Pedestrian Monitoring:
A Standardized Approach for Continuous Count Location Selection in Highly Urbanized Environments

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Abstract

In the wake of the increasing number of North American jurisdictions moving to prioritize active modes of travel, research into traffic data collection has progressed beyond its infancy to a point where cities have begun network wide active transportation monitoring programs. This trend motivated by shifting societal values towards environmental sustainability, public health, and urban vibrancy; requires accurate and accessible data to best inform investment decisions and network improvements. Most data collection of this variety has been conducted in an ad-hoc manner on multi-use paths or simple sidewalk networks and often as a supplement to existing motorized traffic monitoring. This research looks to contribute to the development of a standardized approach for transportation authorities to strategically implement long term active transportation traffic monitoring programs in highly urbanized areas which are prone to the effects of large scale special events. This is achieved by developing a new way to characterize pedestrian traffic in highly urbanized areas that host large scale events. Characterization of pedestrian traffic enables the development of traffic pattern groups that aide jurisdictions in designing a continuous monitoring program that effectively deploys continuous count equipment.

Keywords: *Pedestrian, Traffic Monitoring, Special Events, Active Transportation*

Introduction

In the wake of the increasing number of North American jurisdictions moving to prioritize active modes of travel, research into traffic data collection has progressed beyond its infancy to a point where cities have begun network wide active transportation monitoring programs. This trend, motivated by shifting societal values towards environmental sustainability, public health, and urban vibrancy requires accurate and accessible data to best inform investment decisions and network improvements. Most data collection of this variety has been conducted in one of three ways: (1) short duration manual counts as performed by local cycling and walking organizations, (2) longer duration automated counts performed for academic research, or (3) jurisdictionally motivated ad-hoc inclusion of walking and cycling modes as a part of existing motorized traffic monitoring efforts. This research looks to contribute to the development of a standardized approach for urban transportation authorities to strategically implement long term active transportation traffic monitoring programs. This is achieved by developing a new way to characterize pedestrian traffic in highly urbanized areas that host large scale events. Characterization of pedestrian traffic enables the development of traffic pattern groups that aide jurisdictions in designing a continuous monitoring program that effectively deploys continuous count equipment.

Within the field of traffic monitoring, active modes of travel can be categorized in two ways. The first is based on travel mode, while the second looks at the network individuals travel on. Cyclists and pedestrians both commonly travel on multi-use paths, however in more densified urban networks, cyclists are required to share the road with motorized traffic while pedestrians are restricted to use the sidewalk network. The vast majority of active transportation traffic monitoring to date has been focused on pedestrians and cyclists on multi-use paths due to the relative simplicity of analysis. Given an established foundation for traffic monitoring on paths, more urbanized and complex networks are the next logical step for this field of research. This research specifically will highlight a methodology for assessing pedestrian traffic in highly urbanized environments.

Following the precedent set by motorized traffic monitoring programs, the most effective procedure to estimate network wide average annual traffic statistics is through a modest number of permanently installed automated counters supplemented by a large number of rotating short duration counts. Continuous counts placed at a few strategic locations can be used to assess temporal traffic variation, while short duration counts can serve as a snapshot to understand spatial variation across a network. When used together, the spatially diverse traffic data collected through short term counts may then be expanded by known temporal traffic variation of similarly behaving continuous count locations. In this way, the average annual pedestrian traffic may be estimated wherever these short duration counts are taken.

In 2015, the City of Winnipeg, in partnership with the University of Manitoba, set out to develop its own pedestrian traffic monitoring program in the city's downtown area beginning with the selection of eight continuous count locations. Throughout this process, it became apparent that pedestrian movement in Winnipeg's central business district is dictated by two concurrent patterns: (1) A temporally recurring pattern dominated by commuter work schedules and (2) a non-recurring traffic pattern subject to special events hosted at Winnipeg's downtown arena. This research documents the method used in Winnipeg as an illustrative example to recommend a standard approach to selecting continuous pedestrian count locations in highly urbanized networks amidst the frequent influence of non-recurring special events.

Literature Review

Compared to motorized traffic monitoring in North America, the development of a standardized approach to a pedestrian traffic monitoring program is relatively novel. Much of the research performed to date has focused on automated sensor performance, where and how long to conduct pedestrian counts, and traffic variation on multi-use paths. Recently however, the National Cooperative Highway Research Program, Federal Highway Administration, and Transportation Association of Canada each published guidance on developing system-wide non-motorized traffic monitoring programs. These documents have combined existing literature to summarize and propose a method for jurisdictions to begin collecting pedestrian and cyclist traffic data. The three documents, NCHRP Report 797 (Ryus, et al. 2014), the Traffic Monitoring Guide (FHWA 2013), and Traffic Monitoring Practices Guide (Regehr, Poapst, Rempel, & Montufar, 2016) were relied on to develop an initial framework for selecting continuous count locations. Additionally, previous research on the topic of non-motorized site selection methodology was used to inform the placement of continuous count stations in the City of Winnipeg (Jackson, Stolz and Cunningham 2014).

