depending on their crossings). Pedestrian characteristics and behaviors were recorded by a team of students (4; 2 in each city) without interviewing the pedestrians, so some errors in terms of gender or age group may have occurred.

5.3.3 Other data: intersection characteristics, built environment and traffic

Along with the intersection characteristics shown in Table 5.1, contextual information on the built environment and traffic were obtained from various sources including both city officials. Selected built environment characteristics are shown in Table 5.3. Finally, the most recent available counts of vehicles and pedestrian volume at the same time of day as the observations were obtained from the open access dataset for Montreal [63] and directly from the transport engineering department for Quebec City.

5.3.4 Data preparation: intersection characteristics and context

Prior to the analysis, intersections were categorized into three clusters using Non-hierarchical (K-means cluster analysis) (Table 5.2): large, medium, and small. These clusters were created based on street crossing distance, number of lanes, presence of bus stop, and small refuge islands (Table 5.1). Additional variables (car parking in street, bike lane, and intersection type) were initially included in the clustering, but they were not kept since they did not contribute to distinguishing unique groups.

Table 5.2 Intersection categories

Intersection categories	*Number of intersections (mean)*	*Number of lanes (mean)*	*Width of street (mean)*	*Number of bus stops (mean)*	*Presence of central island (mean)*
Large intersections	6	7.3	27.5 m	2.3	1
Medium intersections	9	5.2	18 m	2.7	0.1
Small intersections	10	3.8	12.6 m	1.8	0

The built environment was also categorized into three groups using Non-hierarchical (K-means cluster analysis) based on the presence of variables in a 500-meters buffer zone around intersections: population density, material and social deprivation index [64], proportion of the buffer being a) residential and commercial, b) industrial and institutional land use [65] (see Table 5.3). The material deprivation index "involves deprivation of the goods and conveniences that are part of modern life, such as adequate housing, possession of a car, access to high speed internet, or a neighbourhood with recreational areas" while the social deprivation index "is characterized by individuals living alone, being a lone parent and being separated, divorced or widowed" [64].

Table 5.3 Built environment categories and their characteristics

	Most urban Mean (Std. Dev.)	***Middle density urban Mean (Std. Dev.)***	***Most residential Mean (Std. Dev.)***
Population density	20,490 (2,680)	11,742 (813)	6680 (1177)
Material deprivation index	-0.02 (0.03)	-0.04 (0.03)	0.00 (0.03)
Social deprivation index	0.05 (0.01)	0.04 (0.01)	0.02 (-0.02)
% Residential and commercial land use in buffer zone	35% (0.11)	32% (0.08)	38% (0.06)
% Industrial and institutional land use in buffer zone*	7% (0.03)	7% (0.07)	7% (0.03)

* This variable is not statistically different between the groups based on One-way ANOVA test (Bartlett's test).

5.3.5 Statistical analyses

Logistic regression models using STATA v. 13 were performed to examine the likelihood of four different dangerous crossing behaviors: 1) start crossing on red (or red hand), 2) finish on red (or red hand), 3) finish on red having started on green (or white silhouette), and 4) start and finish on red (or red hand). The dependent variables were analyzed using pedestrian characteristics, behavior (distractions and head movement), intersection characteristics, and context.

5.4 Results

5.4.1 Descriptive statistics

There were 4711 pedestrian observations in this dataset. The observations descriptive statistics obtained from Chi-squared test are shown in Table 5.4. Some differences can be observed between the two cities. First, the proportion of crossing violations are all much higher in Quebec City than in Montreal. Some differences in the observed pedestrians are of interest with more women and children seen in Montreal (as a share of total observations). No statistical differences in distractions were observed except for being with someone, which was higher in Quebec City. For head movements, the percentage of people looking at the traffic signal before crossing is greater in Montreal. In contrast, pedestrians in Quebec City tended to look at traffic and the ground more. Other head movements were not significantly different between the two cities.

Table 5.4 Descriptive statistics (n=4711 observations)

Variables	***Quebec***		***Montreal***
Observations	48% (2265)		52% (2446)
Female	50.3% (1140)	*	52.3% (1279)
Age groups			
Children (under 12)	0.4% (8)	*	2.4% (59)
Teenager and young adults (13-24)	24.6% (557).	*	21.8% (534)
Adults (25-64)	63% (1430)	*	64.5% (1578)
Seniors (65 +)	12% (270)		11.3% (276)
Distraction before crossing			
Using headphones	15%		17%
Being with someone	16%	*	14%
Cellphone in hand	12%		13%
Talking on a cellphone	2%		3%
Head movements before crossing			
Looking straight at traffic signal	57%	*	85%
Looking at traffic	47%	*	37%
Looking at the ground	18%		20%
Looking at other pedestrians	5%		6%
Looking at electronic device	3.50%		6%
Waiting time			
Average waiting time	30 s		30 s
Average waiting time, respect signals	45 s	*	28 s
Crossing violation			
Start on red	29%	*	8%
Finish on red	32%	*	12%
Start on green finish on red	1%		6%
Cross on red (start and finish on red)	26%	*	4%

* Statistical difference between cities at $p < 0.05$ based on Pearson chi-squared test.

The average wait time at intersections is approximately 30 seconds in both cities, but this includes people who cross illegally. The difference in average waiting time for those who respect the traffic signal is statistically significant. In Montreal pedestrians wait an average of 28 seconds while in Quebec City, this time goes up to around 45 seconds.

5.4.2 Dangerous crossing behaviors

The results of the logistic regression are summarized in Table 5.5.

Table 5.5 Binary logistic regression of dangerous crossing behavior

Variables	***Start on red***		***Finish on red***		***Finish on red, having started on green***		***Cross on red (start & finish on red)***	
	Odds ratio		Odds ratio		Odds ratio		Odds ratio	
Age								
Children (under 12)	NS		NS		NS		NS	
Teenager and young adults (13-24)	1.45	*	NS		0.25	***	NS	
Adults (25-64)	NS		NS		0.32	***	NS	
Seniors (65 +) (ref.)	1		1		1		1	
Sex								
Female (ref.)	1		1		1		1	
Male	1.29	*	1.22	*	NS		1.27	*
Head movement (before crossing; non-exclusive categories)								
Looking at traffic signal	0.41	***	0.52	***	NS		0.4	***
Looking at traffic	4.95	***	1.99	***	NS		4.8	***
Looking at the ground	0.45	***	0.53	***	NS		0.57	**
Looking at other pedestrians	0.48	*	0.44	***	NS		NS	
Looking at electronic device	NS		0.54	*	NS		NS	
Distractions (before crossing; non-exclusive categories)								
Using headphones	NS		NS		NS		NS	
Being with someone	NS		NS		NS		NS	
Cellphone in hand	0.63	*	NS		NS		NS	
Talking on phone	NS		NS		NS		NS	
Intersection categories								
Large intersections (ref.)	1		1		1		1	
Medium intersections	0.24	***	0.36	***	NS		0.12	***
Small intersections	0.27	***	0.31	***	0.21	**	0.16	***
Other intersection characteristics								
Short waiting time (< 30 s)	0.27	***	0.26	***	NS		0.13	***
Posted speed limit	NS		NS		NS		1.02	*
Vehicle traffic volume (1000s)	0.86	***	0.9	***	NS		0.13	***
Pedestrian traffic volume (1000s)	NS		NS		NS		NS	

Table 5.6 Binary logistic regression of dangerous crossing behavior (continue)

Built environment categories								
Most urban (ref.)	1		1		1		1	
Middle density urban	0.32	***	0.4	***	NS		0.3	***
Most residential	0.18	***	0.22	***	NS		0.15	***
City								
Montreal (ref.)	1		1		1		1	
Quebec	3.54	***	1.97	***	8.5	***	3.5	*
Season								
Summer (ref.)	1		1		1		1	
Fall	NS		0.72	**	NS		NS	
Spring	2.1	***	1.36	**	NS		2.3	*
N	4377		4375		2562		4377	
Pseudo-R2	0.31		0.18		0.13		0.39	

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
NS: not significant

Individual characteristics had some effects, but not on all dependent variables. Results show that males are more likely to start, finish and cross on red than females. For starting on red, we see that the odds of doing so for teenagers and young people was higher (OR 1.45) than older people. Children under 12, were not statistically different in any of the behaviors from older people. The odds of older pedestrians to end on red having started on green was much larger than most others (OR 3.1 compared to adults, and OR 4.0 compared to teenagers/young adults), according to the results.

Various head movement measures were significant for three of the four outcomes. Looking at the traffic signal before crossing is statistically associated with being less likely to start, finish and cross on red. In contrast, looking at traffic before crossing was associated with being more likely to start, finish and cross on red. Results show that pedestrians who look at the ground or at other pedestrians are less likely to start and finish on red. Also, pedestrians who look at electronic devices were less likely to finish on red, which might suggest that they walk faster than the average.

The results of all types of distraction illustrate that they were not statistically associated to risky behavior with one exception: pedestrians who have a cellphone in hand are less likely to start on red.

For intersection characteristics, large intersections were more associated with risky behavior. Large intersections were typically broader, having more lanes, had quicker and more traffic, which likely makes crossing riskier for pedestrians. However, they were also more likely to have a pedestrian island, which might allow people to cross in stages. In comparison to large intersections, the odds of pedestrians at medium intersections was lower to start on red (OR 0.24), lower to finish on red (OR 0.36), and was much lower to cross completely on red (OR 0.12). Furthermore, the odds of pedestrians at small intersections was lower to start on red (OR 0.27), was lower to finish on red (OR 0.31), was lower to finish on red when starting on green (OR 0.21) and was much lower to cross on red (OR 0.16) than pedestrians at large intersections.

When the waiting time was short (less than 30 seconds), the odds of pedestrians was lower to start on red (OR 0.27), was lower to finish on red (OR 0.26) and was much lower to cross on red (OR 0.13).

Higher speed limits were associated with more (though only 2 % more) instances of crossing completely on red.

The odds ratio for vehicle traffic volume shows that with increasing traffic, pedestrians were less likely to start, finish, and cross on red at intersections.

The odds of pedestrians in the *middle density urban* category was lower to start on red (OR 0.32), was lower to finish on red (OR 0.4), and was lower to cross on red (OR 0.3) than the *most urban* intersections. Furthermore, the odds of pedestrians in the *most residential* areas was lower to start on red (OR 0.18), was lower to finish on red (OR 0.22), and was much lower to cross on red (OR 0.15) red than pedestrians in the *most urban* category.

The odds of risky behavior in Quebec City to finish on red was higher (OR 2), was higher to start and cross on red (OR 3.5) (start and finish) and was much higher to finish on red having started on green (OR 8.5) than Montreal.

Seasonal differences were observed, though some caution must be taken for the Spring results as this was when the Covid-19 pandemic was significantly reducing traffic [82]. The odds of pedestrians finishing on red was lower in the Fall (OR 0.72) than they were in the Summer of 2019. There was no significant effect for the other measures when considering those two seasons only. For the Covid-19 Spring, pedestrians were more likely to start, finish and cross on red than the prior seasons, probably due to lower traffic.

CHAPTER 6 GENERAL DISCUSSION

This study examined individual, intersection, and contextual influences on four risky crossing behaviors by pedestrians, all related to traffic signal compliance. Five major points can be highlighted when comparing our results with existing research.

First, our results related to individual characteristics such as gender and age group are consistent with previous findings, which indicate that males cross on the "Don't walk" sign more frequently [26] and that seniors are more likely to finish on red [77], probably due to their slower walking speed. As for head movement, Aghabayk et al. [83] also found that looking at traffic relates to searching for a gap to cross, no matter the traffic signal. The same hypothesis stands in the present study.

Our somehow unanticipated result about cellphone distraction, where it was associated with a decrease in risky behavior might be explained in two ways: 1) individuals are aware that they are not fully paying attention, and so rely on the traffic signals more; 2) the cellphone makes waiting longer more bearable, thus not crossing despite longer waiting time. Although there are several studies that link pedestrian cellphone distraction with unsafe behaviors including crossing [18-20], almost none of them considered the crossing context when analyzing those behaviors. Our results put into perspective the “victim blaming” we see in road safety prevention on this specific topic [84, 85].

Our results for the large intersections are in contrast with Duduta et al.[42] which found that the length of crosswalks was negatively related to the likelihood of crossing on red. It is not clear from our study whether this would have been the case had the larger intersections not had central islands. However, similarities between our results and Duduta’s ones can be seen between the small and medium intersections (less likely to start or cross completely on red).

