

# A LOCAL SPATIAL ANALYSIS CRITERION OF POST-TRAUMATIC BRAIN INJURY AND ACCESSIBILITY TO PUBLIC TRANSPORTATION

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## ABSTRACT

Reported cases of traumatic brain injuries are increasing among the Canadian population. With an annual rate of 187,000 reported cases a year and growing, there is an extrapolated growth of 239,000 cases of traumatic brain injuries occurring annually by 2036.

As Ontario intends to be a completely accessible province for those with disabilities by 2025, this paper utilizes GIS to visualize and better understand the relationship between post-TBI residents living in Brampton and their accessibility to public transportation. As Brampton is currently the most expensive city to insure a vehicle because of frequent collisions occurring within the city, creating a more accessible, reliable, and efficient public transportation system can integrate those who have experienced a traumatic brain injury back into society while reducing the required use of a personal vehicle. This will contribute to a safer city, as there are fewer vehicles on the road at risk of being involved in a road accident. There are also further benefits to this, as it will also reduce levels of congestion in the foreseeable future.

Keywords: GIS, Post-Traumatic Brain Injury, Public Transportation.

JEL Classification: I10, I18, C31

## 1. INTRODUCTION

Traumatic brain injuries are an issue as there are over 187,000 incidents reported among annually among Canadians. The incidents in which head injuries occur, such as transportation collisions, work and home environments, violent or from participating in recreational activities pose a health challenge for the Canadian population as it costs over \$6.8 billion dollars annually directly and indirectly (Caro, 2011). Caro (2011) mentioned that the numbers of TBI cases in Canada are extrapolated to grow to more than 239,000 annually by the year 2036 with 66% percent of those cases projected in the high growth provinces of Alberta, British Columbia and Ontario. Having a sustainable system in place to provide effective care for post-traumatic brain injury patients will likely ensure that the tragic incidents would be reduced, as there are common cases of sequelae involved with head injuries.

In Cullen *et al.* (2013) article, neuropsychometric tests were used to predict return to driving after a traumatic brain injury. The participants in this study were drawn from an acquired

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brain injury database (ABI) that was established in 1999 at the Toronto Rehabilitation Institute University Health Network (TRI-UHN). This article addressed Hopewell's (2002) study that determined, among many patients, the possibility of having their ability to drive restricted is of a greater concern than any other functional limitation. Driving is a complex task that requires the person operating the vehicle to be able to process sensory information and make timely decisions but impairments in the speed of processing and information are commonly found among those that suffered a traumatic brain injury (Cullen *et al.*, 2013). To further support this finding, A return to driving after a brain injury has been correlated with a better overall quality of life, such as returning to employment, maintaining social relationships as well as reintegrating themselves back into society (Rapport *et al.*, 2006).

Bivona *et al.* (2012) determined an increased probability of being involved in a road collision with personal responsibility among drivers that returned to driving after a traumatic brain injury. Based on the results of the sixty participants in the survey, the main finding was that those who returned to driving after a traumatic brain injury had a statistically significantly greater risk (more than twice as likely) to be involved in a road accident while being at fault than they did before the injury. The results confirmed that driving ability is impaired after a traumatic brain injury. Though the limitations of this article is that it is a relatively small number of participants, to their knowledge at the time, the article is one of the few long-term follow up studies investigating the risk of being involved in road accident after a traumatic brain injury compared with pre-traumatic brain injury data (Bivona *et al.*, 2012).

Elsayed's (2011) research paper took an approach using surveys completed by staff working with clients from Community Head Injury Resource Service of Toronto (CHIRS), an organization that provides services to adults in Toronto that have acquired brain injuries (ABI). The survey consisted of yes/no multiple choice questions that examined if the client has applied for Wheel-Trans before and if they were declined, why? The assistive devices the clients would use, issues that would impact the client's ability to use conventional public transit, their current method of transportation and whether or not clients miss activities or appointments because they have no reliable transportation (Elsayed, 2011). The purpose of this was to look into accessible public transportation for those who are suffering from brain injuries within Toronto and this study identified that clients were declined from being able to use Wheel-Trans, as they did not have any physical apparent disabilities or rely on the use of assistive devices. Also, it was found that among those surveyed, people who never use public transportation miss more appointments/activities than those who do use a public transit service such as the TTC.