As outlined by the Transportation Association of Canada (TAC), the ability to produce system-wide estimates of traffic statistics is the ultimate goal of any traffic monitoring program which begins with the definition of traffic pattern groups. In the context of non-motorized traffic, the “system” is often limited to specific regions (e.g. a central business district) due to limited resources while the traffic pattern group (TPG) is determined via sampling various locations in the network using short duration counts. By analyzing the behaviour of spatially diverse short duration counts throughout the system, emerging similarities in terms of hourly, weekly, and monthly variation can be used to categorize them. Further to this clustering approach, local knowledge and land use characteristics can be used to contribute an additional degree of pragmatism to the statistically determined categories (Regehr, Poapst, Rempel, & Montufar, 2016).

Following the determination of traffic pattern groups, the process for implementing a system-wide traffic monitoring program includes determining the number and location of continuous count sites, assignment of these sites to appropriate traffic pattern groups, and finally creating a short duration count program with specific locations, frequencies, and durations. As system-wide statistics are based on the program’s defined TPGs, the ability to leverage short duration count data is fundamentally dictated by the precision of these groups.

The selection of continuous count locations in urban environments has been done in a number of jurisdictions in the past. This research looks to extend the understanding of this field in two ways; first towards monitoring pedestrians in dense urban environments, and second, to quantify the influence of frequently occurring, large special events in these environments. The purpose of this is to better define traffic pattern groups which ultimately will lead to improved system wide monitoring programs. An analytical approach used to do this was the selective analysis of specific time periods throughout the study. This was modelled after Luis Miranda-Moreno’s weekend to weekday index (WWI) and morning to midday index (AMI) (Miranda-Moreno, et al. 2013). Illustrated below are Eqn. 1 and Eqn. 2.

Eqn. 1

$$AMI = \frac{V_{am}}{V_{mid}}$$

Where:
$v_{am} = mean\ morning\ peak\ (7am - 9am)\ traffic\ volume$
$v_{mid} = mean\ midday\ peak\ (11am - 1pm)\ traffic\ volume$

Eqn. 2

$$WWI = \frac{V_{we}}{V_{wd}}$$

Where:
$V_{wd} = mean\ daily\ weekeday\ traffic$
$V_{we} = mean\ daily\ weekend\ traffic$

Both the AMI and WWI are used to identify sites which are primarily recreational, mixed recreational, utilitarian or mixed-utilitarian in nature. For example, sites with a low WWI and high AMI would indicate utilitarian use, as they exhibit greater traffic on weekdays and in the morning commuting period as opposed to midday use on weekends. In using this approach, specific locations within the network can be described and grouped based on directed sampling of specific time intervals.

A gap in current research is the influence which frequently occurring special events have on pedestrian activity. Often falling outside the scope of research, it is commonplace to characterize special events as non-recurring variation which is then omitted from short-duration counts, along with construction schedules, extreme weather, and roadway/sidewalk blockages. While this is often appropriate in many circumstances, especially when these events are infrequent, it is currently unclear as to how frequent a non-recurring event must occur before it is explicitly considered in a traffic monitoring program. These non-recurring events are omitted from short duration counts because traditional aggregated factoring methods represent average conditions. However, day-of-year scaling factors, can be used to address this as there is no averaging involved, just reference to the TPG's proportion of annual traffic volumes during the short duration count interval.

In the case of metropolitan downtown areas, many of which are frequent host to large scale special events such as professional sporting games or concerts, a better understanding of their impact should be provided in planning for the safe and efficient accommodation of all road users. Traffic conditions surrounding special events in particular are of importance as these are often the cases where the network's capacity is truly tested. Additionally, incorporating special event traffic benefits help traffic operations and planning tasks by informing design statistics such as the peak hour factor or 100th highest hour measures.

Methodology

To reiterate, this research attempts first to analyze the recurring trends which characterize pedestrian activity in downtown Winnipeg, whose variation is function of schedule, and also to evaluate non-recurring variation due to the influence of special events hosted within the study area. The results of these two objectives will be used for selecting continuous count locations in an ongoing pedestrian traffic monitoring program.