As for the waiting time, a direct consequence of traffic signal programming, our results reflect what is highlighted in the *Highway Capacity Manual* (HCM), namely that pedestrians are extremely likely to cross on red if there is a wait of more than 30 seconds [42, 86]. This threshold is a strong indicator of risky behavior in our dataset, a result consistent with Brosseau et al. and Van Houten et al.’s [27, 87] and Ren et al.’s [88] findings showing that shorter pedestrian wait times lead to better compliance. Moreover, the city where the average waiting time was significantly higher (Quebec: 45 seconds compared to 28 seconds in Montreal) is also the ones with higher odds of risky behaviors for all outcomes. This is not surprising since these two cities practice different approaches to how pedestrians are integrated into traffic phases. As a result, it seems that many pedestrians in Quebec City know that they will likely need to wait a long time and thus reduce this significant wait time by crossing on red, possibly after looking for gaps in traffic. Thus, although such pedestrian phases are preferred by the blind people [89], forcing pedestrians to wait a long time is making them pay for the danger that cars are creating, and is leading to behavior that endangers many of them.

Finally, previous research linking higher volumes of traffic to more pedestrian compliance at traffic signals [90-93] is in line with our results, except for the Spring observations where COVID-19 traffic disruption might have changed usual crossing patterns at the observed intersections. In fact, the significant relationship between this season and greater propensity to start, finish and crossing on red might be another demonstration of the influence of low traffic on risky behaviors.

This study examined pedestrian crossing behavior through direct observation at intersections in two Canadian cities. We examined the variables related to risky crossing behavior such as starting, ending, and completely crossing on red at intersections. The findings demonstrate the importance of geometric design and traffic signal programming, taking all age groups and gender into consideration.

This study had limitations related to gathering data through observations. For example, only an individual's head movement could be observed and not exactly where people were looking. Due to mask wearing during the pandemic (1 of the 3 data collection period), some distractions such as small Bluetooth ear buds may have been missed. Also, it is not possible to know the exact age of people, and some misclassification likely occurred. Not all pedestrians can be observed at the same time with this protocol, and how the random selection relates to all pedestrians is unknown. Finally, observations were limited to a 3-h daytime period and some groups of the population may not normally travel at those times even if we added more time period (morning, lunch, and evening time) during the first Summer of data collection.

On the other hand, the strength of this study lies in the large number of observed pedestrians in a variety of settings. Accordingly, all of our findings highlight the need to perform naturalistic observational studies in order to fully comprehend the role of individual and environmental variables on dangerous crossing behaviors. Our results suggest that intersection characteristics and traffic signal operation, especially waiting time, is more influential than distractions or other pedestrian's individual characteristics. The time given to cross also seems to be a problem as older pedestrians are much more likely to finish on red having started on green. In nearly all of the models, the characteristics of the intersections have larger influences than individual characteristics or distractions on the risky crossing behaviors observed here. As such our results support the new paradigm of Vision Zero which puts increased emphasis on the role of design in improving safety for all road users [2].

CHAPTER 7 CONCLUSION AND RECOMMENDATION

Many pedestrians are injured or killed each year on Quebec's roadways as a consequence of vehicle-pedestrian crashes. One consideration of such crashes is pedestrian behavior which is influenced by a variety of variables. In order to better explain pedestrian behavior, this project assessed various influencing factors on such behaviors. The outcomes of this study show the relevance of geometric design variables such as size (distance to cross) and traffic control, as well as individual characteristics such as age groups and gender. Furthermore, several built environment factors, such as population density, land use type, and number of bus stops, have a strong relationship with pedestrian behaviors.

The objective was to assess three key behaviors: distractions, head movement, and risky crossing behavior. To do this, an evaluation of distraction before crossing such as using headphones, having a companion, holding smartphone in hand, and talking on the phone was done. In addition, head movements such as looking at the traffic light, traffic, other pedestrians, and/or electronic devices before and during crossing were analyzed. In the final part, I looked at risky crossing behavior at intersections.

At 24 intersections in Montreal and Quebec City, data was collected by randomly observing pedestrians as they crossed. In order to assess distractions before crossing the first analysis tried to identify the various type of distraction at intersections. According to the results, among these distractions the most common distraction was the use of headphones (17 percent in Montreal and 15 in Quebec), after that, having a companion (11 percent in Montreal and 9 percent in Quebec). When approaching, a certain number of pedestrians were observed holding a smartphone in their hands (13 percent in Montreal and 12 percent in Quebec). Although some pedestrians were seen approaching with a smartphone in hand, only a few pedestrians were observed talking on their phones (3 percent in Montreal and 2 percent in Quebec). When it came to hazardous crossings (crossing on red), having a smartphone was statistically linked to *not* doing so.

In terms of head movement, in Montreal pedestrians looked at traffic lights more, while in Quebec City, they look more at traffic. These head movements reflect differences in pedestrian behavior in the two cities. In Montreal, around 85 percent of pedestrians looked at traffic lights, compared to 57 percent in Quebec. In Quebec, the percentage of pedestrians who looked at traffic was 48 percent, while in Montreal it was 37 percent. One possible explanation is that pedestrians in Quebec City look for a gap in traffic in order to cross quickly, which results in them crossing on red. Pedestrians generally conduct the same head movements during crossing as before. Here, looking at traffic lights might indicate that individuals are more concerned about the amount of time to cross than traffic movement. As such, it might suggest that pedestrians in Montreal were more worried about how much time was left, while people in Quebec City were more likely to look elsewhere, whether to watch for dangerous traffic or some other point. Looking at traffic light mostly happened at Montreal intersections in densely populated area (most urban area). And looking at traffic more common in Quebec City in Middle density area. Looking at the pedestrian light and the ground were statistically related with avoiding dangerous crossing behavior.

When it comes to dangerous crossing behaviour, such as starting, finishing, and crossing on red at intersection, there are several aspects to consider. Logistic regression models using STATA were performed to examine the likelihood to: 1) start crossing on red, 2) finish on red, 3) finish on red having started on green, and 4) start and finish on red. The findings highlight the relevance of geometric design elements such as size (width) and traffic control across all age groups and genders. According to the results the proportion of pedestrians who started, finished, or crossed on a red light is greater in Quebec City than in Montreal. Distractions before crossing, such as holding a cellphone, were not statistically linked to such behaviors. For head movements, looking at the pedestrian light and the ground were statistically associated with not doing the risky behavior. Looking at traffic was strongly linked to starting, finishing, and crossing red lights. The findings suggest that intersection characteristics, particularly waiting time, is more important to pedestrians than distractions, their age or gender. The length of time provided to cross appears to be a concern as well, as older and younger pedestrians are more likely to finish on red while starting on green. According to the results the phase time management and distance to cross should be the focus of attention in order to decrease pedestrian dangerous crossing behaviors.

Limitation

This study is not without limitations. One limitation was related to gathering data through observation. For example, the head movement and not the specific location of where people are looking could be detected. Some distractions, such as tiny Bluetooth ear buds, may have been ignored due to hair or people wearing masks during the pandemic. In addition, the study focused on certain geometrical characteristics of the intersections (size, type, waiting time, and presence of safety island) and certain characteristics of the built environment (socio demographic features), but there may be other features that are important such as the presence of public transport access points (bus stops, metro entrances, etc.). Furthermore, it was impossible to determine a person's actual age, thus some misclassification likely occurred. Finally, only observations throughout the day and on weekdays were conducted, so behavior in the evenings or weekends is unknown.

Perspective

The evaluation of pedestrian behaviors before and during crossing was made from a small sample of intersections 24 intersection in Montreal and Quebec City. For future studies, it would be interesting to have a larger sample of intersections. Particularly locations with a wide range of pedestrians (students, workers, and tourists) in order to better observe the behavior of pedestrians. Furthermore, the research was limited to three-hour sessions on weekdays. The day and time of collection may have a temporal influence on behavior. It would be interesting to continue the research in order to anticipate pedestrian behaviors on weekends and holidays at different times of the day. Also, future research might focus on testing the validity of these findings over a broader range of intersections and in additional places.

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APPENDIX A OBSERVATION GRID

Items to observe (and to record in Survey 123): pedestrian

Info automatically in the iPad (with Survey 123)
Date and Time
Weather (default value: *sunny*, change it if needed to *cloudy* or *rainy*)
Observer name

City, Intersection and Crossing site	(list)

Chosen pedestrian

Age group (as estimated by the observer)	Child (alone) up to 12 years old (elementary school) Teenager/young adult (12 to 25 years old) Adult (25 to 65) Senior (65+)
Sex	Male female
Distraction: check all that apply	Cell phone in hand/to their ear Talking phone Headphones on With friends Other
Walking aid (choose one)	None Cane, Walker or crutches Wheelchair (electric or not) other (specify)
Load: check all that apply	None Small load in hand (coffee, food) Child-related: Stroller/child in hand/arms Packages (grocery, suitcase or other) Other (specify)

Zone 1: Before crossing (approaching the curb/the crossing)

Waiting zone	Regular (on the sidewalk/in designated area) Non-regular (on the pavement or elsewhere) Did not wait Other (specify)
Number of pedestrians crossing at the same time (without knowing the chosen pedestrian)	Alone 2-4 pedestrians 5 +

Pedestrian speed/pace approaching the crossing	Normal pace/Regular speed Walk slowly Walk quickly or run
Head movement before crossing: check all that apply	Towards the ground Towards other pedestrians nearby Straight ahead or towards traffic light Towards traffic or cyclists Towards electronic device (in hand) Other

Zone 2: At the beginning of the crossing

False start (i.e. foot on the street and back)	Y/N
Diagonal crossing	Y/N
Pedestrian location at the beginning of the crossing	At the pedestrian crossing (+/- 1 metre) Outside of the pedestrian crossing
Traffic light at the beginning of the crossing	Candle (transit priority) light Straight green arrow Blinking green light Green light Amber light Red light
Bicycle light at the beginning of the crossing (if applicable)	Not applicable (default) Green bike Amber bike Red bike
Pedestrian light at the beginning of the crossing (if applicable)	Not applicable(default) White silhouette Blinking red hand Red hand

Zone 3: Mid-crossing

Head movement mid-crossing crossing: check all that apply	Towards the ground Towards other pedestrians nearby Straight ahead or towards traffic light Towards traffic or cyclists Towards electronic device (in hand) Other
Pedestrian speed/pace mid-crossing	Stop Slow down Accelerate Keep a regular pace

Zone 4: End of the crossing

Pedestrian location at the end of the crossing	At the pedestrian crossing (+/- 1 metre) Outside of the pedestrian crossing

Traffic light at the end of the crossing	Candle (transit priority) light Straight green arrow Blinking green light Green light Amber light Red light
Bicycle light at the end of the crossing (if applicable)	Not applicable (default) Green bike Amber bike Red bike
Pedestrian light at the end of the crossing (if applicable)	Not applicable (default) White silhouette Blinking red hand Red hand

Items to observe (and to record in Survey 123): INTERACTION

Was there any interaction with a vehicle? Y →open another sub-table No: end of the questionnaire

Vehicle information

Type	Vehicle Bike Motorcycle and 2 wheels Trucks Taxi Skate-roller-scooter Buss
Position of the vehicle in relation to the stop line	Is conform Passes the stop line N / A: no visible line

Driver behavior

Approach speed	Constant speed Accelerated Decelerates Waiting (if on red)
Movement of the driver after passing the pedestrian	Straight ahead left turn right turn