What was derived from these articles was that those who suffer from head injuries are likely to suffer impairments depending on the severity. This has many drawbacks as it affects how they operate within society and ways to better accommodate them should be considered. Though, driving is associated with an increase in personal independence, those that experience a traumatic brain injury are at greater risk of being involved in a collision and being at fault when driving (Bivona *et al.*, 2012; Cullen *et al.*, 2011). An efficient and accessible public transportation service as well as assistive public transportation service (such as Wheel-Trans) can be used to increase the well being and better implement those that suffer from traumatic brain injuries back into society while reducing the need for them to return to driving and being an increased risk.

## 2. STUDY AREA

Brampton is Canada's fourth fastest growing city and as the population increases the importance on becoming a more accessible city rises. Traumatic Brain Injuries (TBI) are a concern for Canadian healthcare systems as they pose significant challenges related to the financial sustainability and safety within a society. A current estimate constructed from US data suggests that there are approximately 500 in every 100,000 Canadians per year that are likely to experience a TBI (North Eastern Ontario Brain Injury Network, 2015). Based on those results there is a projected total number of 187,000 TBIs reported to be inflicted on Canadians each year along with the possibilities of severe head injuries not being reported or going underreported. There is an estimated \$6.8 billion in costs to serving TBI patients both direct and indirectly across Canada (Caro, 2011) as TBIs are the most common type of injury resulting in death and disability for those aged 45 years and younger.

The challenges associated with helping patients with TBIs vary depending on the severity of the head injury but those that experienced a TBI in moderate and severe cases are likely to require further adaptations to help assist them effectively in society as their lifestyle will require changes to accomplish daily tasks (Sherer *et al.*, 2000). Individuals that experienced a moderate to severe TBI commonly encounter complications affecting their cognitive, physical and psychological abilities as it becomes more difficult for them to perform adequately as they did before the injury was sustained (Lundqvist & Alinder, 2007). Sequelae associated with moderate and severe cases of TBIs are the increased susceptibility to having a seizure, the loss of muscle control, speech, vision, and hearing plus in some cases, resulting in paralysis. The cognitive abilities that endure impediments as a result of a post-TBI comprise of an increased difficulty in concentration as well as short-term and long-term memory loss. Suffering from these conditions lead to the increased difficulty of mentally and physically impaired individuals that endured a moderate or severe TBI to perform adequately within society (Community Head Injury Resource Services, 2013).

In this sense, the unexpected nature of post-TBI incidents must be carefully monitored at all scales. Particularly when dealing with complex tasks where additional and often incremental risk may exist. Driving is such a complex task that requires the use of motor skills, cognitive abilities, along with behavioral management. Potential impediments caused by coping with a TBI, patients that were able to previously travel on their own accord before having received the injury are faced with the possibility of driving restrictions as it is essential for drivers being able to process information to problem solve quickly, making important and timely decisions while on the road (D'apolito *et al.*, 2012). As a result of post-TBI sequelae impairing the ability for patients to drive commendably, driving is considered an unsafe task for the patients suffering from conditions of post-TBIs (Cullen *et al.*, 2012). In the United States, the reported rates of individuals that had experienced a moderate to severe TBI returning to driving are between 40% to 60%. The use of an automobile is known to be associated with the multiple aspects of independence and well-being. Having detained someone's ability or privilege to drive has been correlated with lowered rates of employment, community integration and life satisfaction (Labbe *et al.*, 2014). Respective studies have been done pertaining to the relationship between road traffic accidents following TBIs. This study revealed that individuals with severe TBI that resume driving pose a greater risk of being involved in a road accident than those that did before acquiring a severe TBI (Bivona *et al.*, 2012).

Based on the cities high insurance rates, AllState Insurance claims that drivers travelling within the city of Brampton were more likely to get into a car accident than anywhere else in Ontario as the city of Brampton holds the highest frequency of collisions (680 News, 2010). A safe and effective alternative to driving an automobile after enduring a TBI is an area of

importance as Brampton is a sub-urban city where most households own and rely on the use of automobiles (Vaz & Arsanjani, 2015). Based on the statistics of post-TBI victims and Brampton's current structure, the likelihood of individuals driving after a TBI and getting into a motor vehicle accident is further increased when returning to driving.