The study area (Figure 1) is characterized by a high density of office and commercial buildings as well as a large event-hosting arena. This arena has a capacity of 15,000 and holds events frequently throughout the year. In order to strategically select continuous count locations, a 16 week short duration count rotation was performed to provide insight into current pedestrian activity across Winnipeg's central business district. Using eight passive infrared automated pedestrian counters, short duration counts consisting of at least seven days of continuous data collection was conducted at 45 unique locations spatially distributed throughout the study area. The selection of these short-duration counts was made to approximately sample east-west running sidewalks equally with those running in the north-south direction. Also considered was the installation suitability of specific sidewalk locations. The suitability was dependent on the availability of existing street-side poles or trees to mount the sensor as well as the presence of a non-reflective surface across from where the sensor would be mounted. This procedure was conducted from July to September and resulted in 635, 24-hour pedestrian counts.

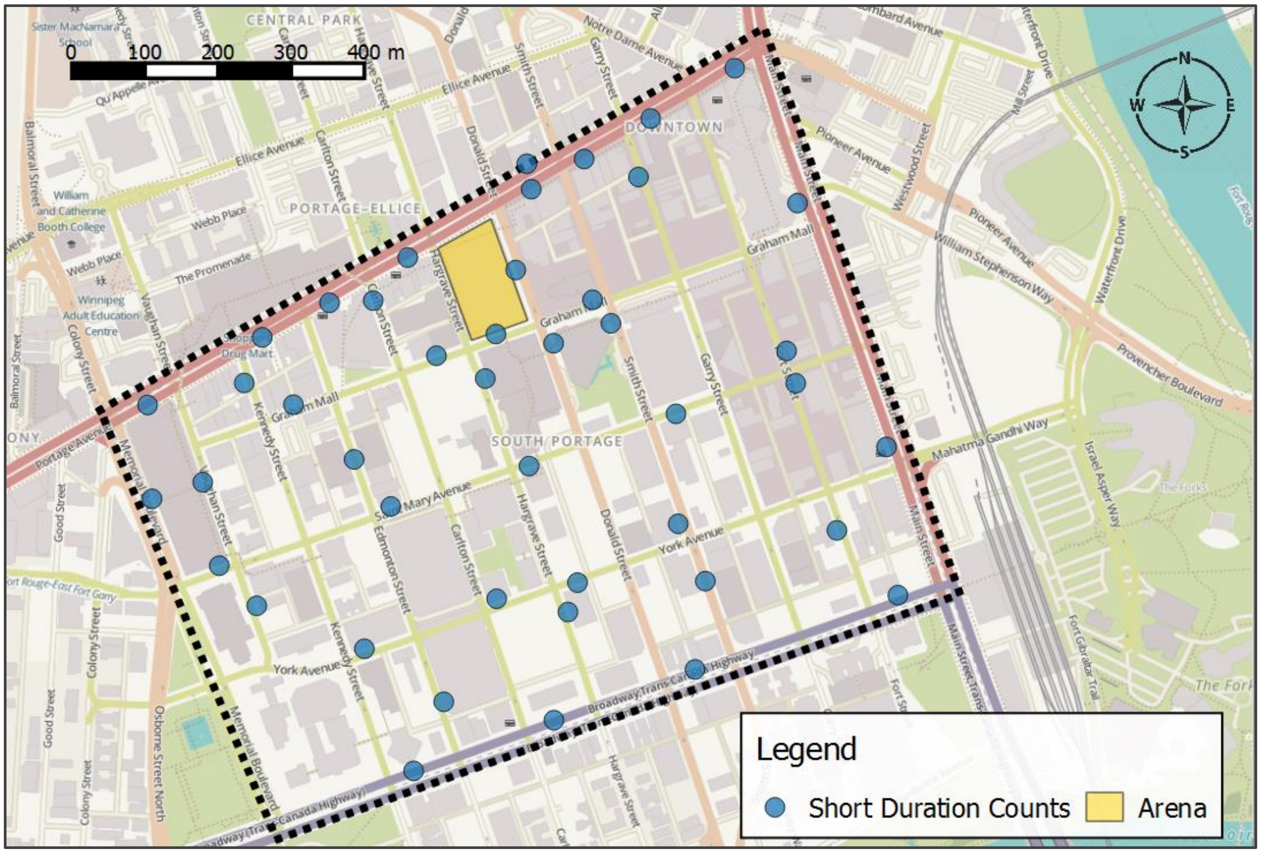

Figure 1: Winnipeg Central Business District and Short Duration Count Locations

In order to produce the most accurate dataset possible, it was important to identify potential sources of error and conduct appropriate quality control measures to ensure validity in the analysis. Four potential sources of error were identified which were dealt with throughout the short duration count rotation as well as in the quality control process. These sources of error included large over counts due to loitering pedestrians, undercounts due to sensor blockages, missing data due to a sensor failure, or low counts due to construction and sidewalk closure. In order to mitigate the effects of using data influenced by any of these factors, a number of automated flagging methods were used to highlight suspicious values in the data set. The purpose of the flagging procedure was not to eliminate values but rather to reduce the amount of manual effort needed to review the data set. Once a value had been flagged, it was then inspected manually to determine whether or not to keep the data.

