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Pedestrian movement modelling for a commercial street considering COVID-19 social distancing strategies

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Abstract

This research attempts to understand the impacts of social distancing on dense urban pedestrian environments through pedestrian movement simulations. It develops a pedestrian microsimulation modelling framework that evaluates three scenarios for a commercial street in the Halifax Regional Municipality (HRM). The Business-as-Usual scenario mimics pre-COVID conditions with no social distancing protocols. Pandemic *Scenario# 1* represents social distancing without any changes in the pedestrian infrastructure. The HRM has adopted a mobility response plan for COVID-19, this generates Pandemic *Scenario# 2* depicting the widened sidewalks within the pedestrian microsimulation model. The results reveal that the social distancing strategy in the pandemic scenarios significantly improved pedestrian flow in terms of the reduction in contact violations. These violations are described as instances in which a pedestrian violates the 2 m social distancing rule. The simulation of the first pandemic scenario (no sidewalk enhancement) showed a significant reduction of 43% in the number of contact violations during the one-hour pedestrian simulation of the street. The second pandemic scenario showed a 68% decrease in violations. The conclusions derived from this research support the actions of the municipality as the simulation results indicate that an increase in sidewalk width can influence contact rates and time travelled. When comparing the two pandemic scenarios, the scenario that incorporated wider sidewalks showed a decrease in total travel time and contact rates.

Keywords: COVID-19; Pedestrian microsimulation; Active Transportation Improvements; Social Distancing;

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1. Introduction

This paper presents a modelling framework for pedestrian movements that accounts for social distancing strategies adopted by public health agencies. In the wake of COVID-19, non-clinical solutions such as stay home orders and social distancing became prominent to reduce transmission rates of COVID-19 [1]. Both government restrictions and voluntary precautions have changed the patterns of activity participation, pedestrian movement, social interactions, and mobility across the globe [2]. A study in Italy, one of the first countries to implement strict nationwide public health measures explores mobility changes due to the lockdown measures [3]. In the U.S., nationwide mobility studies are conducted to evaluate the impacts and mitigation strategies to adapt with COVID-19 challenges [4]. As cities have begun the re-opening of activities, it is necessary to examine how the city streets are capable to accommodate COVID-19 measures, as well as what needs to be improved during re-opening stages, which is limited in the existing literature. This paper aims to develop a pedestrian microsimulation modelling framework that incorporates a shift in pedestrian movement behavior from a business as usual to pandemic conditions to evaluate a commercially dense street in downtown Halifax, Canada. In alignment with the city's mobility response plan due to COVID-19 [5], it also examines how improved pedestrian infrastructure, specifically widening of sidewalks, assist in maintaining social distancing. This research considers Spring Garden Road, which is one of the most vibrant, pedestrian oriented streets on the east of Quebec City in Canada as the study area.

The paper develops a pedestrian traffic microsimulation modelling framework in which parameters are set for pedestrians to maintain distance from one another. The simulation will run under three scenarios: (a) Business-as-Usual, (b) Pandemic *Scenario# 1* (without infrastructure improvement), and (c) Pandemic *Scenario# 2* (with infrastructure improvement). The three scenarios were developed to represent the different stages that have been experienced during the first wave of the pandemic. The 'Business-as-Usual' case will represent the beginning of the outbreak where social distancing was encouraged but not enforced by law. In this scenario, pedestrians will travel without the enforcement of social distancing. This will provide a baseline scenario to compare with the pandemic scenarios that required social distancing. Pandemic *Scenario# 1* will represent the initial stage of the pandemic. In this scenario the lockdown is in full effect and social distancing and other regulations are now being strictly enforced by the local government. The regulations have encouraged many people to avoid leaving their homes entirely, especially those living in dense urban areas. Commercial street usage has dropped significantly in this stage as many small businesses have been forced to shut down temporarily. As the threat of mass infection diminishes, and provincial case numbers reduce, the municipality has begun to implement strategies for transitioning back to normal city life. In Pandemic *Scenario# 2*, the city will be initiating a mobility response plan by widening sidewalks along Spring Garden Rd. to increase the opportunity for safe pedestrian movements. Activity remains partial in this scenario as businesses are slowly beginning to re-open and individuals are becoming more comfortable with travelling on busy streets. The following sections will provide a brief review of literature, followed by methodology and discussion of results.