Referring to the Accessibility for Ontarians with Disabilities Act (AODA), Ontario has a goal for making public services (including transportation) to be accessible for all by the first of January 2025 (AccessON, n.d.). The aim of this paper is to offer a spatial analysis with the location of reported patients that experienced a TBI and their accessibility to public transportation within the city of Brampton. The questions that the spatial analysis intends to address through visualization are:

- Which post-TBI residents are within reasonable walking distance from a bus stop?
- Where are there clusters of post-TBI residents?
- What is the average family income of census tracts where TBI patients reside?

### 3. METHODOLOGY

#### 3.1 Description of Data

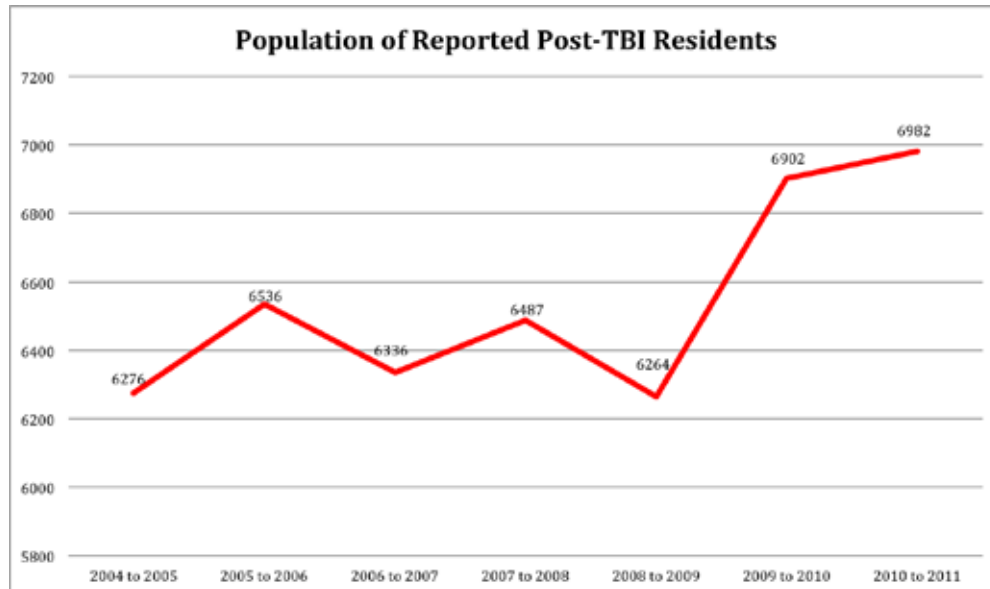
Based on research that recognized post-TBI patients having an increased risk of being involved in a road accident while driving (Bivona *et al.*, 2012) and post-TBI patient's that have had their ability or privilege to drive seized with correlations to lowered rates of employment, community integration and life satisfaction (Labbe *et al.*, 2014), it is of importance to create a more safe and accessible public transportation service in a city that experiences the highest rates of vehicle collisions in the country because Brampton relies heavily on private forms of transportation. The purpose of this research paper is to provide a spatial analysis to aid in better understand how accessible post-TBI patients residing in Brampton are to public transportation.

Head injury data was obtained by Dr. Eric Vaz, co-investigator of the project from the Canadian Institutes of Health Research (CIHR) grant "STAIRS TBI and Violence Project" with St. Michael's Hospital and partnered with the Ontario Ministry of Health. It includes the records of residence of all patients that have been hospitalized with reported trauma to the head. It is ordered annually throughout the years 2004 and 2011. This particular dataset has attributes that contain information indicating where the patient resides through the use of their postal code, as well as the patient's gender and if other injuries were sustained in conjunction with the head injury. This data is significant as it uses real life incidents that were conveyed and then organized to provide a spatial representation to be visualized with the use of GIS.

