Pedestrian Tours in Different Urban Forms: Evidence from Smartphone Data

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Introduction

Municipalities and transportation professionals are eager to increase active transportation, which consists of cycling and walking, to reduce environmental impacts, promote public health, facilitate sustainable travel patterns, and enrich the travel alternatives within a multimodal transportation system (Cerin et al., 2007; Pucher et al., 2010). Investments and policies concentrating on pedestrian infrastructure and services have grown rapidly in past decades. In order to forecast the potential impacts of significant investments in or policies towards transportation, regional travel forecasting models estimate the travel demand based on the data collected from a current baseline. However, conventional travel forecasting models are inadequate in addressing active transportation because of the lack of empirical data and the inability to develop appropriate generalized cost functions. Moreover, walking behaviour is hard to predict due to its complexity.

Most travel forecasting models either eliminate walking trips from total trips or do not provide sophisticated estimations compared to mechanical trips (Clifton et al., 2016). Porter et al. (1999) claim that mainstream transportation models pay marginal attention to pedestrians. A more recent study summarized that while a growing number of MPOs included non-motorized modes into their regional travel demand analysis, inadequate zonal structure, data limitations and poor measurements of pedestrian-relevant environment and land-use attributes are major barriers to improve models' accuracy and sensitivity (Singleton & Clifton, 2013; Singleton et al., 2018).

From a data collection point of view, walking trips are underreported by conventional data collection methods such as landline-based phone interviews and paper-based surveys. The tendency to underreport results from a number of challenges. First, walking trips are normally short trips. The duration and distance of pedestrian trips are generally shorter compare to mechanically powered (auto, public transport) trips. Since conventional data collection methods rely heavily on participants' recall of their activities, most of the "short" trips are overlooked by participants (Safi et al., 2015). Second, traditional survey questions fail to capture the connectivity within trips. For example, a person who walked to a bus station, then took a bus to reach their workplace, often reports only a bus trip on the survey, while excluding the walking trip, even though the time duration of these two trips might be approximately the same. Hence, access and egress walking trips are often not captured.

More recently, new data collection methods such as using GPS portable devices have helped to overcome the challenges of gathering comprehensive data. But, the provision of unique GPS devices can be expensive for a regional scale travel data collection effort. However, the increased functionality of smartphones, including the widespread inclusion of GPS, presents an opportunity to gather pedestrians' travel patterns conveniently and cost-effectively. In Canada, the adoption of smartphones is vast. According to the Survey of Household Spending Statistics Canada 2017, the proportion of Canadians over 18 years old who own smartphones has increased from 62% in 2013 to 78% in 2017. To obtain a representative sample of the general population, the smartphone-based survey has become more effective than landline survey or mail survey.

To have a better understanding of travel patterns, the University of Waterloo has developed a smartphone application to passively record travel information generated by travellers (Nour, Casello, & Hellinga, 2015). The travel information consists of users' travel paths as GPS trajectories including location, speed, and time stamp. Through geographic information system (GIS) techniques, it is possible to identify travellers' OD(s), travel paths, and a preliminary assessment of the travel modes. In 2015, a household travel data collection sponsored by the City of Edmonton, in partnership with R.A. Malatest employed both an online survey and the smartphone application to gather travellers' activities with the ultimate goal of using these data to inform the local regional travel forecasting model. In that study, 1,177 participants responded to the self-reported online survey and provided smartphone-based GPS data. Participants contributed nearly six million GPS points that collectively constitute over 5,000 traces. By using the data passively collected from travellers in the City of Edmonton, the intention of this study is to have a better understanding of the characteristics of pedestrian tours in different urban forms (urban core and suburban). The primary questions of this study include: what are the commonly observed characteristics of pedestrian tours based on these empirical data? What are the duration of these tours in time? What are the length of these tours in distance? And, how many activities were accomplished on a given tour? Each of these questions is considered as a function of the built environments – urban or suburban – in which the tours took place.