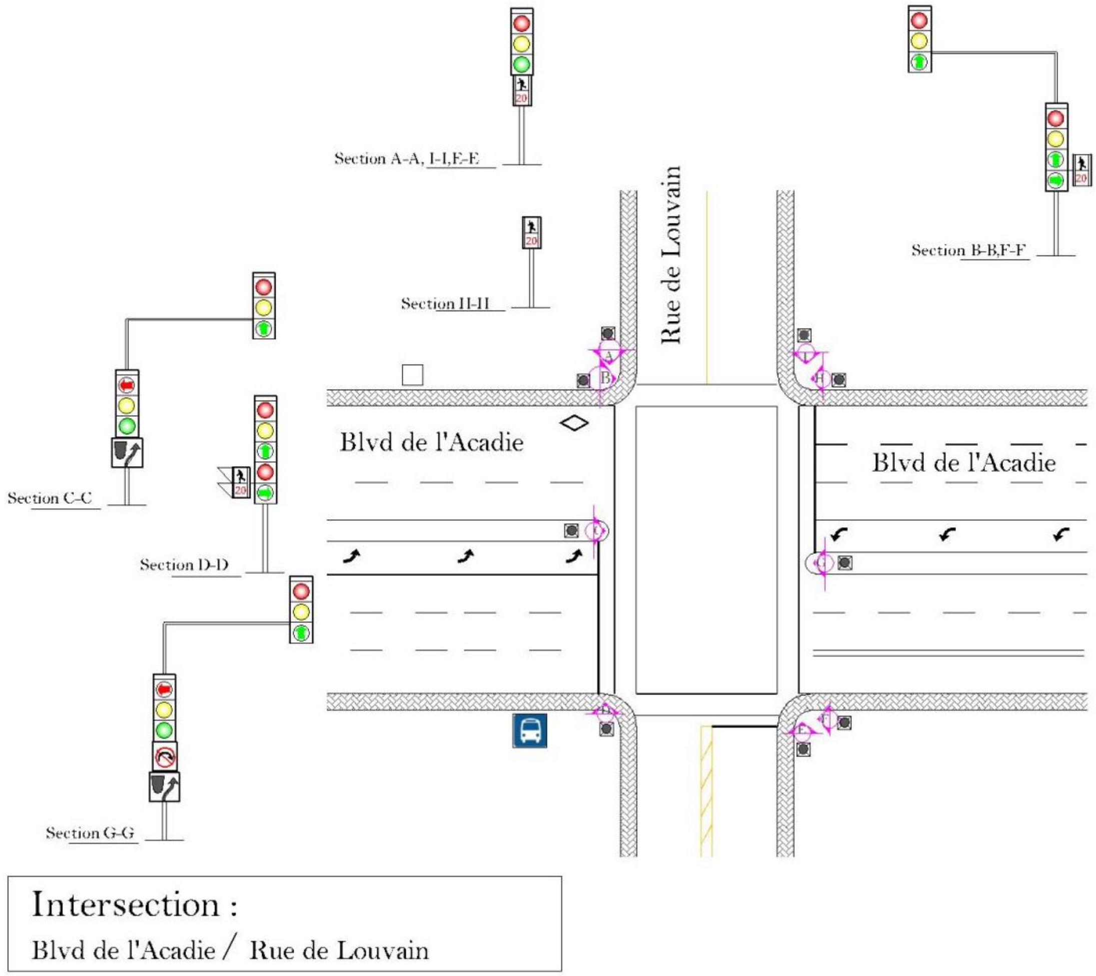
Interaction diagnosis

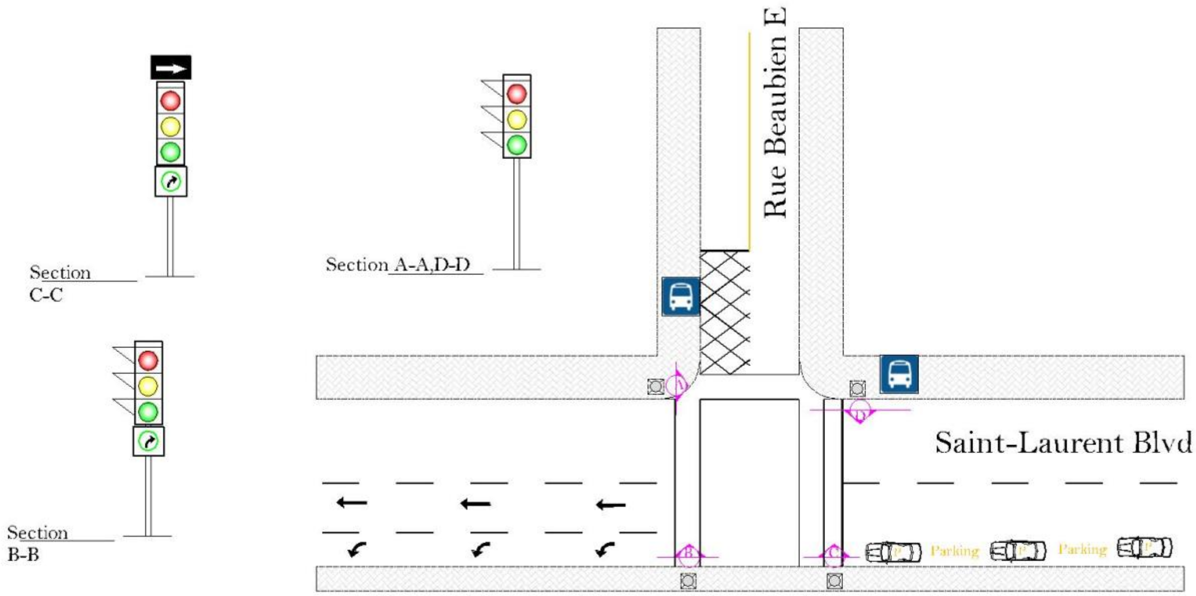
Vehicle-pedestrian distance during interaction	Less than a meter 1 to 2 meters More than 2 meters

Respect for priority	The vehicle has yielded the right of way to pedestrian The pedestrian has yielded the right of way to the vehicle N/A
More than one interaction for the pedestrian?	Yes No