2. Literature Review

Although there is limited research surrounding COVID-19, interest in studying mobility patterns during the pandemic is rising. The majority of current literature are large-scale mobility studies that consider transportation as a vector for the transmission of infectious disease. These studies have been conducted nationwide by several of the most vulnerable populations including the U.S. and Italy [3, 4]. The study conducted in Italy obtained data from 170,000 smart phones throughout the country before and during the pandemic. These studies show consistent evidence that the enforcement of social distancing regulations has positively impacted the effort to contain the virus. Read et al. [6], conducted research on large scale infectious disease spread to look at current research practices that aim to quantify the social interactions responsible for the transmission of viral infections. Simulation modelling approaches are used to understand pandemic induced mobility trends in urban environments. Borkowski et al. [7], explored disease contraction for a medium-sized U.S. city using data driven, agent-based modelling strategies.

In case of pedestrian microsimulations and the spread of infectious disease, a recent study explores a multi-scale model that combines pedestrian dynamics with stochastic infection spread models [8]. This study mainly looks at integrating pedestrian movement models with infectious disease spread models to understand how various queue configurations can impact the likelihood of infection. The study tests different horizontal and vertical aisle patterns, floor geometry, and tools such as ropes and wall separators. The research looks to understand how these infrastructure and design changes can influence contact and infection rates under a variety of disease profiles. The results obtained show that the wall separators in queuing areas were the most significant in terms of reductions. Lower contact numbers were also found in rectangular floor patterns over square floor patterns. Moreover, contact rates are directly correlated with infection rates and high-density pedestrian zones are hot spots for transmission of viral infections.

Xiao et al. [9] examines the spread of infectious diseases caused by pedestrian contact in enclosed indoor spaces in response to the current COVID-19 pandemic. The study found that the time spent in grocery stores for individuals increased when travel was restricted, and the capacity of buildings was limited. From this information it can be questioned as to whether capacity and travel restrictions increase the risk of contact between individuals. It was found that a balance of social distancing and capacity restrictions while using optimized queuing approaches is the most efficient strategy to minimize unsafe contact in indoor spaces during a pandemic. Using an Optimal Steps Modelling technique, a recent study attempts to adjust pedestrian spacing parameters to develop a default social distancing model that can be used for COVID-19 research [10]. This study utilizes two scenarios to develop the social distancing model. The first involves a strict social distancing rule in which pedestrians are unable to violate the social distance constraint. The second scenario considers the social distancing rule as only a rule of thumb. On average pedestrians will maintain the appropriate distance, however in certain cases the social distancing rule may be violated. These models were tested in high-density pedestrian bottle neck simulations. The simulation showed that clogging of pedestrian lanes in a bottle neck scenario will occur under social distancing regulations.

Although newer simulation techniques are proposed for COVID-19 mobility modelling, there is a significant gap in developing pedestrian movement model at the street level. This research aims to fill the gap by adopting a modified social force model within pedestrian microsimulation modelling framework. In addition, the study attempts to understand how pedestrian traffic behavior changes under social distancing scenarios, while also demonstrating the impacts of pedestrian infrastructure improvement planned by the municipal government.

3. Methodology

3.1 Traffic Microsimulation Modeling of Spring Garden Road

3.1.1 Network Model

This study develops a traffic microsimulation model that considers vehicle and pedestrian movements simultaneously under the business-as-usual and pandemic conditions. The microscopic traffic simulation model is developed utilizing VISWALK within the VISSIM platform and consists of 229 links and connectors, 4 major intersections and 14 pedestrian zones as illustrated in Figure 1. Figure 1 and Figure 2 present an isometric view of the Spring Garden Road, and microsimulation of vehicles and pedestrian movements, respectively.