The data provided by St. Michael's Hospital is confidential and contains hundreds of thousands of reported cases of head injuries that have been registered within hospital databases across Canada. Narrowed down to the city of Brampton, there are over 6000 cases of head injuries being reported that happen every year with a total of  $n = 45,783$  that occurred throughout the seven years (Figure 1). The data utilizes problem codes that can be identified through the use of the International Statistical Classification of Diseases and Related Health Problems (ICD-10-CA). The ICD-10-CA is a descriptive catalog used to categorize diseases, injuries, and causes of death along with the external causes of injury and poisoning. It contains 23 chapters with alphanumeric categories and subcategories that are not limited to diseases but also risk factors to health such as occupational and environmental factors (Vaz *et al.*, 2015). The ICD-10-CA is used to organize the information pertaining to each patient's injury by having a main problem code, which is a TBI for the case of this paper,

that indicates the primary injury and additional problem codes that contribute in providing further detail relating to the injury. These problem codes contain useful information such as whether or not the injury occurred in an industrial or construction area, a place of trade, while engaged in sports or recreational activity, or if a vehicle was involved.

Figure 1. Post-TBI population in Brampton (2004-2011)



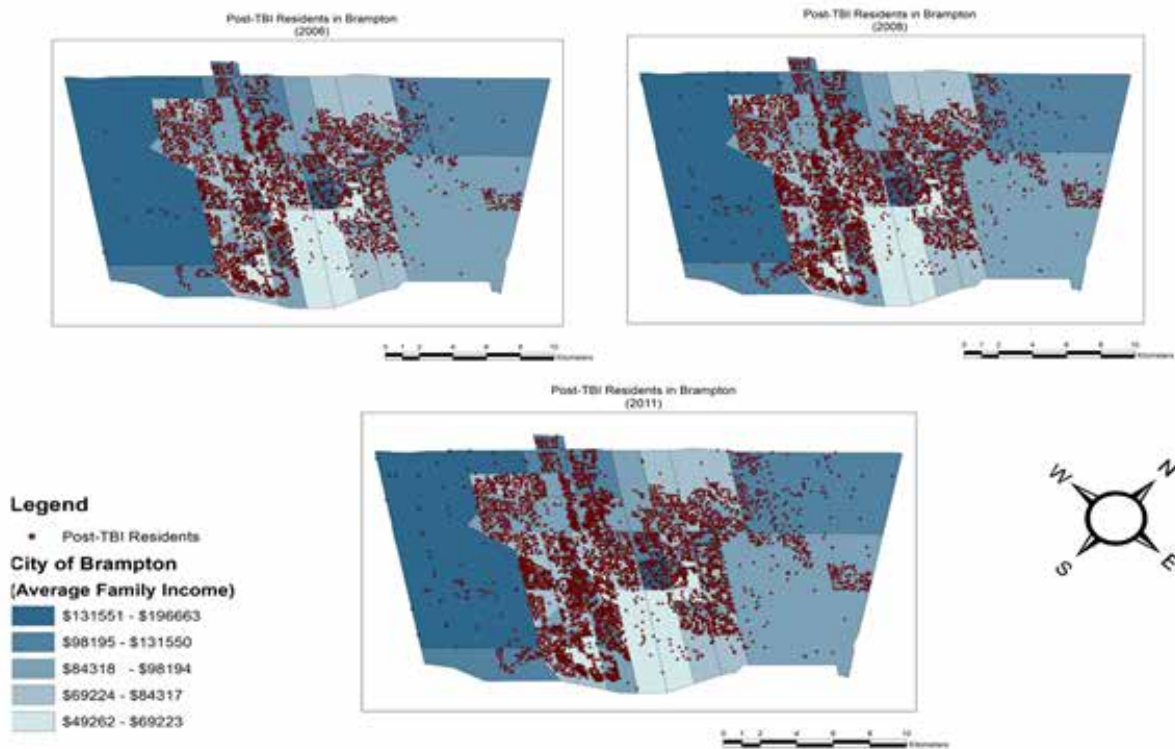
Source: Own Elaboration

Information pertaining to the public transportation system for the city of Brampton was retrieved directly from Brampton Transit's database along with additional data, which was extracted through the use of Overpass Turbo, a web-based data-mining tool for OpenStreetMap. The information provided by Brampton Transit contains records of each bus route and its traces that are displayed as lines within ArcMap. Brampton Transit also provided a list containing the location of all 2776 bus stops linked to Brampton Transit as well as the description of each stop indicating the street they are on and the bus route each stop belongs to.