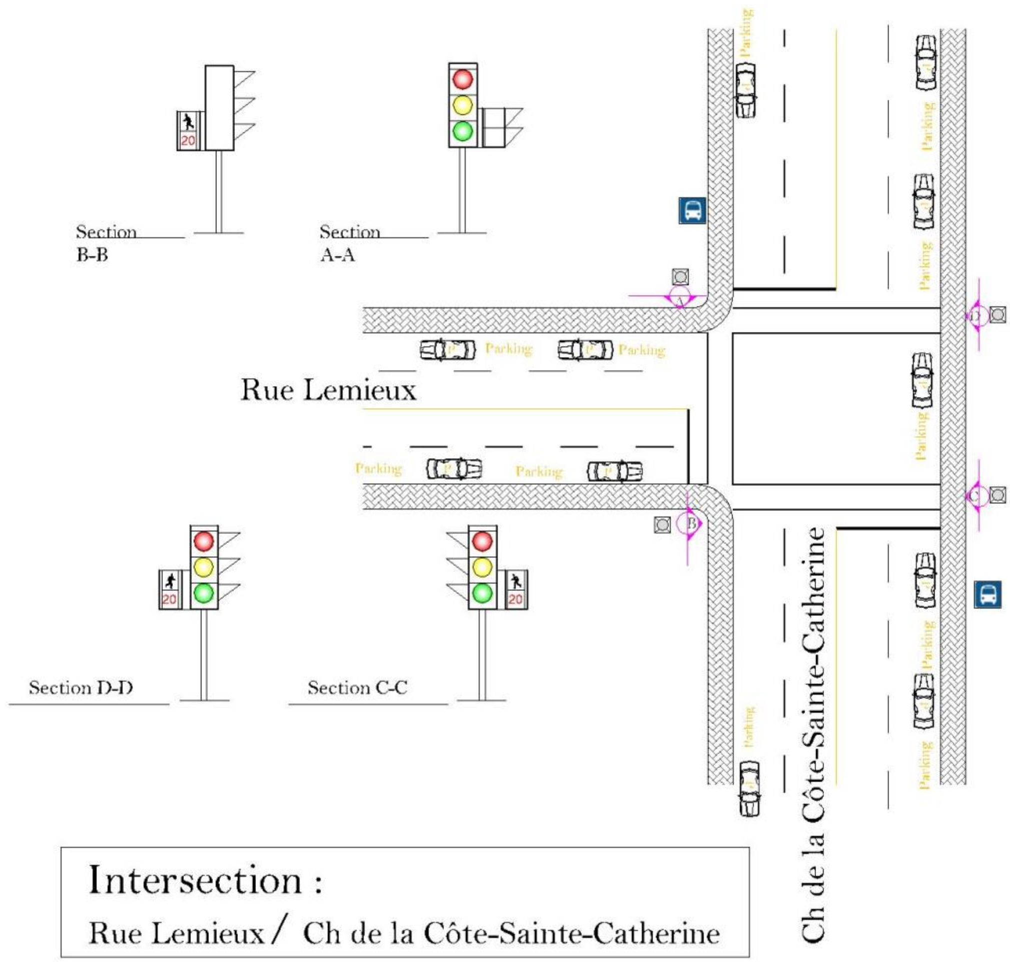
APPENDIX B INTERSECTION DIAGRAMS

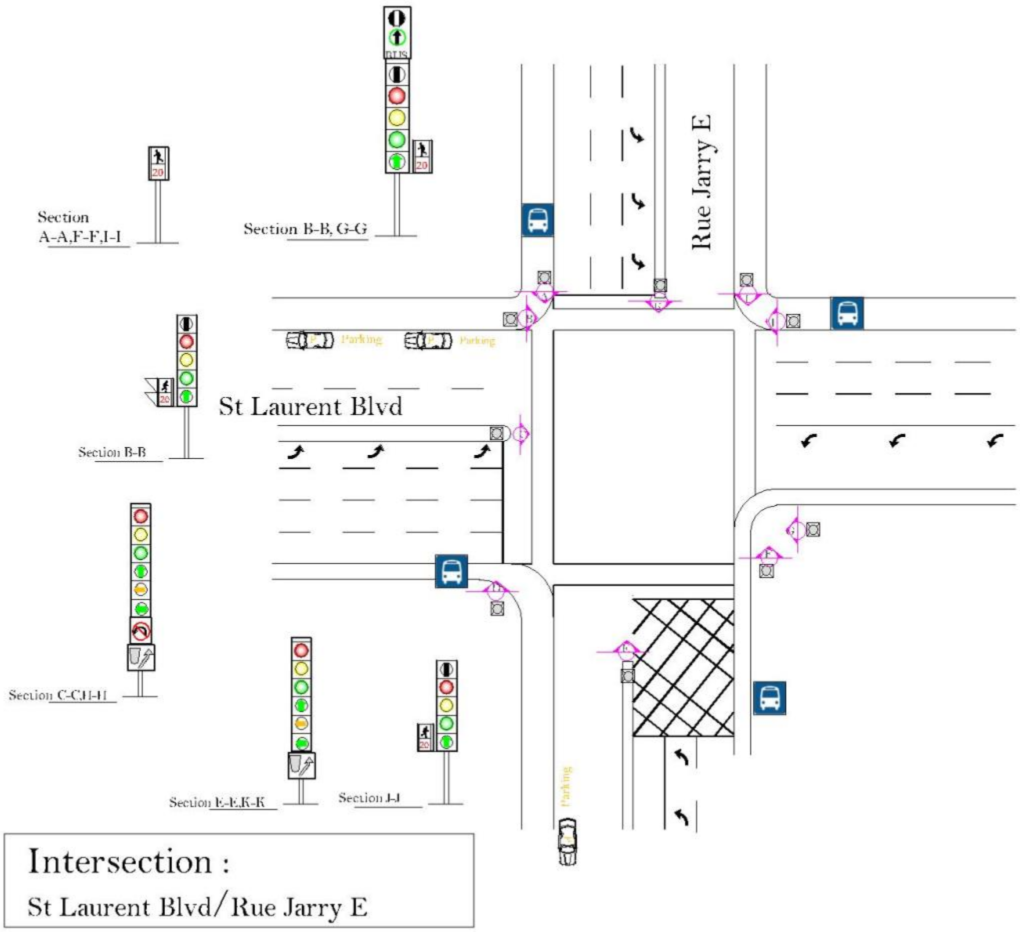
Montreal intersections



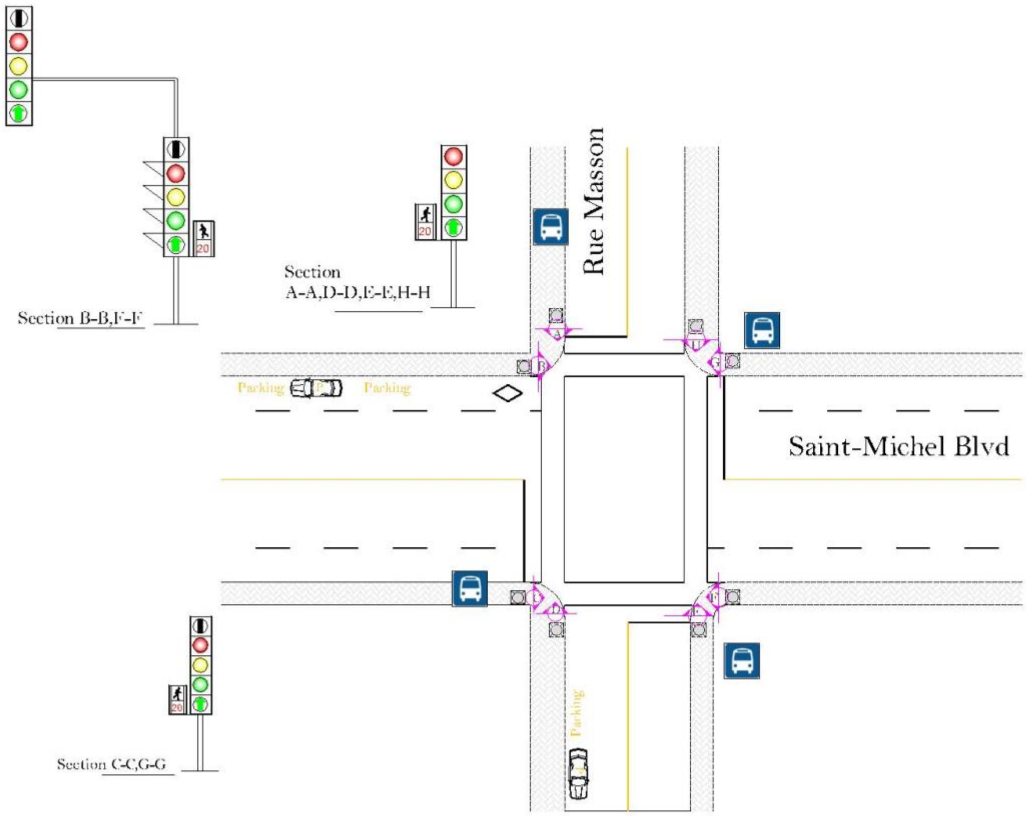


Intersection :
Rue Beaubien / Saint-Laurent Blvd

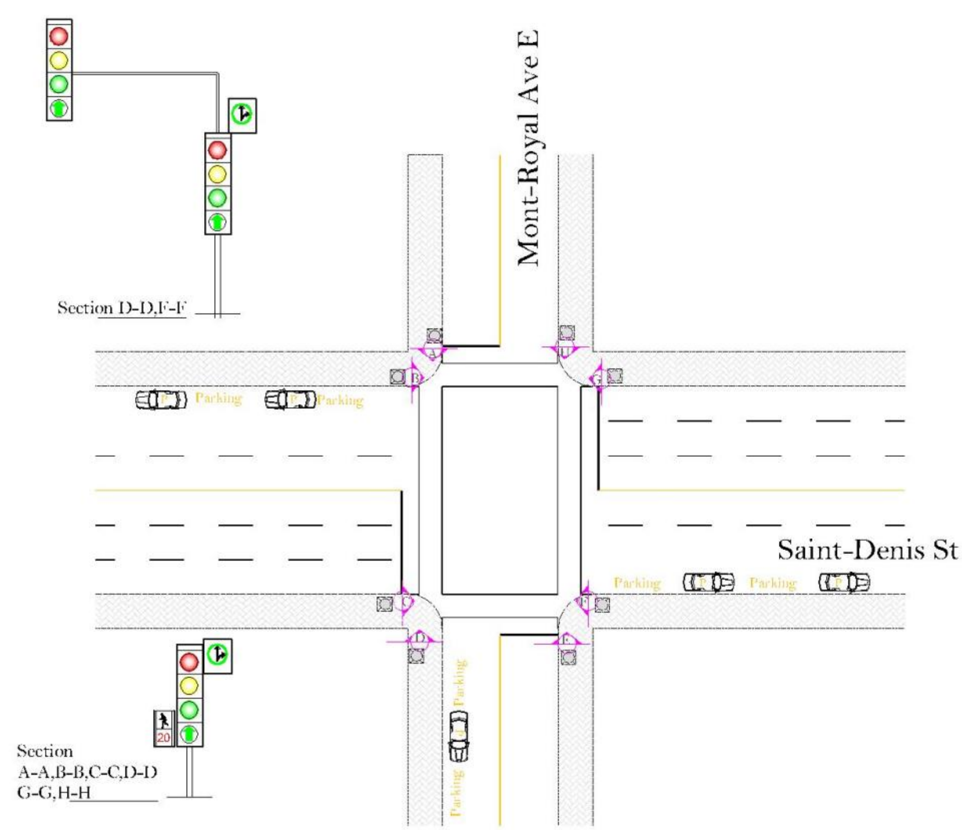

Section
B-B
Section
A-A
Section D-D
Section C-C
Rue Lemieux
Ch de la Côte-Sainte-Catherine
Parking
Intersection :
Rue Lemieux / Ch de la Côte-Sainte-Catherine



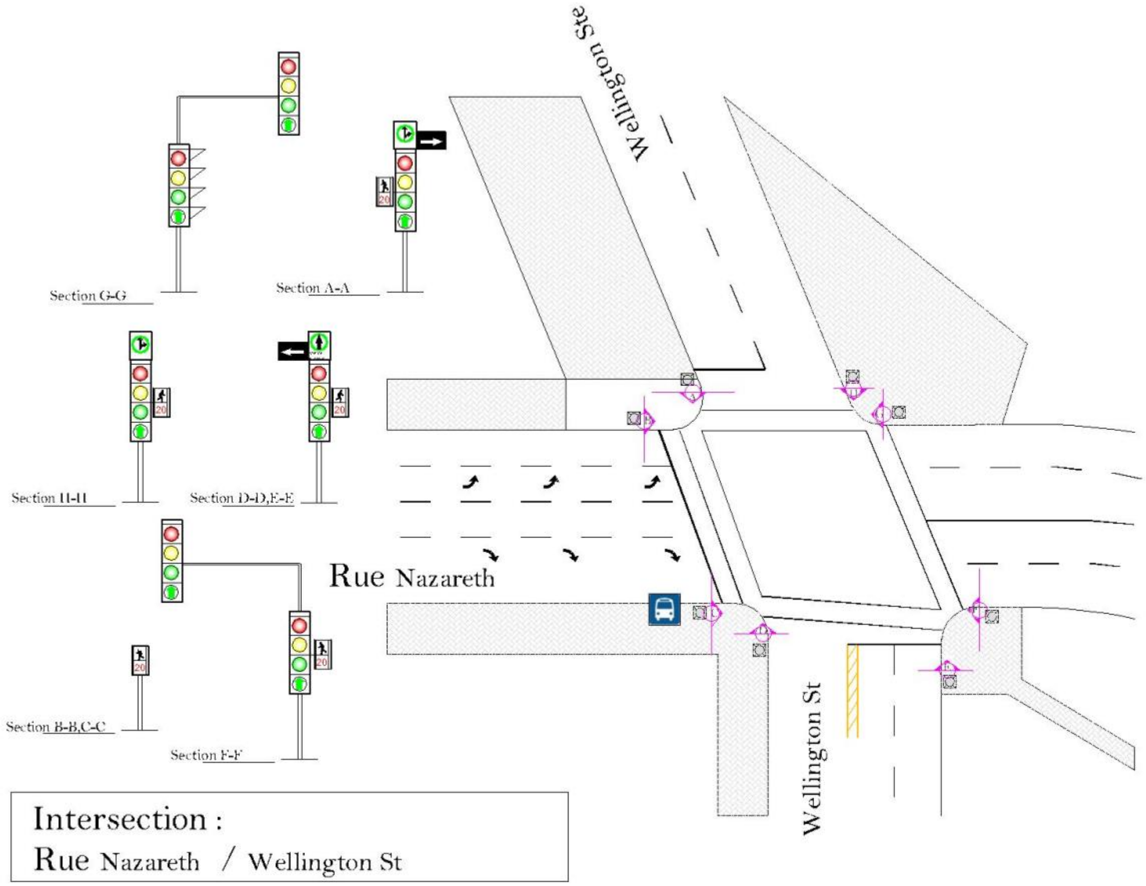
Rue Jarry E
St Laurent Blvd
Section A-A,F-F,I-I
Section B-B, G-G
Section B-B
Section C-C,H-H
Section E-E,K-K
Section J-J
Parking
Parking
Parking
Intersection :
St Laurent Blvd/Rue Jarry E