Fig. 1. Isometric view of the Spring Garden Road

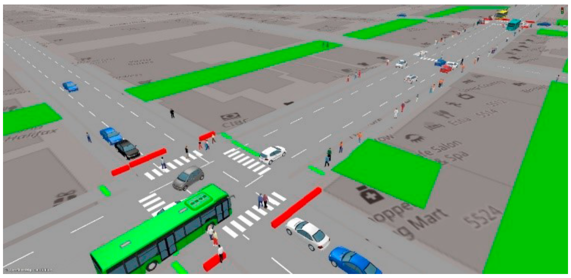

Fig. 2. Microsimulation of vehicles and pedestrians

Signalized intersections are represented with signal controllers, stop signs, and priority rules. Signal controllers are utilized to develop signal phases using signal timing data obtained from the HRM. To avoid vehicle conflicts at intersections, all turning conflicts are resolved using the active-passive concept in the simulator. A detailed description of a signal controller can be found in Alam and Habib [11, 12]. The model also includes 26 parking lots which are used as trip origin-destination endpoints. The model implements a dynamic traffic assignment process to address traffic congestions and the driver's route choices in the network.

3.1.2 Vehicle Demand

The dynamic traffic assignment requires an Origin-Destination (OD) travel demand matrix. 14 vehicle loading zones are constructed within the microsimulation model. A Halifax Regional Transport Network Model [13] is utilized to estimate trip generations and distributions at 14 traffic analysis zones considered in this study. The regional model encompasses the entire Halifax Regional Municipality consisting of 219 traffic analysis zones, 2,249 link nodes, and 2,985 truck permitted links out of 5,232 directional links. Among 219 TAZs, 93 are urban, 93 are suburban and 33 are rural.

This study uses trips estimated from 16 traffic analysis zones (TAZs) of the regional model. The adjacent TAZs external to the study area that share the same link are grouped to form 14 loading zones. The passenger car demand model uses trip rates from the Nova Scotia Travel Activity (NovaTRAC) Survey, which was conducted by Dalhousie Transportation Collaboratory (DalTRAC) in partnership with the province of Nova Scotia and the Halifax Regional Municipality to capture travel behavior of the area's population.

3.1.3 Pedestrian Trip Generation and Distribution

To consolidate the pedestrian component in the simulation model, 18 zones are constructed, representing the endpoint of the pedestrian's trip. Pedestrian zones are created based on the Halifax Cyclic Coalition (HCC) survey 2018, which was conducted by DalTRAC to understand pedestrian travel patterns in the study area. Among 18 zones, 14 zones are internal to the study area and the remaining 4 are external zones. The external zones are used for loading pedestrian into the model from neighboring communities. Trips attracted to the study area are calculated using the survey. Trips are distributed following a gravity modeling approach. The obtained OD matrix is used for the assignment of pedestrian demand in the network.

3.1.4 Calibration and Validation of the Driving and Pedestrian Behavior parameters

This study utilizes the values of driving behavior parameters derived by Alam et al. [14] which are 1.0 for the average standstill distance, 0.6 for the additive part of safety distance, and 0.7 for the multiplicative part of safety distance. Using the values, a goodness-of-fit of the model is obtained as 0.87 in terms of R^2.

The study uses a Social Force Model (SFM) in the simulation of pedestrian behavior [15]. Pedestrian behavior parameters in SFM are calibrated for two conditions: (i) business as usual, and (ii) pandemic when social distancing is encouraged. The calibration is conducted through simulations of different combinations of the values of parameters to replicate business as usual pedestrian behavior on Spring Garden Road. Lagervall and Samuelsson [16] identifies parameters that significantly influence walking behavior, which include *tau*, *ASocIso*, *BSocIso*, *VD*, and *lambda*. Briefly, *tau* represents the relaxation time of pedestrian, which indicates a relaxed or aggressive behavior of the pedestrian. A lower value of *tau* induces an aggressive behavior of pedestrian resulting in a close counter. *lambda* measures the influence of an incident on pedestrian movement depending on the location of the occurrence, while θ measures the angle between the pedestrian and the incident location. This parameter is used to determine a factor during simulations that weights the impacts of any surrounding events on a pedestrian's movements. *ASocIso*, and *BSocIso* govern the forces between pedestrians while *ASocIso* takes relatively a higher value than that of *BSocIso*. These two parameters are used in calculating repulsive forces among pedestrians. They govern the force based on the distance among pedestrians (body-surface to body-surface) as calculated using equation 1.