The quality control codes used are highlighted in Table 1 below. The standard thresholds identified were used in an effort to highlight approximately 5% of the data for each short duration count, greatly reducing the amount of manual review required. Due to varying pedestrian activity at each location, these thresholds occasionally were adjusted to flag an appropriate amount of data for review.

Table 1: Automated Quality Control Flags

#	Flag Name	Description	Standard Threshold for Flag
1	Consecutive Zeros	If a specified number of zero counts are observed, that hourly volume is flagged	3
2	Consecutive Count	If a specified consecutive hourly bin report the same volume data, the last hour is flagged	3
3	Average Hourly	If an hourly volume is a specified proportion greater or lesser than the average hourly weekend or average hourly weekday volume at that location, the hour is flagged	70%
4	Preceding Count	If an hourly volume is greater than a specified proportion of the previous hour's volume, that hour is flagged	70%

Finally, using a similar procedure as in previous research (Aultman-Hall, Lane and Lambert 2009), days with total precipitation over 10 mm were removed from the data set as wet weather has been observed to significantly reduce pedestrian traffic. It was the goal of each short duration count to include at least each weekday and weekend day without precipitation. If precipitation occurred during the short duration count, the automated sensors would be left installed until each day of the week was represented within that count period.

The resulting data from this short duration pedestrian count rotation included 45 unique count locations which collected traffic volumes over 89 days resulting in 15,240 hours of recorded pedestrian volumes. This data set, once cleaned for erroneous data was used in the analysis to describe recurring and non-recurring trends in this research's study area.

Analysis

The process of determining an appropriate metric for characterizing pedestrian activity in Winnipeg's central business district was in part based on previous research in this field, while also incorporating aspects specific to the anticipated special event influence on pedestrian traffic. The method used for describing the effects of both recurring and non-recurring traffic variation was based heavily on the weekend to weekday index (WWI) and the morning to midday peak index (AMI).

These two indices look at the ratio of non-motorized traffic volumes over different time intervals to first categorize a site as utilitarian, mixed utilitarian, mixed recreational, or recreational and then to determine the degree to which it is influenced by special events. The main principles taken from these indices is that a comparison of select daily traffic volumes can be used to describe the weekly trends of a count location, while select hourly volumes can be used to describe the daily trends. The WWI and AMI as described above were used as a starting point for classifying the recurring pedestrian activity for each count location within the study area.

Site Classification

The initial attempt to characterize the short duration counts performed in the study area based on the WWI and AMI proved to be problematic. Using traditional factoring methods, non-recurring traffic levels due to special events are omitted from short-duration count data in an effort to report typical volumes. If this approach was used, the frequency of special events at the arena would require many days of traffic to be omitted from the analysis while looking to describe a typical day or week of pedestrian activity. Since it was observed that a vast majority special events hosted at the arena within the study period occurred after 7:00 PM, the weekday to weekend index calculation of this analysis was made to only consider traffic volumes which occur between the hours of 6:00 AM and 6:00 PM. By truncating the data in this way, every day of data could be used since the influence of special events was eliminated. Otherwise these hours of traffic would have produced high levels of variation when trying to derive predictable trends across the study area.

Volumes from Tuesdays through Thursdays were used to calculate the average weekday volume while Saturdays and Sundays to determine average weekend volumes. As mentioned above, the daily volumes were only calculated between 6:00 AM and 6:00 PM to exclude large scale special events which are often hosted in the evenings within the study area. This allowed our analysis to determine a WWI for more sites than if entire days were omitted for landing on a special event date. Omitting Mondays and Fridays also enabled the analysis to remove holidays which occurred during the study period. Hourly volumes used to calculate the AMI were selected to analyze hourly traffic variation as these already only use traffic volumes between 7:00 AM-9:00 AM and 11:00 AM - 1:00 PM.

The intent on applying the WWI and AMI to each site within the study area is to determine whether all count locations behave similarly over a typical daily and weekly timeframe. If this is the case, further categorization of the central business district can be made based on special event trends which may be used to select permanent count locations.

A WWI value greater than one is typical of sites which are commuter based, while sites with a WWI less than one would normally describe count sites with recreational use patterns. The AMI on the other hand compares peak periods within a typical day, looking at the morning commute peak compared to a lunchtime peak. An AMI greater than one is typical of utilitarian use, while values less than one indicates high traffic levels during the middle of the day, which is typical of recreational sites.

Following the analysis approach outlined above, the WWI and AMI were calculated for each specific short duration count. Figure 2 below depicts these values of across the study area related to each individual short duration count ID.