Literature Review

Walking trips are complex. On the one hand, walking trips can be multi-purpose and multi-stop. Several activities can be accomplished within one single walking trip. For example, a home-based work trip by walking can contain routine shopping or pick-up food/coffee activities. Sometimes a walking trip itself can be the main purpose of travel, such as walking for recreation or leisure. On the other hand, walking can be combined with any type of travel mode and can affect the major mode choice decisions. The mode choice for walking can be influenced by many factors such as the built environment's impacts (Cervero & Kockelman, 1997), the personal and household characteristics such as availability of vehicles (Yeung & Casello, 2018), or specific attractive destinations such as large parks. Other socio-economic attributes such as car ownership, age, and gender have crucial effects on travel decision making. Given this complexity, it is essential to gather robust and detailed information about pedestrians and their travel activities.

It is also important to consider pedestrian trips as part of travel tours, because all trips, regardless of modes, contain pedestrian activities. Trip-based travel forecasting models, with their emphasis on single-purpose, single-mode designations, fail to capture these pedestrian components. Hence, a more adequate representation to describe walking behaviour is urgent.

Pedestrian tours as a function of walking trip-chaining, household status, and land use patterns, provide a more adequate way to represent walking travel behaviour in travel analysis. Unlike trips, which are defined as travel between two locations, a *tour* is a sequence of movements starting and ending at the same location (Bowman & Ben-Akiva, 2001). Tours can be classified into a simple or complex tour (more than one activity). The degree of tour complexity represents the number of activities involved in a tour (Ho and Mulley, 2013; Harding, Zhang & Miller, 2015). Pedestrian tours, their lengths in distance, duration in time, access mode, the number of activities accomplished, and destinations of activities can provide a meaningful representation of pedestrian activities in travel forecasting models. More importantly, a pedestrian tour not only links the activities and related walking trips, but also reflects the sequence, frequency, and duration of scheduled pedestrian activities.

In transportation planning practice, more municipalities and transportation planning sectors are trying to improve their ability to evaluate interventions to promote active transportation. Regional travel forecasting models that include non-motorized travel provide more opportunities to predict the demand for using services and infrastructure for active transportation (Porter et al., 1999). However, due to the complexity or heterogeneity of pedestrian travel behaviour, and the lack of reliable sample data, most current travel forecasting models are inadequate in addressing impacts of investments in or policies towards walking. More specifically, the accuracy of these models is limited due to: insufficient data to model trips by active transportation; the inability to develop an appropriate representation for pedestrians costs; and the failure to consider the complexity of pedestrian tours.

This paper presents empirically derived data on pedestrian tours to classify those tours by modes, origins and purposes. The paper also demonstrates a method to develop quantitative attributes for those tours in terms of their distances, duration and activities completed. Finally, initial methods are presented that can correlate these tours' attributes to different urban forms.

Study Area

The City of Edmonton is the capital of the province of Alberta, Canada; Edmonton is located in central Alberta, approximately 1000km from Canada's west coast (See FIGURE 1). According to the Municipal Census, the population of the City of Edmonton was 877,926 in 2014 and 932,546 in 2016. Edmonton's population and employment are heavily reliant on the energy sector; when the industry is strong, population and employment tend to grow.

Public transportation service is provided by Edmonton Transit Service (ETS), an agency owned and operated by the City government. The modes and services provided include citywide bus and two light rail transit (LRT) lines - the Capital Line and the Metro Line – that total 24.3km of alignment with 6 underground and 12 at grade stations. Neighborhoods in Edmonton are classified into geographic areas with homogeneous characteristics. The Way We Grow (City of Edmonton, 2010), Edmonton's municipal development plan, divided the neighborhoods into four geographic areas: central core areas, mature areas, established areas, and developing areas. This classification proved useful in the current study as it provided the basis by which different urban forms could be identified. To understand the pedestrian tours in different urban forms, the downtown – the primary central core sector – and the southwest – an established suburban sector – are chosen as study areas.