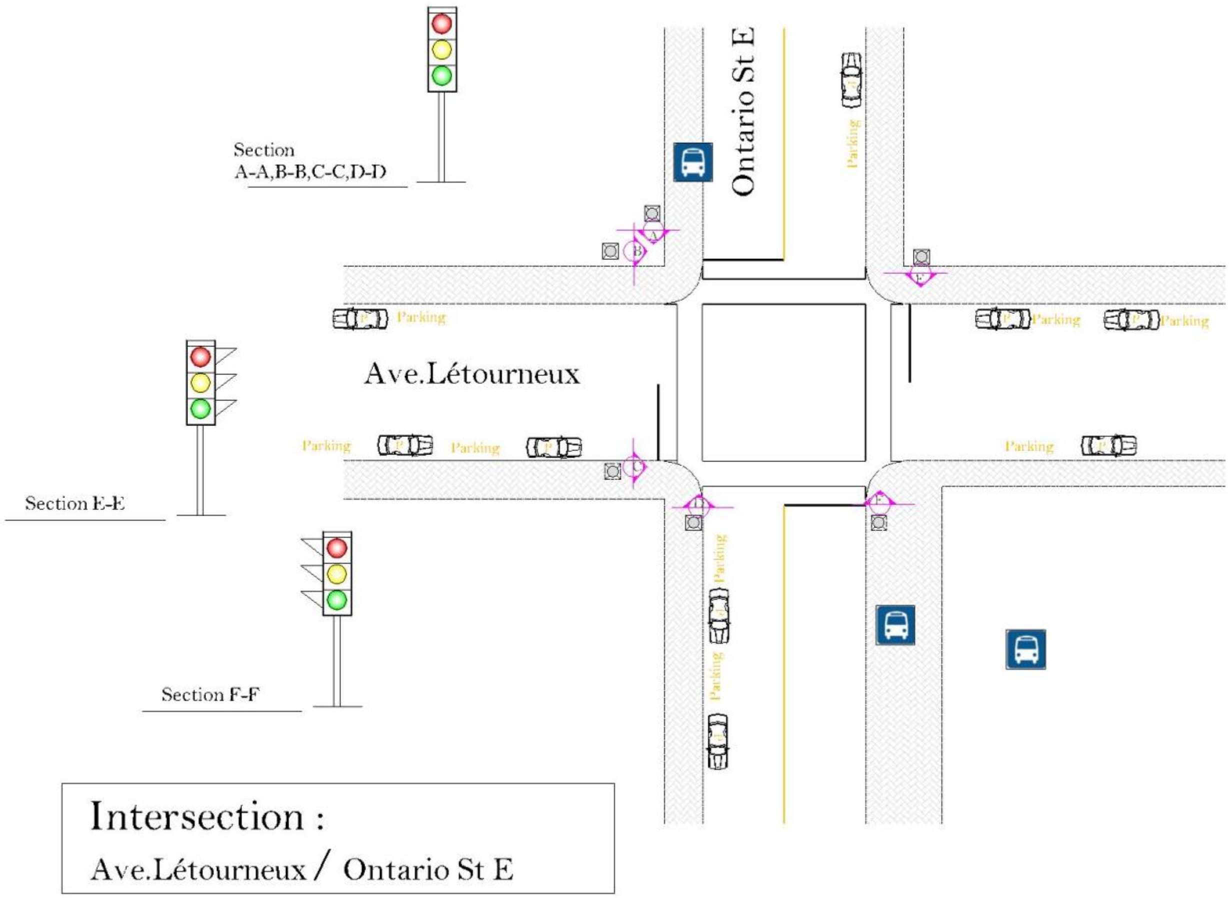


Intersection :
Rue Masson / Saint-Michel Blvd

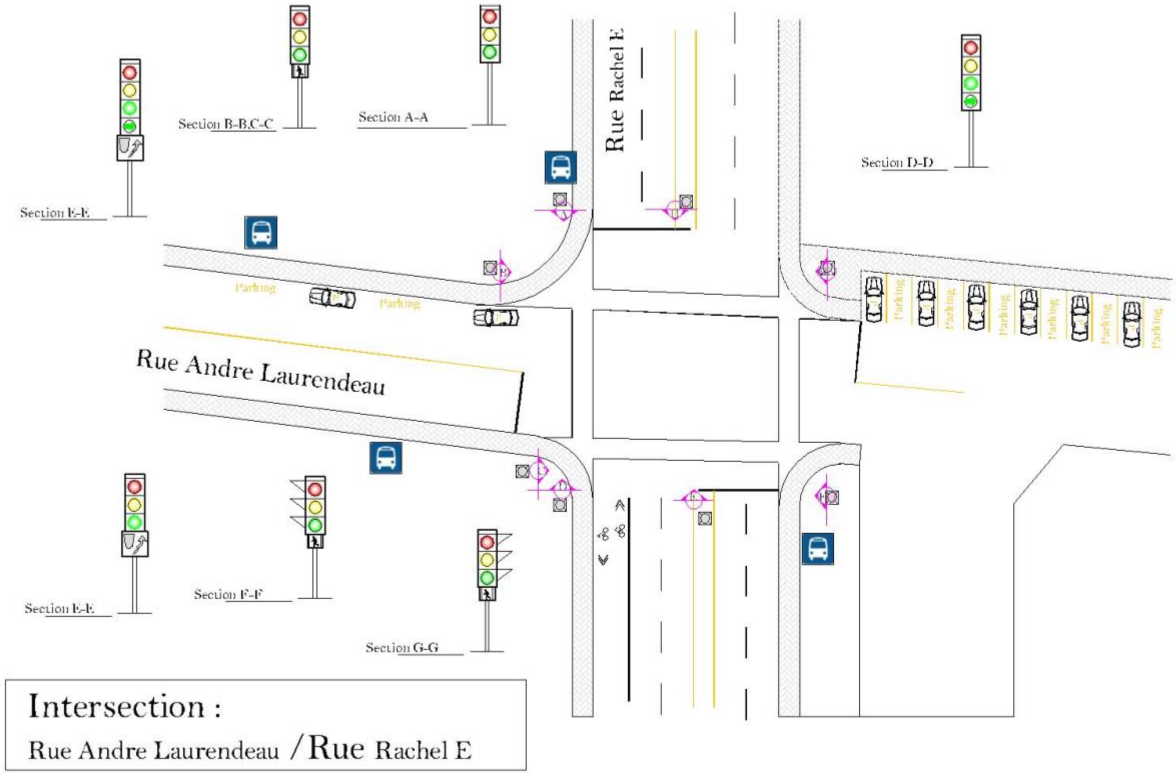


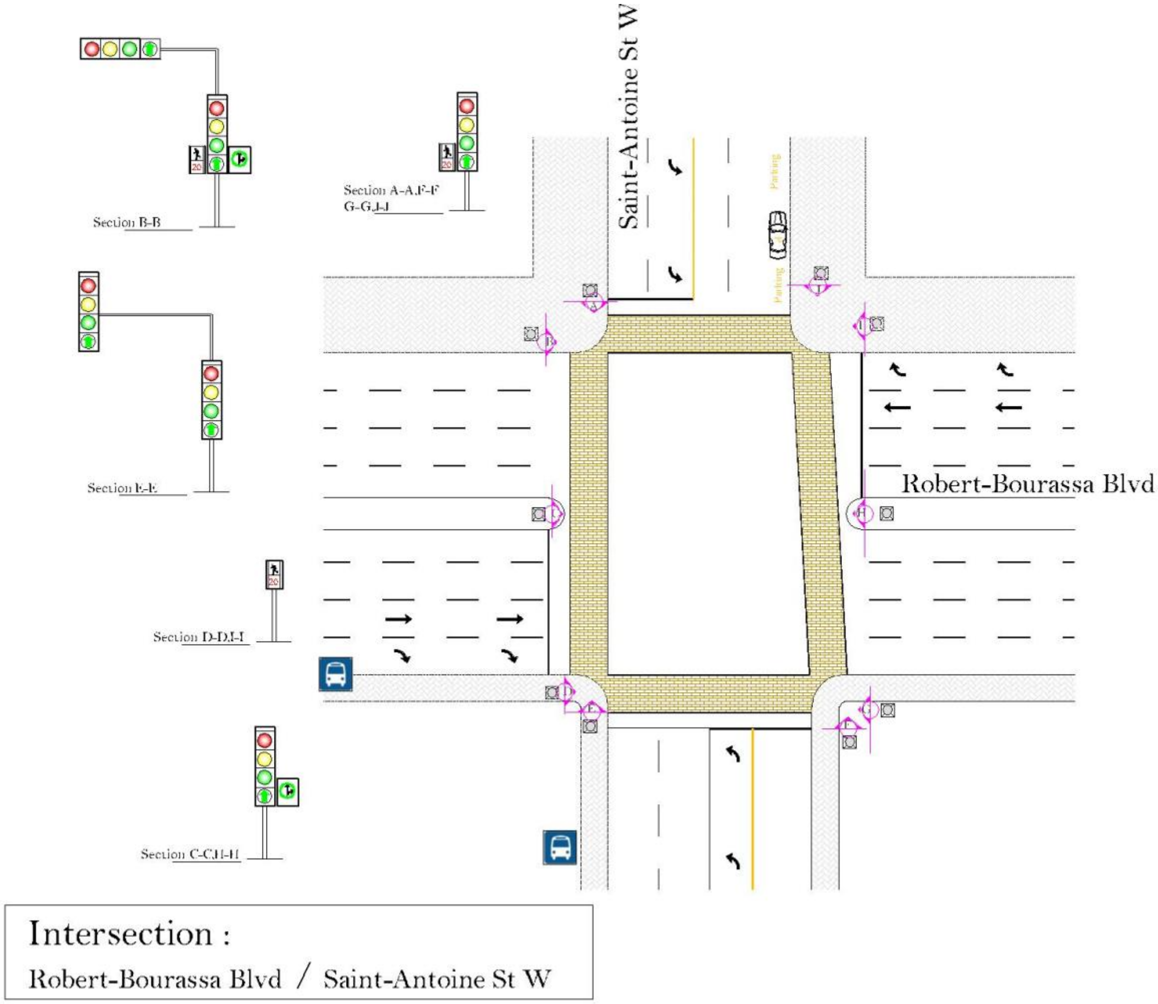
Intersection :
Saint-Denis St/ Mont-Royal Ave E

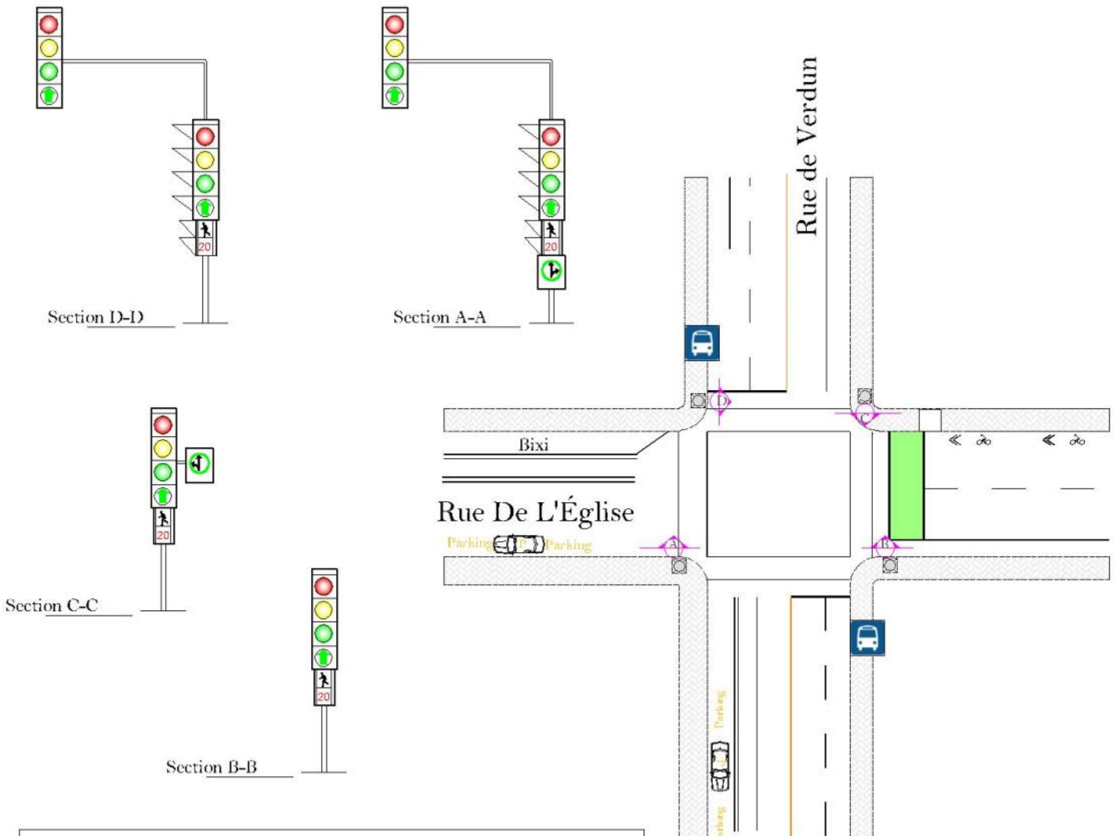

Wellington Ste
Section G-G
Section A-A
Section H-H
Section D-D,E-E
Rue Nazareth
Section B-B,C-C
Section F-F
Wellington St
Intersection :
Rue Nazareth / Wellington St



Section
A-A,B-B,C-C,D-D
Ontario St E
Parking
Ave.Létourneux
Section E-E
Section F-F
Intersection :
Ave.Létourneux / Ontario St E

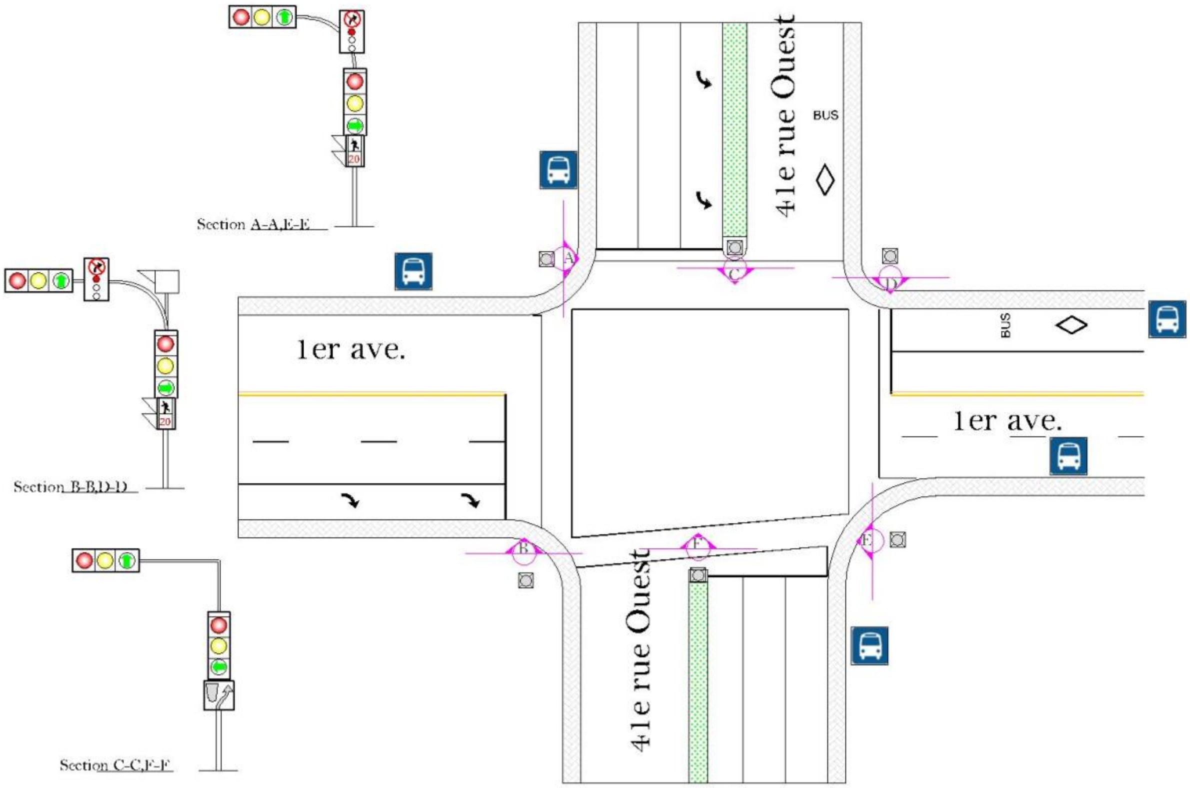

Rue Rachel E
Section B-B,C-C
Section A-A
Section D-D
Section E-E
Parking
Parking
Rue Andre Laurendeau
Section E-E
Section F-F
Section G-G
Intersection :
Rue Andre Laurendeau /Rue Rachel E