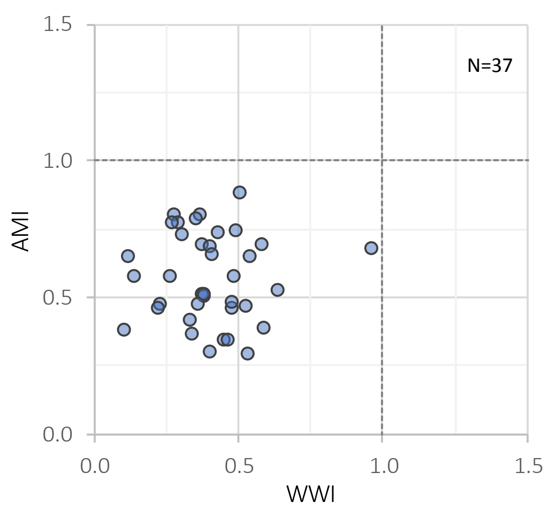

Figure 2: AMI vs. WWI of Short Duration Counts

As seen in Figure 2, the AMI of all short duration counts fall below 1.0 while the WWI is below 0.75 at all but one location. Referencing the classification of count sites proposed by Miranda-Moreno, none of the sites fall neatly into a defined category of utilitarian or recreational. From manual observations of traffic throughout the study area as well as visual inspection of daily and weekly volumes, it was noted that activity during the morning peak is relatively high as people are going to work downtown. While this would normally lead to a utilitarian classification, a very large lunchtime peak is also observed which normally reduced the value of the AMI calculation to below one. From these observations, it can be seen that during the morning peak period, these locations all exhibit utilitarian patterns, but the existence of an office-type work schedule also produces a significant peak over the noon hour. Additionally, a relatively low amount of pedestrians are observed on weekends as compared to weekdays. For our procedure, we will classify all sites as exhibiting an "urban-utilitarian" traffic pattern where the AMI is less than 1.0 and the WWI is less than 0.75.

The Evening Proportion Ratio

An investigation was performed to confirm whether sites behave differently within the study area during evening hours due to special events hosted at the downtown arena. This was done for all sites in the study area in the same way as each site has been determined to behave according to the urban-utilitarian traffic pattern during daytime hours. To categorize sites based on event influence, a second metric was derived for this analysis called the "Evening Proportion Ratio" (EPR). This metric considers only hours of day from 6:00 PM to 11:59 PM of each day for each counter. This window allows for evening traffic to be compared between days which have scheduled events at the arena, and those which do not. An illustration in the difference between sites which were highly and moderately affected by special events hosted at the arena is shown in **Error! Reference source not found.** below.

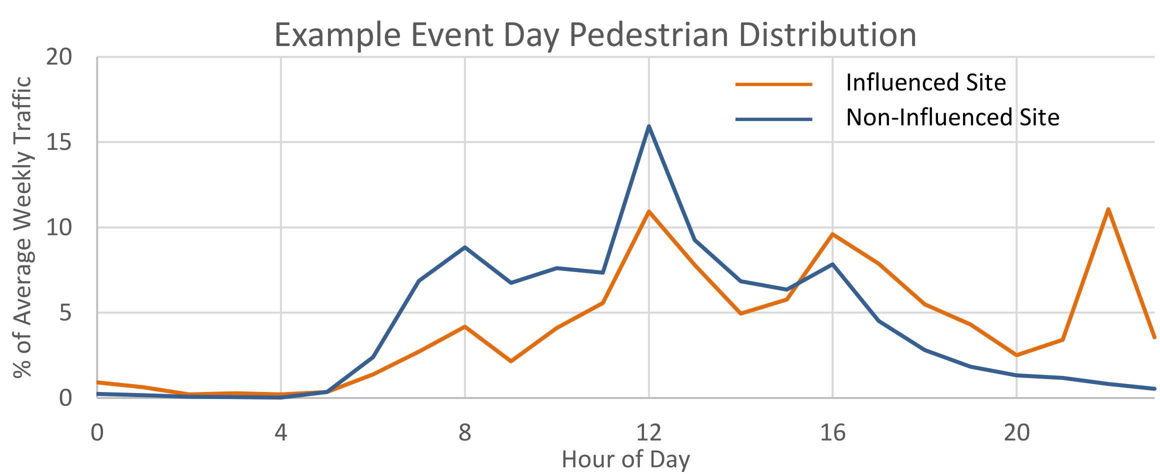

Figure 3: Typical Event Day - Sites Influenced vs. Non-Influenced by Events

Arriving at the evening proportion ratio to quantify these observed trends requires several steps. First, the total evening pedestrian volume (6:00 PM – 11:59 PM) is divided by the total daily volume. This produces the proportion of that day's volume that occurs during the evening period. This proportion is expressed as an evening's percentage of daily pedestrian traffic which is referred to as the evening proportion index (EPI). By dividing the average EPI of event days by the average EPI of non-event days for each counter, the influence of special events occurring at the arena can be evaluated. This value is referred to as the Evening Proportion Ratio is shown below.