The total area of downtown is 2.34km^2. In 2014, the population was 13,148, resulting in a population density of about 56 persons per hectare. Downtown is not only the economic centre of the city, but also has a high density of employment, business, and political and educational services. The main transportation mode for people to travel from home to work is reported as walk and bicycle. The southwest sector is a suburban residential area that consists of 16 neighborhoods. The total area is 16.00 km^2. In 2014, the population was 52,100. The population density of the southwest, then, is about 32.5 person per hectare, or 58% of the downtown. The main transportation mode for people living in the southwest to travel from home to work is reported as car, truck, or vans as a driver.

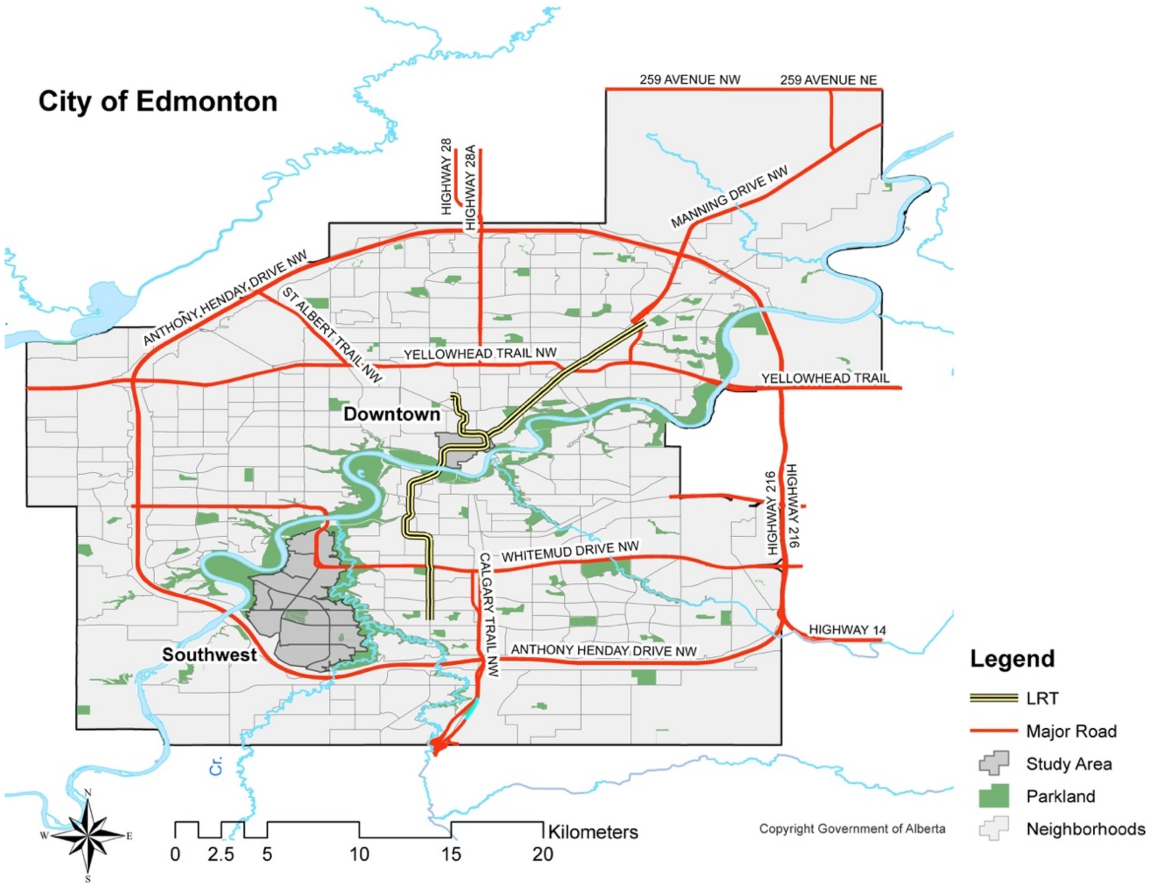


FIGURE 1 City of Edmonton, Alberta, Canada

Summary of the data set

The data collection was conducted between July and December of 2015. In total, 1,772 respondents recorded their daily travel behaviour – origin, destination, time, travel mode, and trip purpose – by utilizing a smartphone app, EdmoTrack. A summary of the data collected by the smartphone application can be found in TABLE 1. The City of Edmonton conducted a self-reported online survey that gathered people's travel patterns at the same time; 1,826 individuals took this online survey. Finally, 1,177 participants contributed to both data collection methods. In this study, we use self-reported locations (origins and destinations) to validate the activities.