Saint-Antoine St W
Robert-Bourassa Blvd
Section B-B
Section A-A,F-F
G-G,J-J
Section E-E
Section D-D,I-I
Section C-C,H-H
Parking
Intersection :
Robert-Bourassa Blvd / Saint-Antoine St W

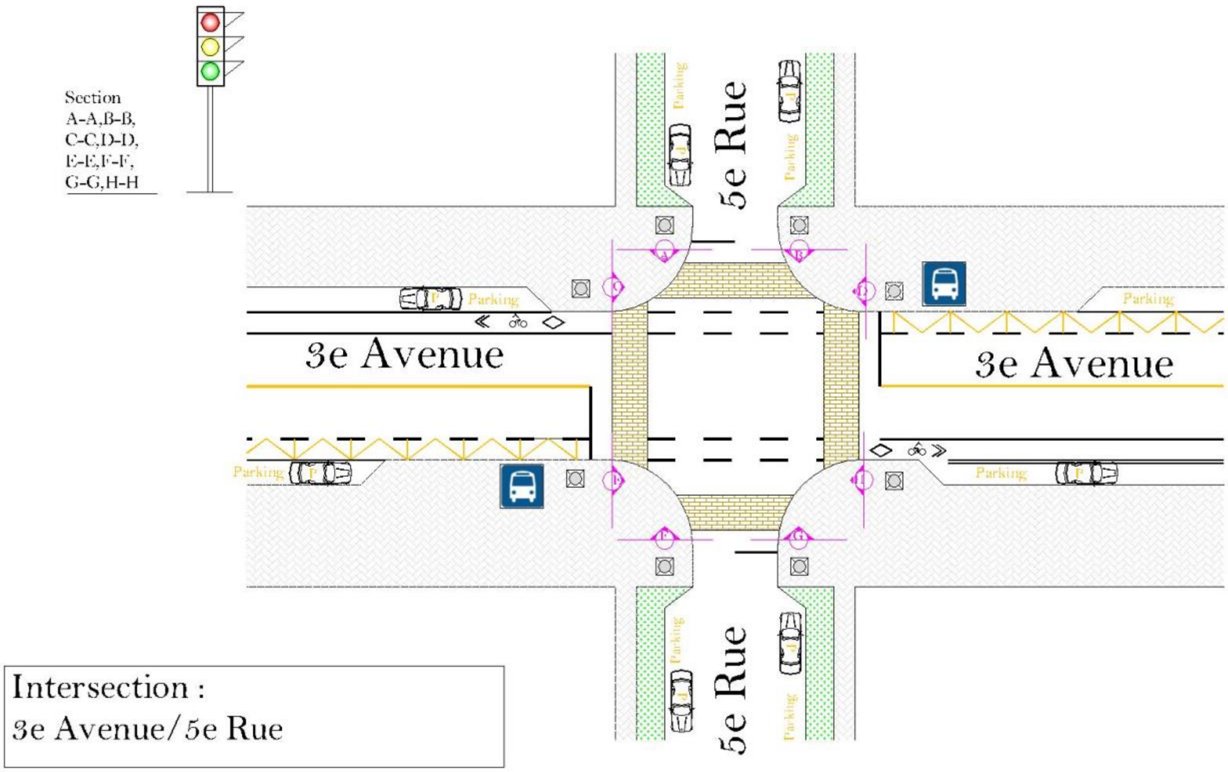


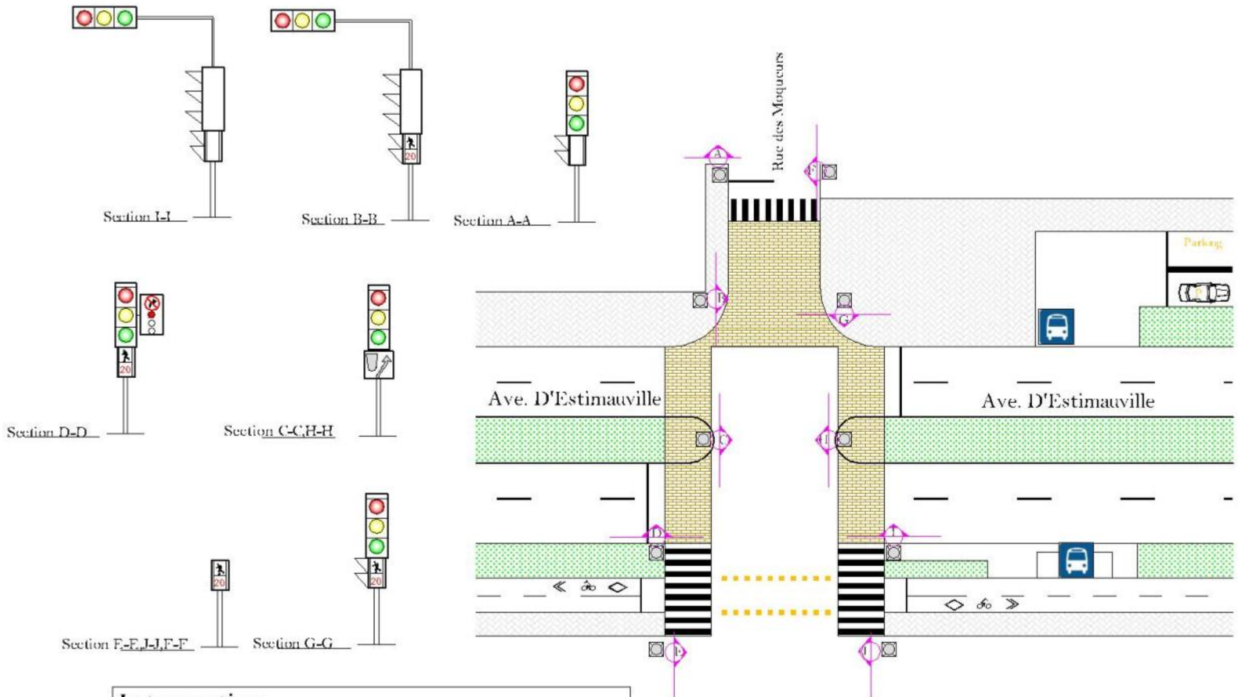
Intersection :
Rue de L'Église / Rue de Verdun