Brampton Transit offers Züm, which is its Bus Rapid Transit (BRT) service that derived from the city's response to improved transportation options, as Brampton is the fourth fastest growing city in Canada.

Three separate maps were used to display the spatial locations of post-TBI residents recorded in 2004 between 2011 and how they are dispersed throughout the city of Brampton in 2006, 2008, and 2011 (Figure 2). This process was done by using a spatial join to add the attributes of the head trauma data to a map of Ontario. The clip feature was then used to isolate the city of Brampton from the map of Ontario and the post-TBI in that city as well. For further detail, census 2006 data was also added and was used as a choropleth to display the average family income for each census tract across Brampton.

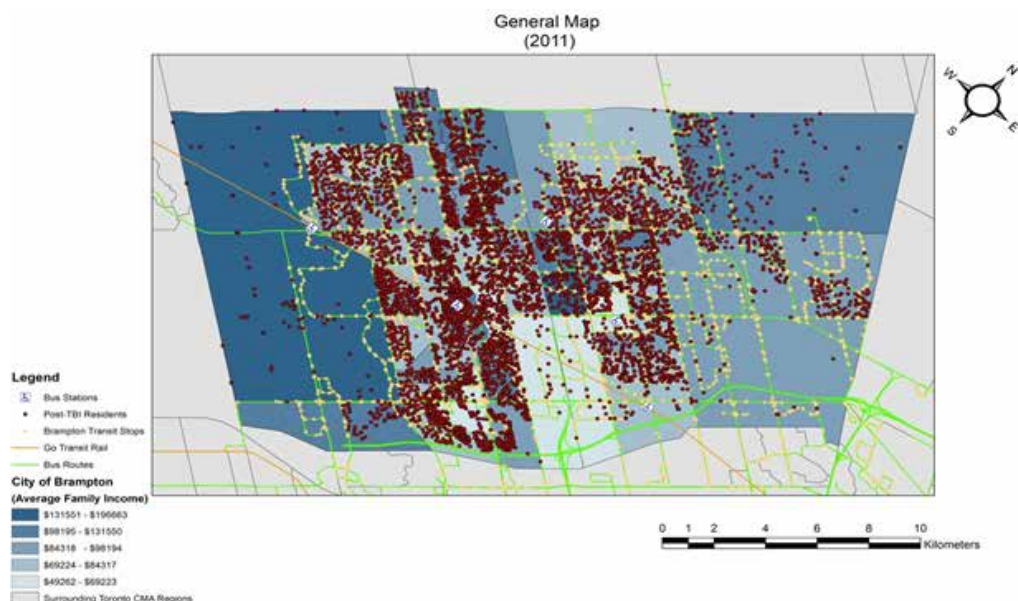
**Figure 2. Maps displaying the spatial distribution of post-TBI residents across Brampton in 2006, 2008 and 2011**



Source: Own Elaboration

In addition to Figure 1, public transportation data obtained from OpenStreetMaps through the use of Overpass Turbo along with the data attained from Brampton Transit’s database provided the opportunity to add route traces and its respective bus stop locations to the map. Figure 3 offers a direct visualization to present an idea of where the post-TBI residents are located in relation to the route traces, bus stops, bus stations and the average family income of each census tract.

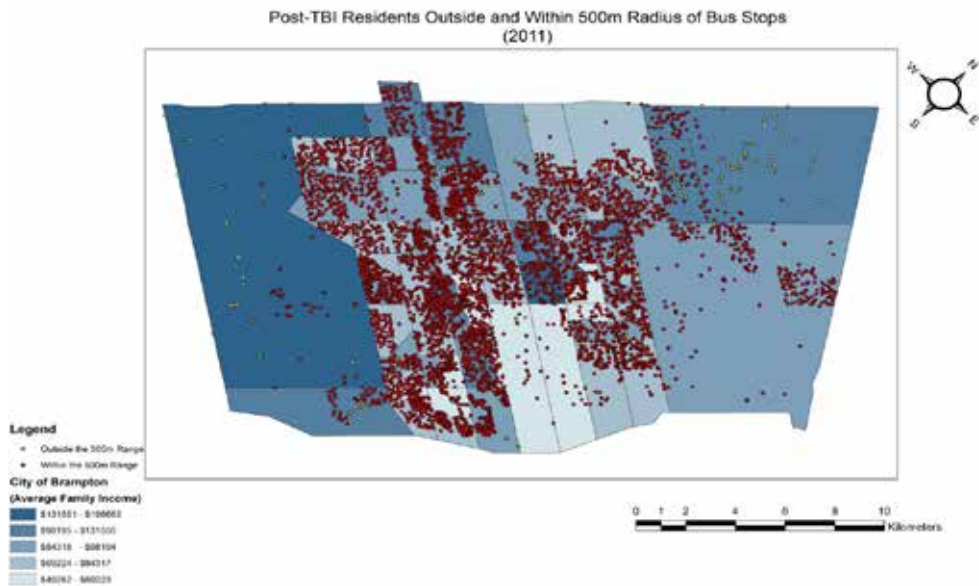
**Figure 3. Post-TBI residents in Brampton displayed with bus routes, bus stops/stations and average family income**