TABLE 1 Data collected by smartphone application

Data Label	Definition
GPS_Survey_ID	Anonymous participant identifier
Point_ID	Individual point identifier
TimeStamp	Date and time for each GPS point collected
GPSLat	Latitude value for each GPS point
GPSlog	Longitude value for each GPS point
Speed	Speed (m/s)
Bearing	Bearing in degrees East of true North
GPS_Accuracy	Distance (m) by which the true location differs from reported location with 90% confidence. The estimated accuracy of this location.
DeviceOS	Operating system of the smartphone. Android = 1, iOS = 2

Method

To identify and validate pedestrian tours, this study adopted several steps shown in FIGURE 2, including data filtering, mode detection to facilitate pedestrian tour identification, and validation. The data filtering process reduced the number of incomplete, erroneous, and duplicate values in the raw data set. The process by which data were filtered is summarized in TABLE 2.

The first step in the filtering process eliminated those data points that were observed outside of the City boundaries. Next, participant identifiers which contain fewer than 30 data points or total recorded data spanning less than 1 hour were also excluded from the data set. Those traces were not sufficient to provide effective analysis for pedestrian tours. Those GPS points that were recorded with a GPS_Accuracy higher than 50 – reflecting a data point that is within 50 meters of the true point at 90% confidence – were also excluded from the data set.

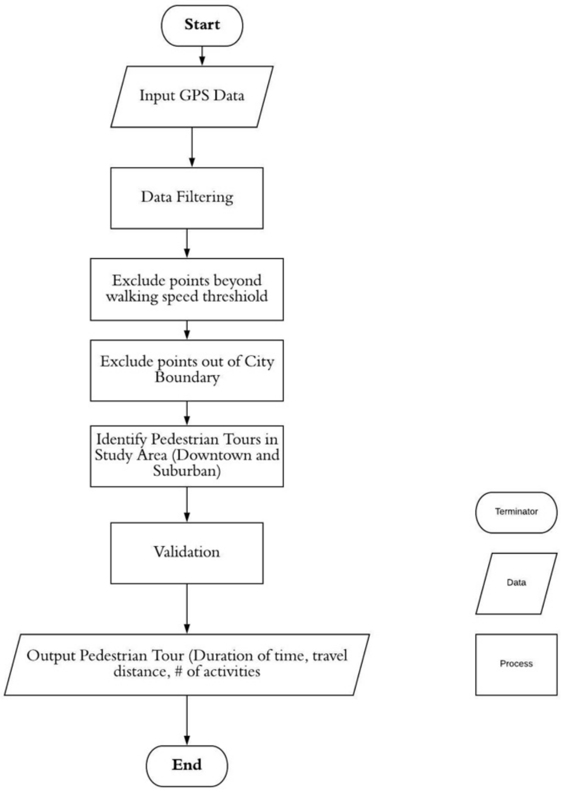


FIGURE 2 Identification of pedestrian tours

TABLE 2 Data filtering process

Step	Filtering Process	# of GPS Points
Raw Data		5,838,258
1	Delete the GPS points without the anonymous participant identifier	-1,198
2	Delete the GPS points collected beyond data collection period	-223
3	Delete participants who have total number of GPS points below 30 or total data collection duration less than 1 hour	-468
4	Exclude the GPS points have GPS_Accuracy > 50	-415,920
5	Exclude the GPS points beyond the borders of the City of Edmonton	-462,787