Quebec intersections

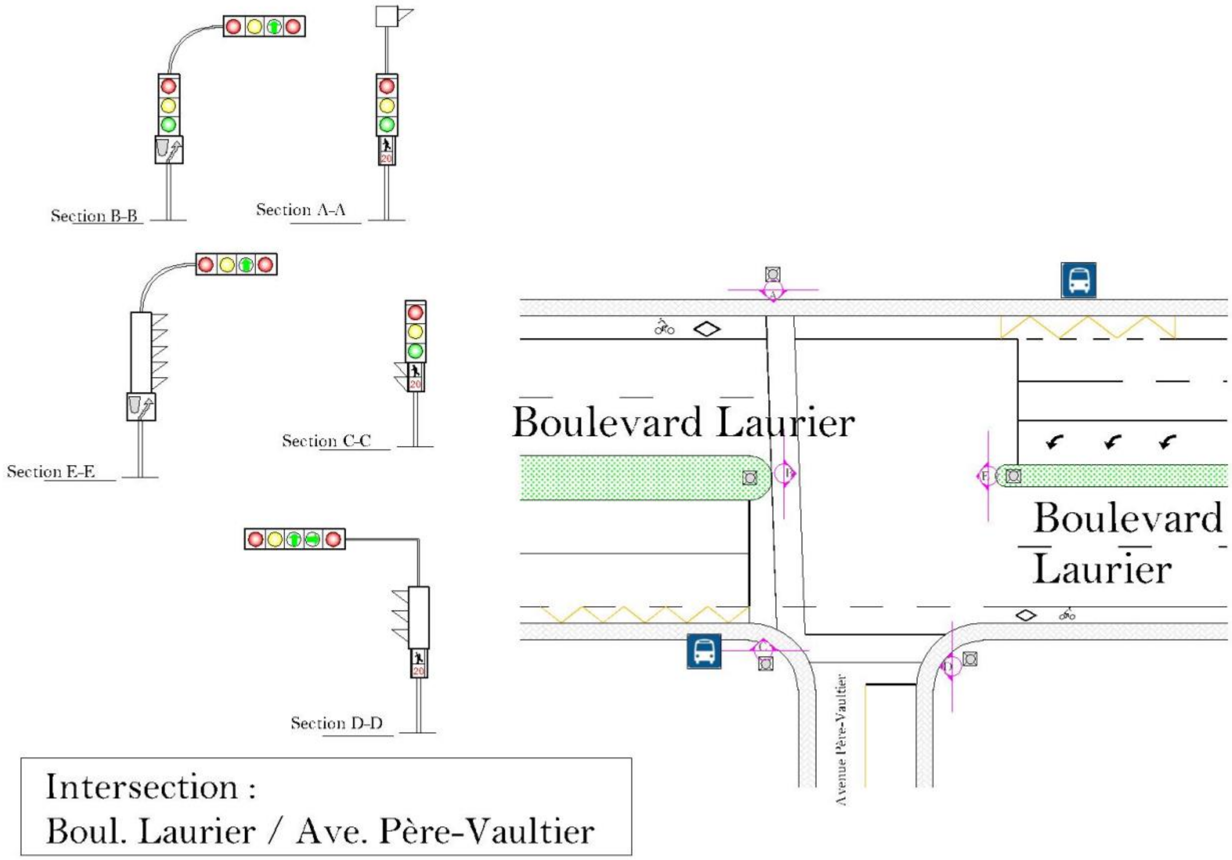


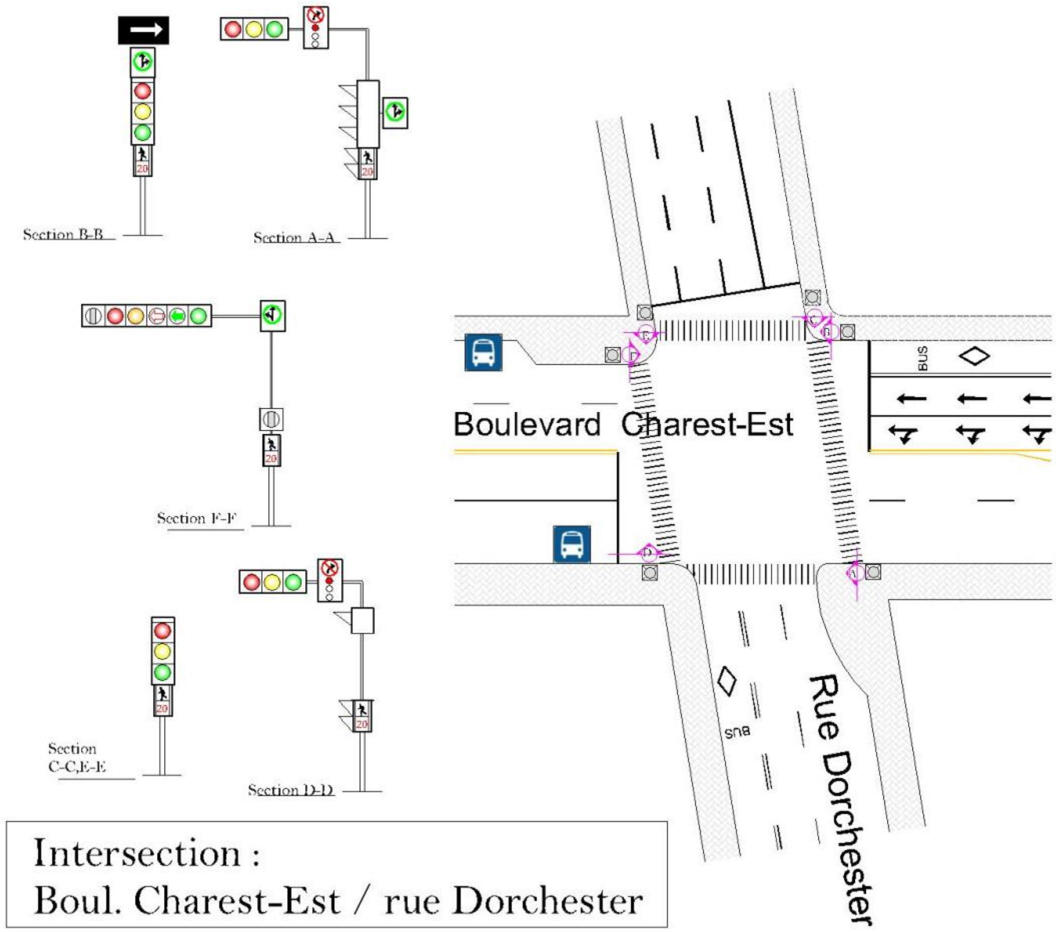
Intersection :
1er ave. / 41e rue Ouest

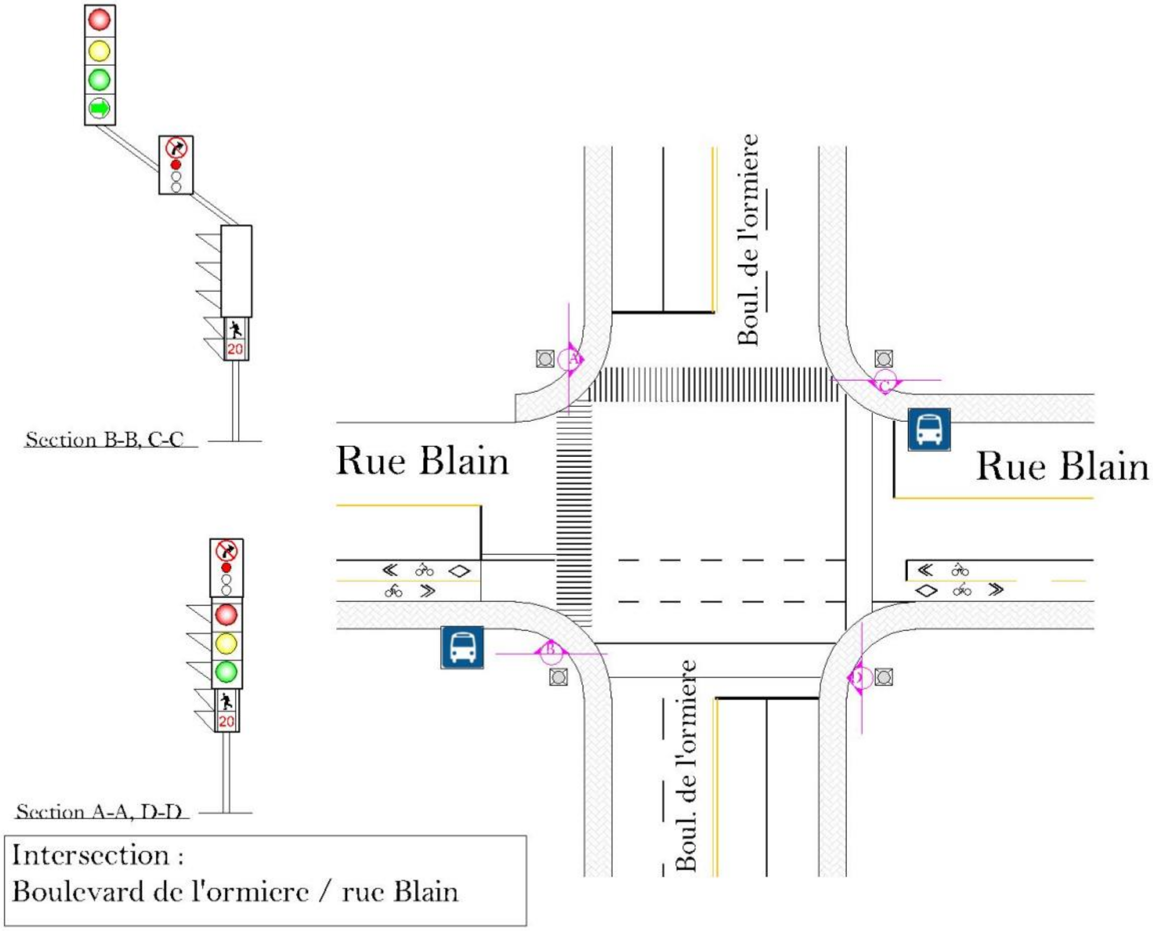

Section
A-A,B-B,
C-C,D-D,
E-E,F-F,
G-G,H-H
5e Rue
3e Avenue
Parking
Intersection :
3e Avenue/5e Rue

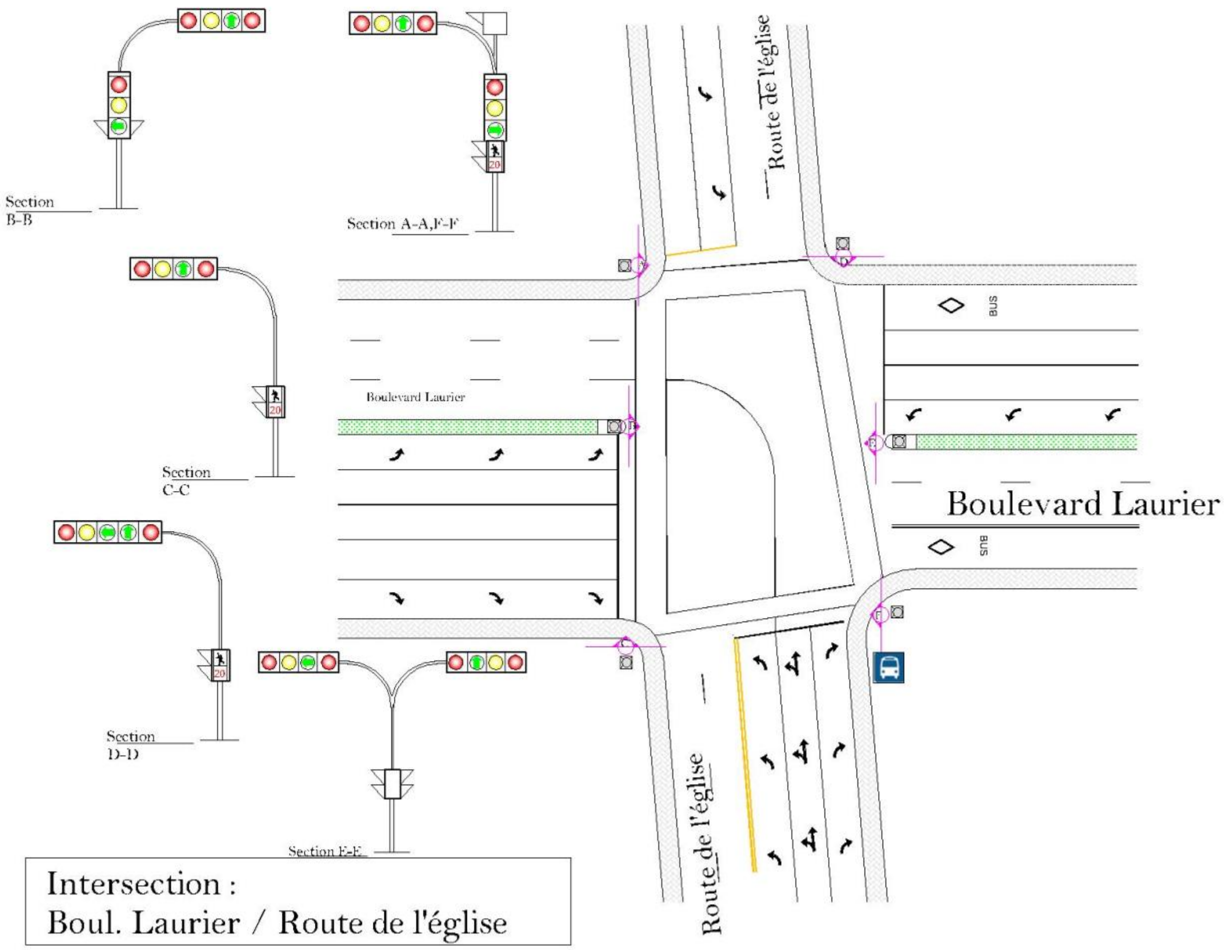


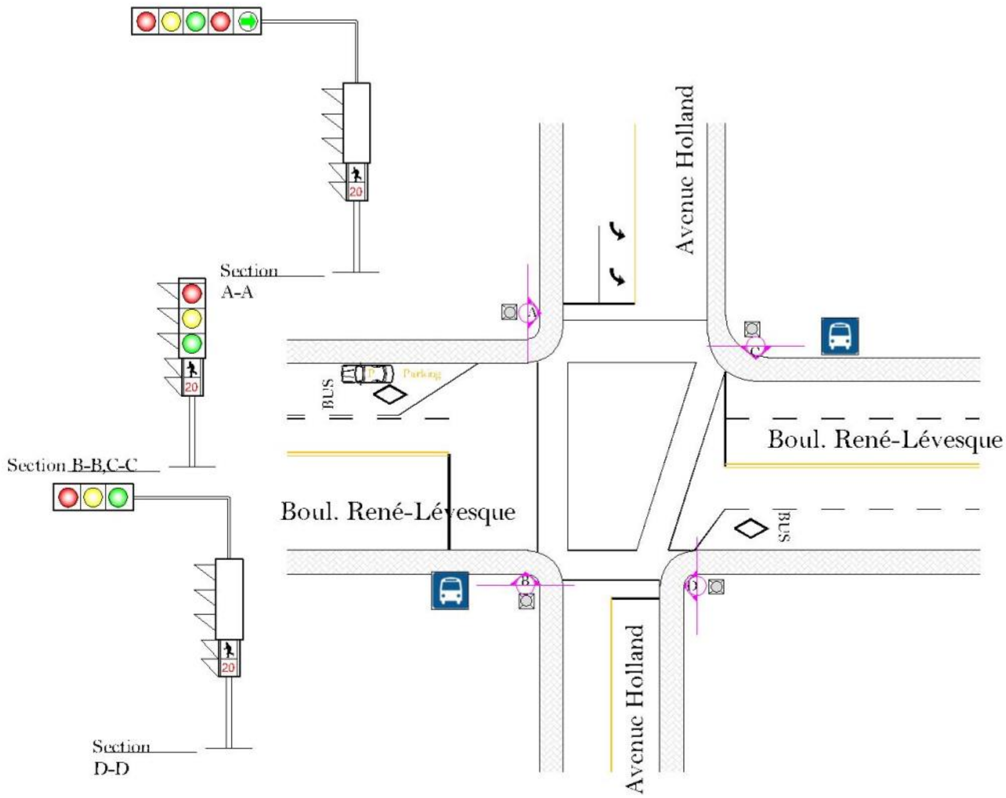
Intersection :
Ave. D'Estimauville / rue des Moqueurs


Section B-B
Section A-A
Section E-E
Section C-C
Section D-D
Boulevard Laurier
Boulevard Laurier
Avenue Père-Vaultier
Intersection :
Boul. Laurier / Ave. Père-Vaultier