$$F_{mn} = ASocIso * \left\{ lambda + \left(1 - lambda\right)\left(1 + cos\theta\right) / 2 \right\} * exp(D_{mn} / BSocIso) \quad (1)$$

Where, F_{mn} is the repulsive force and D_{mn} is the distance between pedestrian m and n. Another parameter, *VD* captures the reaction of a pedestrian to counterflows and is measured in seconds, which influences the distance calculations in combination with the relative velocity of pedestrians within the simulation. To experiment different values of the parameters, the typical range is obtained from the existing work [17, 18]. Table 1 shows the values and the criteria for performance evaluations of the parameters used in this study.

Table 1. Pedestrian Behavior Parameters, Standard Values, and Performance Measure Criteria

Parameter	Standard values	Criteria
Tau (τ)	0-1	Average speed
Lambda (λ)	0-1	Queue time
VD	≥0	Pedestrian density
ASocIso	2.72	Pedestrian density
BSocIso	0.2	Pedestrian density

The simulation yields that *ASocIso* and *BSocIso* take values in the range of 2-6 and 0.01-0.5, respectively to create a realistic pedestrian movement. A recommended value of 0.4 and 0.176 for *tau* and *lambda* exhibit a business-as-usual pedestrian behavior. Simulations are conducted with different values of the parameters *ASocIso*, *BSocIso*, and *VD* to identify the impacts of these parameters on pedestrian movements. The simulation results show that pedestrian density decreases as their value increases. The combinations of the parameters providing the highest R^2 value of 0.83 assigns values of 1.2. 0.3, and 8 to *ASocIso*, *BSocIso*, and *VD* respectively. A pedestrian count data obtained from the Halifax Regional Municipality is compared to the simulated count to estimate R^2.

For social distancing scenarios, parameters are calibrated to achieve a pedestrian behavior that yields the least number of pedestrian movement instances with a proximity of less than 2 m between pedestrians. Alam et al. [19] developed a process for pedestrian behavior parameter calibration in relation to a pandemic scenario when social distancing is encouraged. Simulations are conducted for different combinations of the pedestrian behavior parameters. Pedestrian coordinates in the network are recorded at half a minute interval. A Python script is utilized to calculate distances among all pedestrians for all instances occurred within the specified time interval. Parameter values that achieve the least number of instances (3.8%) when pedestrian comes in contact within 2 m distance include *tau* (=0.4), *lambda* (=0.176), *ASocIso* (=2.0), *BSocIso* (=0.4), and *VD* (=11).

4. Results of the Microsimulation Model

The study analyzed key attributes of pedestrian movement, including distance travelled, time travelled, experienced density, zone density, and the number of instances of infection spreading contact. The results reveal that significant changes are observed in pedestrian travel for the three scenarios. In the two pandemic scenarios, parameters were set to encourage pedestrians to maintain approximately two meters from one another while traveling along the sidewalk. Variation between the scenarios comes in the form of small changes to infrastructure and simulation capacity. Zones are used in this simulation to represent areas of commercial business. The average density of each zone was compared across all scenarios to demonstrate how businesses activity on the street may be affected in each scenario. Table 2 summarizes key results of all scenarios considered in this study.