Source: Own Elaboration

People with disabilities have difficulties walking long distances. UK guidelines suggest that stops should ideally be placed so that no one should have to walk more than 400m along a route to reach a bus stop near amenities (International Best Practice in Accessible Public Transportation for Persons with Disabilities, 2010). To identify which post-TBI patients were in an optimum range to be considered either accessible or least accessible a radius of 500m from each bus stop was chosen. An extra 100m was used to keep minor detours into account such as a need to cross the road at a stop light or to walk around a fence. Also, the points displaying the positions of post-TBI residents are based on postal codes and this can result in there being a difference of a few meters from the actual location of their home. A map was created to deduce the population of post-TBI residents to show those that fall within and outside a 500m radius of bus stop locations (Figure 4). This was done by using the buffer tool set at 500m for each bus stop and then the clip tool to filter the selected post-TBI residents within the 500m radiuses.

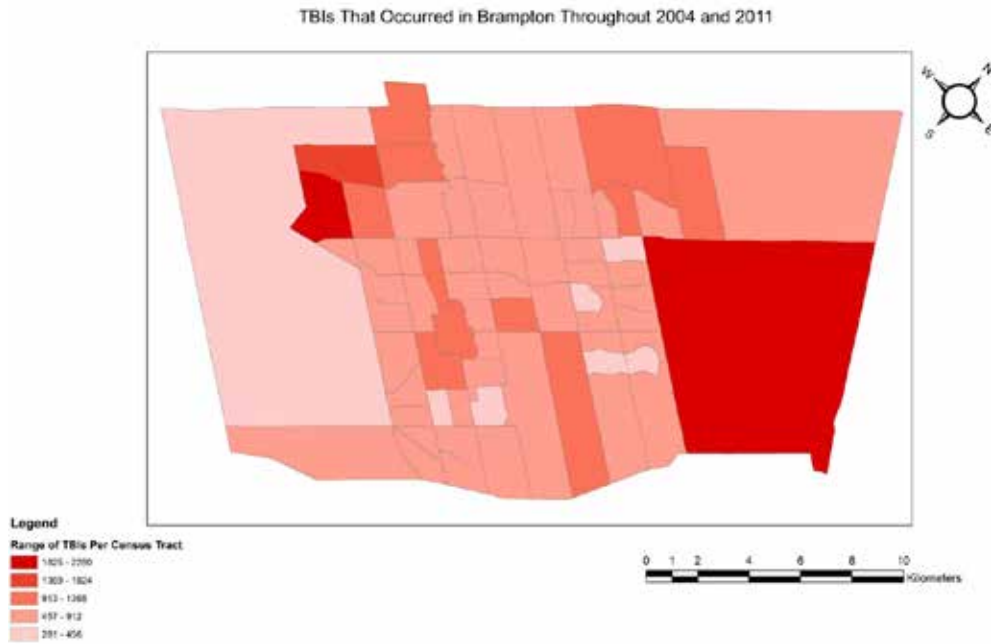
Figure 4. Map displaying post-TBI residents within and outside 500m radiuses of bus stops



Source: Own Elaboration

Since there can be multiple post-TBI residents belonging to a single postal code and the map can only show one point per postal code, a choropleth map was used with the purpose of revealing the density of post-TBI residents that had been reported between 2004 and 2011 dwelling within each census tract (Figure 5). The lowest population of post-TBI residents residing in a census tract is 281 and the highest is 2280. The values were classified using an equal distribution of 20% per colour gradient.