Eqn. 3

$$\overline{EPI} = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=18}^{24} \%DailyVolume_{ij}$$

Eqn. 4

$$EPR = \frac{\overline{EPI}_{event}}{\overline{EPI}_{non-event}}$$

EPI_{event}	=	$EPI\ calculated\ on\ event\ days$
$EPI_{non-event}$	=	$EPI\ calculated\ on\ non\ event\ days$
n	=	$number\ of\ days\ in\ shord\ duration\ count$
i	=	$day\ in\ the\ counter\ duration$
j	=	$hour\ of\ day$
$\%DailyVolume_{ij}$	=	$j^{th}\ hourly\ proportion\ of\ daily\ traffic\ on\ the\ i^{th}\ day\ of\ the\ count$

The value resulting from the EPR calculation for each short duration count is an indication of the degree to which that location is influenced by special events hosted at the arena. If the value of the EPR is equal to one, it means that a specific site does not experience higher evening traffic volumes coinciding with special events. As the EPR value increases above one, it corresponds with a greater level of pedestrian traffic increase on the evenings where special events are hosted at the arena.

With the evening proportion ratio, it is possible to assess the degree to which each short duration count site was influenced by events occurring t the downtown arena. For this to be true, it would be expected that there is a significant correlation between distance from the arena and the EPR value. Once this correlation is assessed and the influence of events is mapped, the study area can be separated into different zones which exhibit varying degrees of event influence. Based on the emerging trends within the study area, the central business district could then be categorized into different traffic pattern groups, each receiving an equal number of continuous counters in the future.

Results

Due to similarly behaving count sites during daytime hours (AMI analysis) and weekly trends (WWI analysis), each site can be classified as urban-utilitarian. From here, the interpretation of our results can move towards how daily traffic patterns respond to special events. To do this, the evening proportion ratio (EPR) was calculated based on the data from each short duration count. Figure 4 below illustrates the relationship between the evening proportion ratio calculation and each count site's direct distance from the arena. It is the intent that from this calculation, the study area will be able to be categorized into different groups of varying levels of influence for the installation of continuous counters.

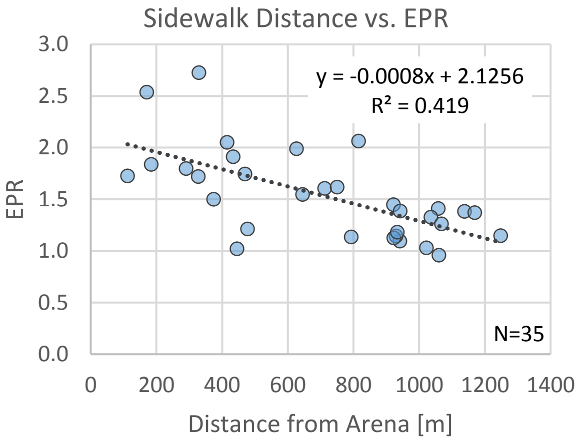

Figure 4: EPR vs. Distance from Event Centre

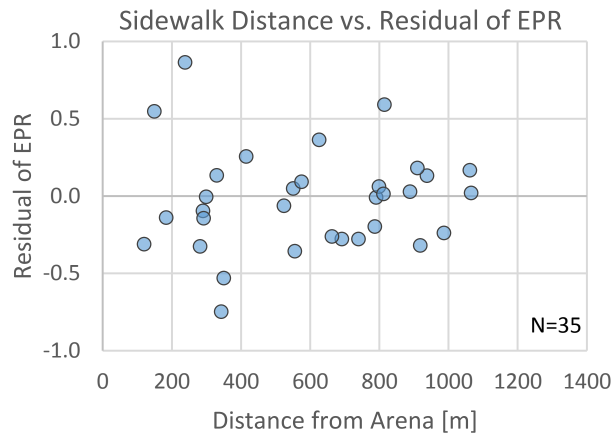

Figure 5: Residual of EPR vs. Distance from Event Centre

Based on the results illustrated in Figure 4, there is a negative relationship between distance and event influence with a moderate correlation value of $R^2 = 0.419$. Given that the points of the residual plot (Figure 5) are randomly dispersed about the horizontal axis, it can be concluded this relationship is approximately linear.