The next step in the analysis is mode detection. The most commonly used variables identified in the literature to classify modes from GPS data are speed and acceleration (Gong et al., 2012; Schuessler & Axhausen, 2009). Because the work described in this paper is concerned about tours, and the activities occurring during these tours, identifying segment modes is insufficient. Our work also requires that we are able to understand the purpose of a pedestrian segment in the context of a multimodal, multi-activity tour. For example, a pedestrian tour can be (and often does include) a combination of several modes such as walking-public transit-walking or walking-car-walking. The walking trips detected by speed and acceleration threshold can be the access or egress walking. When people change their travel mode from mechanically powered modes to walking, for example when searching for a spot in a parking lot then walking to destination, the threshold of speed and acceleration itself is not accurate enough to determine the transferring time and location. In this study, speed threshold, self-reported locations and map-matching are used to identify and classify pedestrian tours. By applying speed and acceleration thresholds to GPS points for a continuous period, one can make estimates of times and locations where mode changes happen (See FIGURE 3).

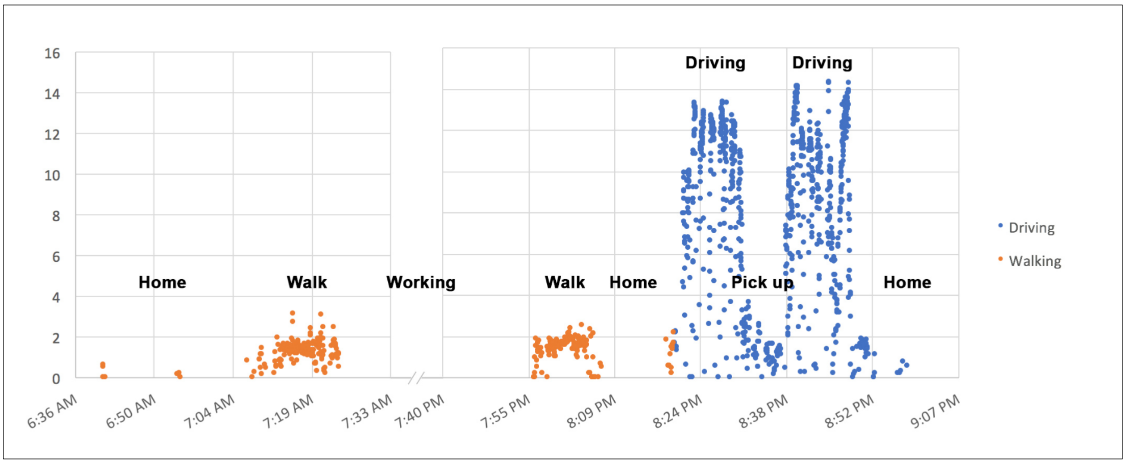


FIGURE 3 An individual's daily speed-time distribution from GPS

The self-reported location data were extracted from self-reported online survey which sharing same identification number for each individual participant. The locations they reported are classified into primary locations (home, work, school), and activity locations (entertainment, dining out, pick-up/drop-off, social, recreation, business, and personal business). Rather than applying speed threshold on the mass dataset, each individual's daily GPS trajectory are extracted and analyzed. Three essential queries are applied to determine and classify the pedestrian tours:

1. Does the tour start and end at an activity location (home, work, school, shopping, etc.) rather than stations or parking lots? This query can ensure the start and end location is not a transferring location. At the same time, the primary purpose (home-based) for the tour can be determined if the location is home. If not, move to the next self-reported location. If yes, move to the next query.
2. Is walking the only travel mode? If yes, this pedestrian tour is classified as unimodal, otherwise as intermodal.
3. Does this tour have other activities located in study area? If yes, this pedestrian tour is classified as utilitarian, otherwise as recreation. The process can be shown as FIGURE 4.