Table 2. Summary of Scenario Results

Scenario	Average Time Travelled (s)	Average Distance Travelled (m)	Average Experienced Density (p/sqm)	# of distancing violations	% Reduction in violations compared to BAU	Average Zone Density (p/sqm)
Business-as-usual (BAU)	221.08	222.93	0.054	160	-	0.046
Pandemic scenario# 1 (PS1)	224.23	228.85	0.030	91	43	0.023
Pandemic scenario# 2 (PS2)	222.49	228.97	0.019	51	68	0.016

4.1 Results from Business-as-Usual (BAU) Scenario

In the BAU scenario, the sidewalk width remains unchanged at 2.4 meters wide, and the pedestrian capacity will remain at 100%. The simulation represents an hour of pedestrian traffic movement on Spring Garden Road. Within this one-hour period, 2,217 pedestrians entered the commercial street in the BAU scenario. The average distance travelled for all pedestrians was 222.93 m, the average time travelled was 221.08 s, and the experienced density of pedestrians was 0.054 pedestrians/sq. meter. In this scenario, there were 160 instances where pedestrians encountered each other at less than 2 m distancing. As part of the network development process, the street was subdivided into seven zones to provide density information for commercial areas. From the perspective of zone density with regards to the businesses that these zones represent, the first scenario showed an average density of 0.046 pedestrians/sq. meter between the seven zones (see Figure 3).

4.2 Results from Pandemic Scenario# 1 (PS1) - Early Stage

The PS1 scenario uses social distancing parameters to encourage pedestrian distancing while maintaining the existing 2.4 m sidewalk width. However, this scenario will see a 50% reduction in the overall capacity of the street to represent an environment that less pedestrians travels on busy streets due to risk of infection, capacity limits, and business closures. Within the one-hour time, 1,109 pedestrians entered the street in this early-stage scenario. The average distance travelled was 228.85 m, the average time travelled was 224.23 s, and the average experienced density was 0.030 pedestrians/sq. meter. This scenario also saw the number of instances of contact violations decreased substantially with only 91 instances where individuals violated the 2 m social distancing bubble. The average zone density in this scenario was 0.023 pedestrians/sq. meter.

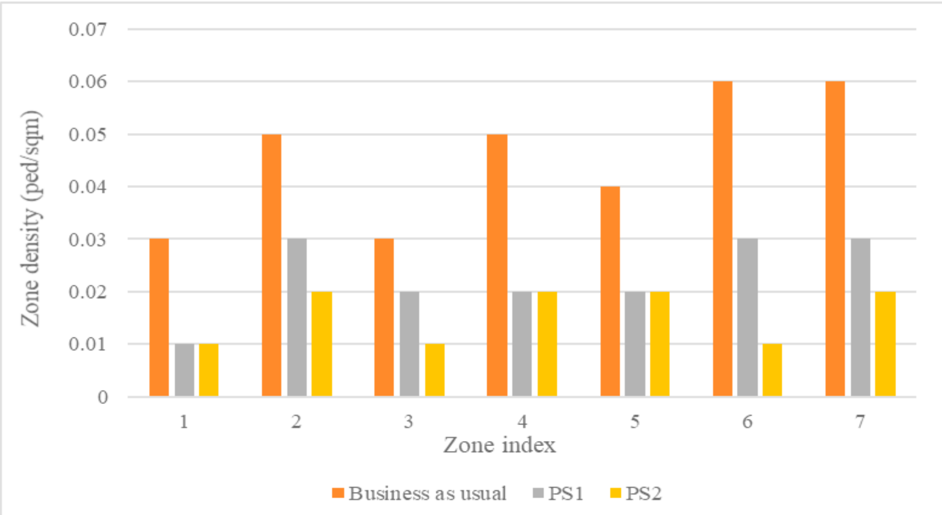

Fig. 3. Zonal Density under business as usual, and pandemic conditions

4.3 Results from Pandemic Scenario# 2 (PS2) - Re-opening Stage

The final scenario, PS2, represents the re-opening stage. For this scenario, street capacity will remain at 50% with 1,109 pedestrians entering the street over the course of one hour. However, in this re-opening stage the sidewalk width has been increased to 4.8 m to represent the actions of the city's mobility response plan. In this scenario, the average distance travelled was 228.97 m, the average travel time was 222.49 s, and the average experience density was 0.019 pedestrians/sq. meter. The number of instances of contact violations was reduced again nearly in half down to 51 instances. Whereas the average zone density was reduced to 0.016 pedestrians/sq. meter.