To visualize this relationship spatially, Figure 6 shows a summary map of the evening proportion ratio calculated from each short duration count across the study area. Orange symbols indicate that the EPR value at that location exceeds 1.5 which designate sites as being highly influenced by events occurring at the arena. Values of the EPR for this analysis fell between value of 0.81 and 2.7 indicating a wide variation in the degree to which locations are influenced by special events.

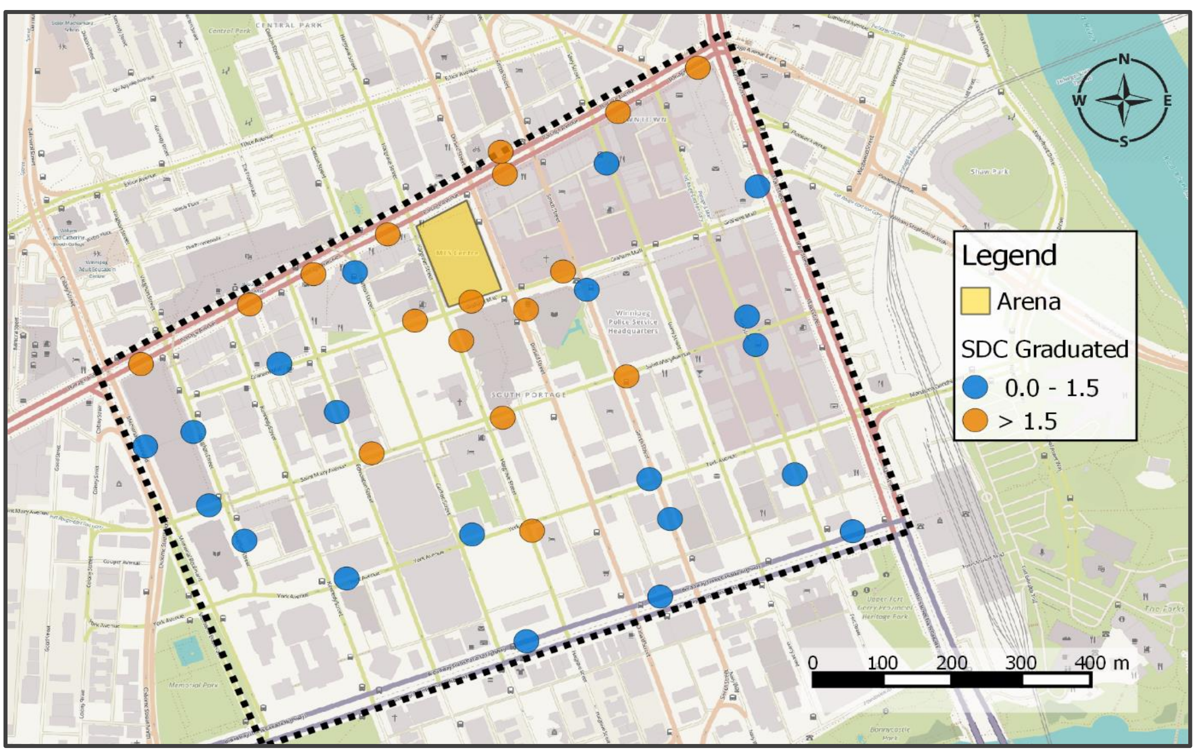

Figure 6: Evening Proportion Ratio for Short Duration Counts

In analyzing Figure 6, it can be observed that there is a concentration of highly influenced counters around the arena and along the north border of the study area. Also, as distance from the arena increases, sites become less influenced by special events. Using the results from the determination of the WWI, AMI, and EPR of each short duration count location, the study area could be categorized into two separate groups into which continuous count locations could be selected.

Discussion

The practical application of this research was to recommend continuous count locations within the study area for the City of Winnipeg. These continuous counts would serve as reference for average annual daily pedestrian (AADP) expansion for periodic short duration counts performed throughout the study area. Previous research performed indicates that at least three continuous counts are required per traffic pattern group for non-motorized traffic to accurately determine AADP (Jackson, Stolz and Cunningham 2014). Given distinct high and moderate event influence zones, two traffic pattern groups were defined spatially each of which was assigned four continuous counters.