Figure 5. Choropleth map showing clusters of post-TBI residents in Brampton



Source: Own Elaboration

## 4. DISCUSSION

### 4.1 Population

This research paper highlights the occurrences of residents that have been reported to sustain a TBI dwelling in Brampton. Using the locations of post-TBI residents in Brampton and bus stops, accessibility to public transportation among post-TBI residents could be assessed. As the fourth fastest growing city in Canada, the populations of those that have experienced a TBI are increasing as well (Figure 1). Brampton held the highest growth rate between 2006 and 2011 among Canada's largest 20 cities in 2011. This has been consistent since 1981 and has been so at a higher rate than the Toronto Census Metropolitan Area (CMA) (Statistics Canada, 2011). As more housing became available to support the increasing population of Brampton, the reported locations of where those that experienced a TBI began to expand further from the centre of the city and more to the northern and western parts of the city from 2006 and 2011 (Figure 2). The clusters of post-TBI residents are located in the northwestern area, city centre, as well as the north and southeastern areas of Brampton (Figure 5). Brampton is notorious for its high vehicle insurance cost as collisions are most frequent among residents within this city (680 News, 2010). With knowledge obtained from a study that identifies the higher relative risk for drivers that have experienced a TBI to be 2.3 times more likely to be involved in a collision while driving than those who have never suffered a TBI (Bivona *et al.*, 2012).

### 4.2 Accessibility

Using GIS to display the locations of patients that had experienced a TBI was effective in getting an idea to determine how accessible public transportation was to them within the city of Brampton. The suggested walking distance to a bus stop is 400m based on UK public transportation planning guidelines (International Best Practice in Accessible Public Transportation for Persons with Disabilities, 2010) and keeping in mind both the occurrences of obstacles such as a fence or road intersection not allowing for a direct path as locations



based on postal codes can vary a few meters from the point placed on the map. The extra 100m was added to create a 500m buffer of post-TBI patients within a 500m radius of bus stops. This provided the result of there being 45,198 reported post-TBI residents that are well within the 500m walking distance of a bus stop and 585 reported post-TBI residents that are not. 99% of post-TBI residents have access to public transportation and many of them are dwelling in a census tract with an average household income of \$69,224 or more. The 1 percent that is not within the 500m radiuses of bus stops is located mostly to the western and northern parts of Brampton. Those that are among the 1 percent outside of the 500m radiuses of bus stops that are located in the city centre are still fairly close and fall just outside of the radius. Many of the post-TBI residents among the 1% that fall outside of the 500m radiuses of bus stops reside in a census tract that has a family income earning \$84,318, or above.

## 5. CONCLUSION

There are limitations associated with the data that has been used in this research. Because the data retrieved from St. Michael's database is confidential, personal information regarding the patient's age, marital status, education, and whether they were currently licensed to drive in Ontario at the time of the injury are unavailable. Furthermore, the severity of their injury is not disclosed so the condition of the patient could be much better or worse from when the injury was reported. This resulted in every reported patient that experienced a TBI to be treated the same, regardless of the severity of the TBI and whether it resulted in a permanent disability or not. Each reported TBI patient is considered to have further difficulty coping with rehabilitating themselves back into society as they were pre-injury and are also considered an increased risk while driving post-TBI relative to other drivers that have not sustained a TBI. In addition, public transportation data is as of 2015 and the reported TBI residents were recorded from 2004 to 2011. A possibility of them relocating when this research paper was constructed is present but still does not negate the implementation of a more accessible public transportation system.

In conclusion, 99% of reported post-TBI residents residing in Brampton are within the 500m walking distance of a bus stop that provides access to public transportation system that can take them to many key locations in the city. In theory, creating a more reliable, accessible public transportation system would be able to provide a much more safe and convenient alternative for post-TBI residents as well as current and future citizens living in Brampton to travel and avoid driving. This would allow for those who suffer from symptoms of post-TBI to assimilate themselves back into society in a safe and effective way that also reduces congestion and decreases the increased risk of a collision, as they are not driving with impairments.

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