5. Discussions

5.1 Pedestrian Traffic Flow

The results of the simulation provide insights into the impacts that regulations and infrastructure changes can have on traffic flow when mitigating the spread of COVID-19. The most significant findings from the scenario testing reveals that social distancing reduced the number of possible contacts that may lead to infection. As explained above, this number represents the instances in which two pedestrians violate the 2 m social distancing regulation. In the BAU case, no social distancing parameters were adjusted to encourage distancing. Therefore, the number of instances of contact during one hour of pedestrian traffic simulation on Spring Garden Road was 160. In PS1, that number was reduced by 43% down to only 91 instances of contact. In PS2, this number was again reduced considerably by 44% down to 51 instances. The significance of this data comes from the reduction observed between the PS1 and PS2 scenarios. In the BAU scenario, the number of pedestrians entering the street is double that of the two pandemic simulations. Therefore, an argument could be made that 43% reduction in the instances of infection was a direct result of the 50% reduction in overall street capacity seen in PS1 and PS2. However, where PS1 and PS2 have the same street capacity, a 44% reduction in the number of instances supports infrastructure changes as being a viable solution to limit contact rates. These results show the potential for wider sidewalks to reduce the spread of infection on busy pedestrian streets which directly supports Halifax's mobility response plan.

From the other observed data, it is shown that pedestrian distance travelled, and travel time was not greatly impacted. The BAU scenario resulted in an average travel distance of 222.93 m while PS1 and PS2 saw that distance increases by 5.92 m and 6.04 m, respectively. The BAU scenario resulted in an averaged travel time of 221.08 s while PS1 and PS2 saw that time increase by 3.15 s and 1.14 s, respectively. This data simply shows the impact of the regulations in place for social distancing in PS1 and PS2. In PS1 the average pedestrian travelled slightly further and took a few seconds longer to reach their destination. In PS2 the average pedestrian travelled further, however reached their destination quicker than in PS1. This represents the positive impact of increased sidewalk widths, as pedestrians were able to avoid congestion, pedestrian counterflow, and arrive on-time despite travelling a bit further in total distance travelled.

5.2 Pedestrian Activity

This simulation provides general pedestrian density information for designated zones. The results show that the 50% street capacity reduction implemented in the social distancing scenarios is the primary reason for significant change in zonal density. The average zonal density for the two social distancing scenarios was roughly reduced by 50%. There was a slight decrease from PS1 to PS2 in terms of zone density as well. This signifies that the improved pedestrian infrastructure allows quicker movements despite the social distancing measures in place.

6. Conclusion

The COVID-19 pandemic necessitates the development of alternative modelling techniques to understand the impacts of public health measures in the transport network. It is also urgent for decision-makers to reflect on the successes and failures of employed mitigations techniques, while also considering future strategies that may further protect public health. The objective of this research is to simulate and analyse pedestrian traffic within a microsimulation model to observe changes that may occur when social distancing protocols are applied. The pedestrian behaviour parameters are adjusted to encourage social distancing to observe and compare business-as-usual and pandemic conditions.

It is evident from the results of the two pandemic scenarios (where social distancing rules were applied) that the risk of infection from contact is significantly reduced when compared to the BAU scenario. The scenario testing demonstrated 43% and 68% reductions in social distancing violations when comparing the two pandemic scenarios with the BAU scenario. The study also concludes that improved pedestrian infrastructure, specifically widening of the sidewalks brings positive impacts on pedestrian movements, in terms of distance travelled, average travel time and pedestrian density despite social distancing measures in place in the city. Therefore, governments should consider improvement of pedestrian networks for safer movement of people in congested streets.

This research provides an initial step in developing a pedestrian simulation modelling framework to assess COVID-19 impacts. It has certain limitations, including reliance on existing data. More observational research is necessary to further calibrate the modelling parameters. Future research should also consider surveys of business activities and assess how public health measures affect pedestrian demand. Nevertheless, this research provides useful insights regarding the impacts of social distancing measures on pedestrian movement, which will be useful for decision-makers in articulating the benefits of the infrastructure improvements in tackling COVID-19 challenges.

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