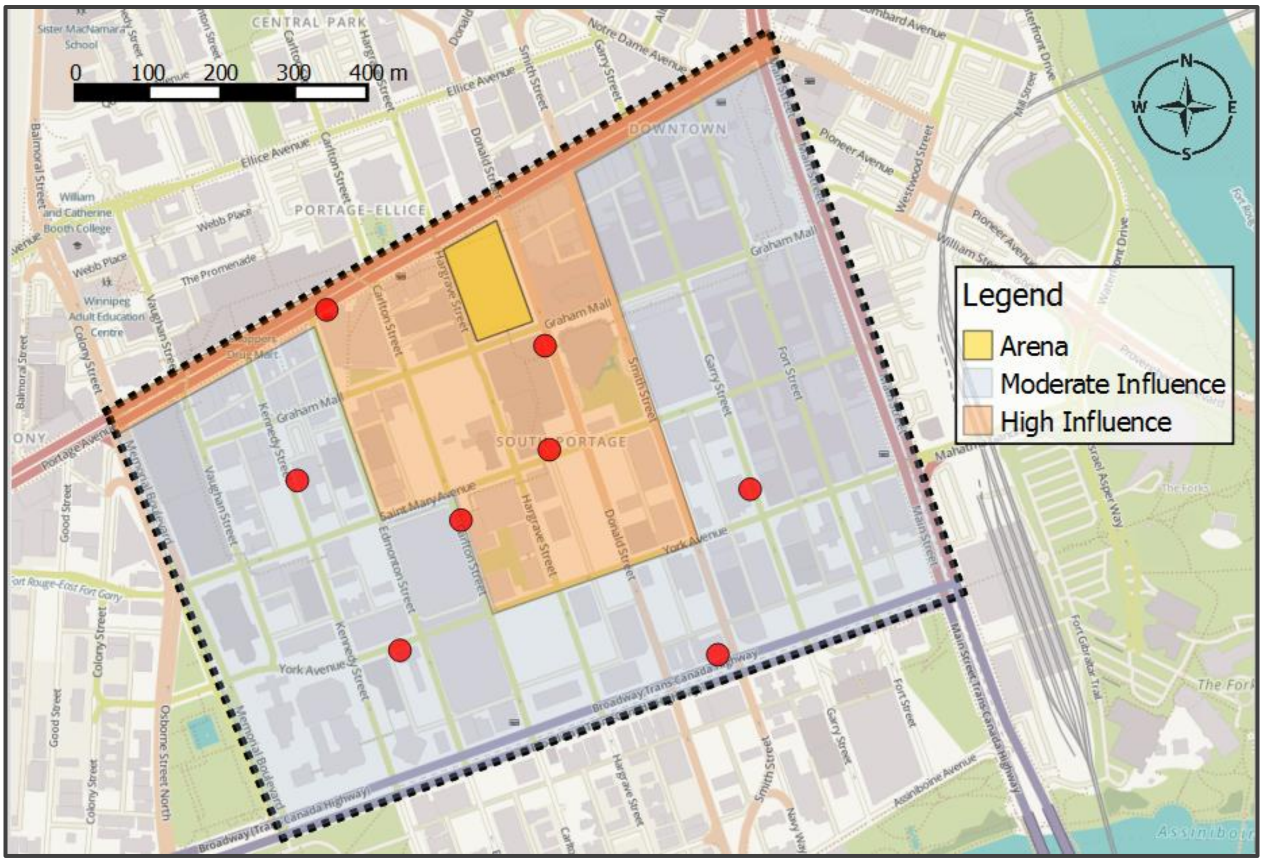

Figure 7: Event Influence Zones with Continuous Count Locations

Figure 7 illustrates two proposed zones within the study area; one considered to be highly influenced by special events hosted at the arena and one which is moderately influenced. Within each area, four continuous counting devices were installed on randomly assigned sidewalks. These sites were randomly assigned while considering installation availability (presence of a mounting pole, non-reflective detection zone).

Since installation, the eight continuous counters have collected over a year's worth of pedestrian volumes. The City of Winnipeg's development of a pedestrian monitoring program which expands short duration counts is ongoing. Once a short duration count schedule is developed, this research recommends all counts within the "highly influenced" zone be expanded by continuous counts within that zone, while all other short duration counts be expanded by annual volumes of continuous sites from the "moderately influenced" zone.

Conclusions

The documentation of this procedure looks to illustrate how continuous counters within a pedestrian traffic monitoring program may be selected in highly urbanized environments. While the fundamental approach is similar to other types of networks, this work builds upon existing research in its method of addressing frequently occurring large scale special events. By employing a short duration count rotation throughout the study area, an initial understanding of recurring patterns could be developed, and count sites characterized. Once a similarity of behaviour between sites was established, the sites were further described by their variation due to events hosted at the downtown arena using the evening proportion ratio.

From this analysis, it was determined that day time traffic at each site can be classified within the "urban-utilitarian" traffic pattern group which exhibit an AMI value less than 0.9 and a WWI value less than 1.0. Despite this single consistent classification, the study area was subdivided into two areas, one which was highly influenced by events at the downtown arena, and one which was only moderately influenced. Within each of these two areas, four automated pedestrian counters were installed to collected continuous data for a full year. These eight continuous count sites will serve as the framework for an ongoing pedestrian monitoring program, which is in development for the City of Winnipeg.

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