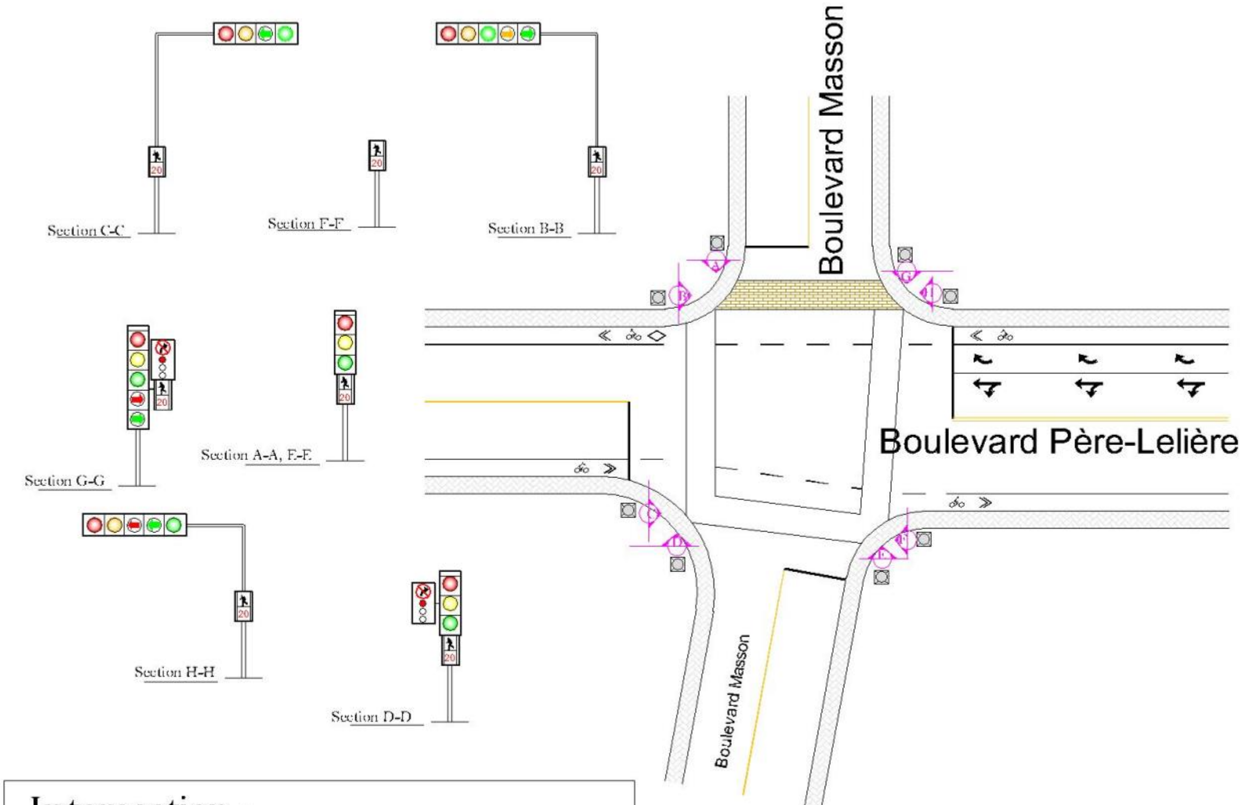

Section B-B
Section A-A
Section F-F
Section C-C,E-E
Section D-D
Boulevard Charest-Est
Rue Dorchester
BUS
BUS
Intersection :
Boul. Charest-Est / rue Dorchester


Section B-B, C-C
Section A-A, D-D
Rue Blain
Rue Blain
Boul. de l'ormiere
Boul. de l'ormiere
20
20
Intersection :
Boulevard de l'ormiere / rue Blain

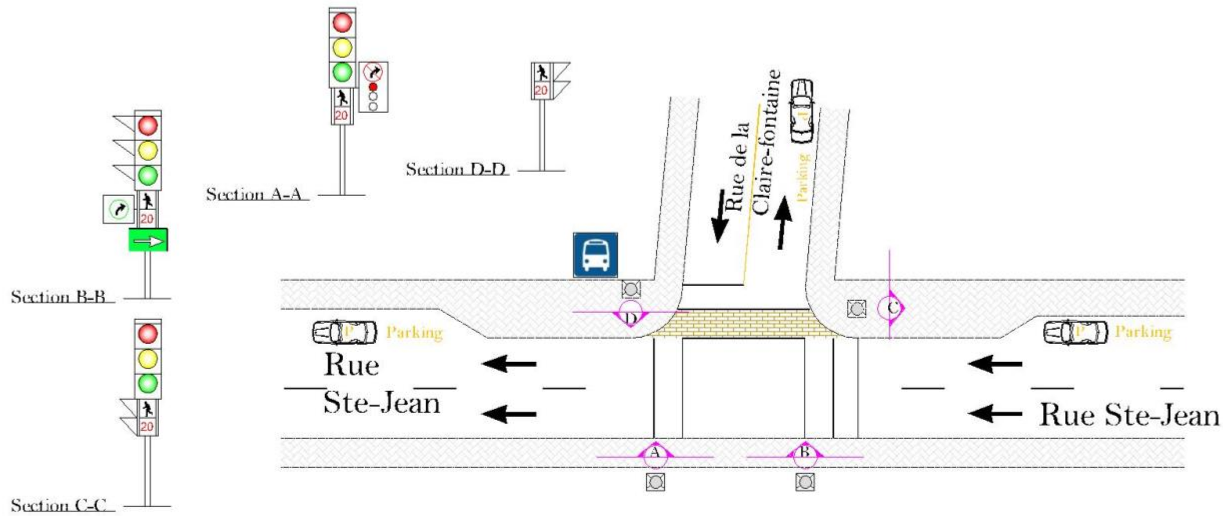

Section
B-B
Section A-A,F-F
Section
C-C
Section
D-D
Section E-E
Boulevard Laurier
Route de l'église
Boulevard Laurier
Route de l'église
BUS
BUS
20
Intersection :
Boul. Laurier / Route de l'église



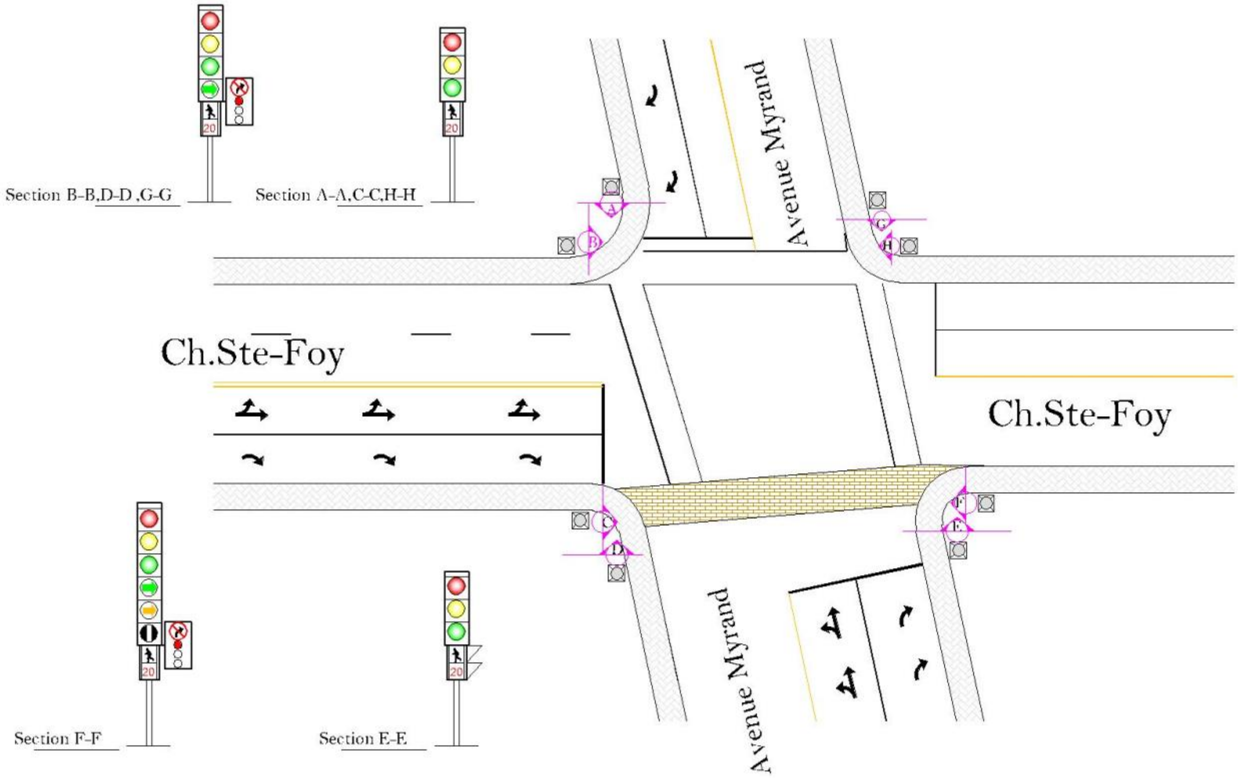
Intersection :
Boul. René-Lévesque / ave Holland



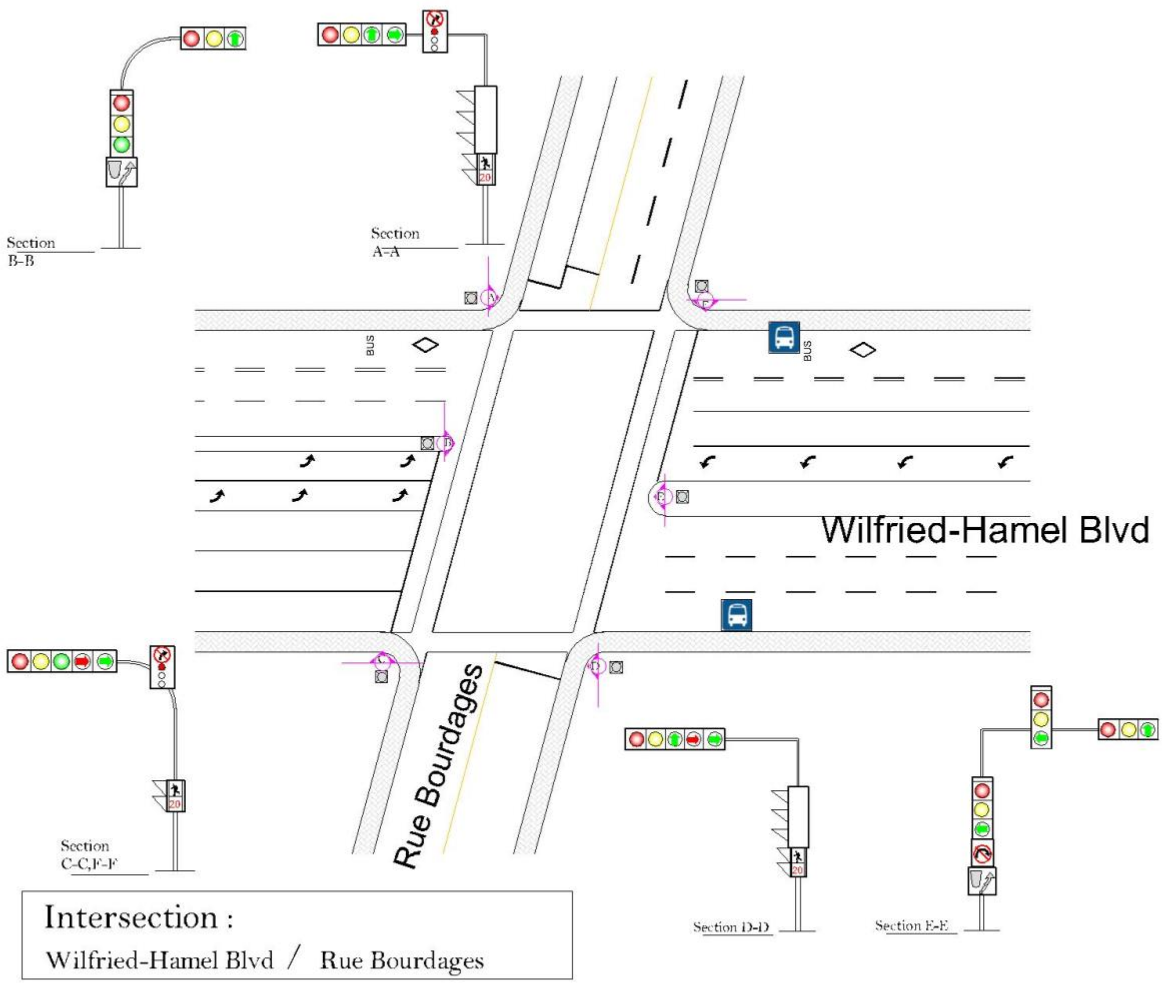
Intersection :
Père-Lelière/ Boul. Masson



Intersection :
Rue Ste-Jean/Rue de la Claire-fontaine



Intersection :
Ch.Ste-Foy / Avenue Myrand



Section B-B
Section A-A
BUS
BUS
Wilfried-Hamel Blvd
Rue Bourdages
Section C-C,F-F
Section D-D
Section E-E
Intersection :
Wilfried-Hamel Blvd / Rue Bourdages