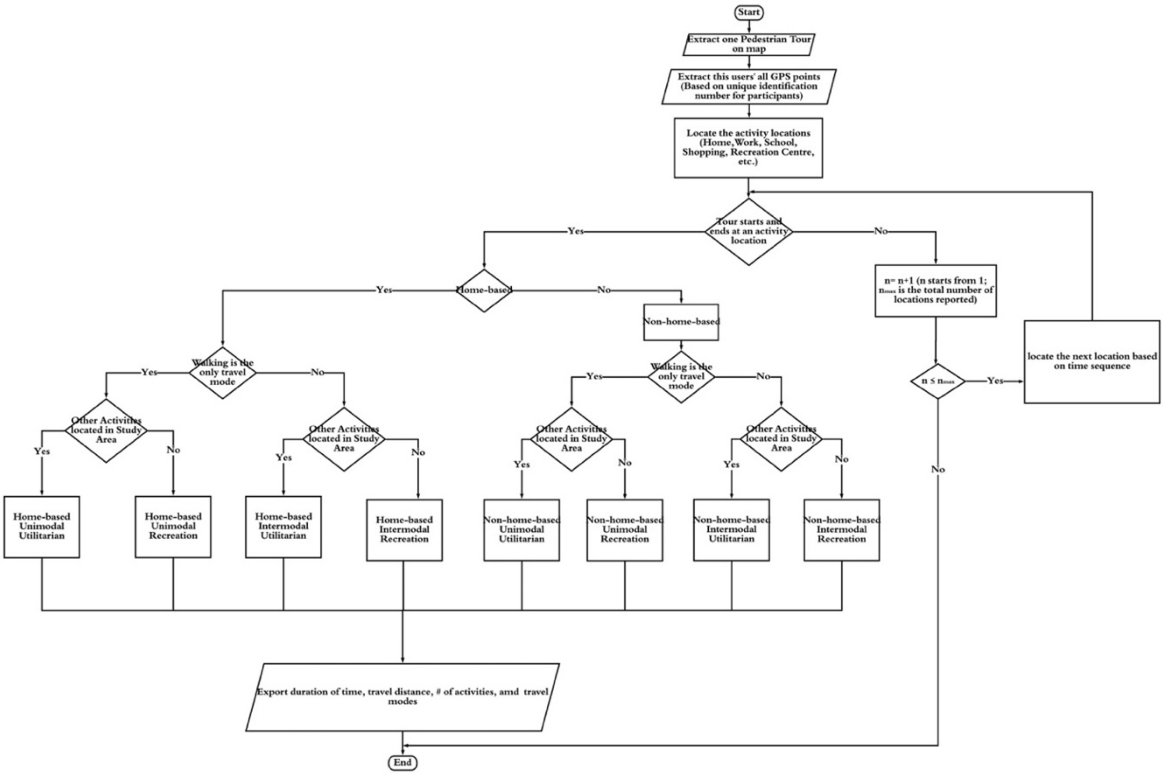
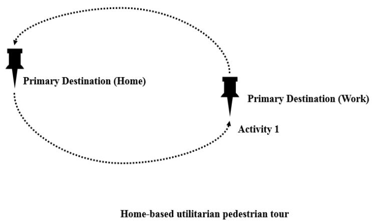
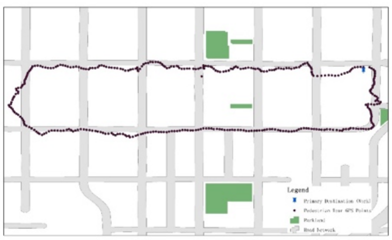
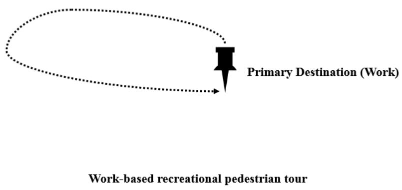


FIGURE 4 Classification of pedestrian tours

Findings

The findings include the classification of pedestrian tours, their distribution duration in time and distance in length in downtown and suburban, and distribution of activities. The following table shows a classification scheme that describes the majority of the tour types observed.

Model #	Empirical GPS data	Model
1 Unimodal Home-based Utilitarian		
2 Unimodal Work-based Recreation		

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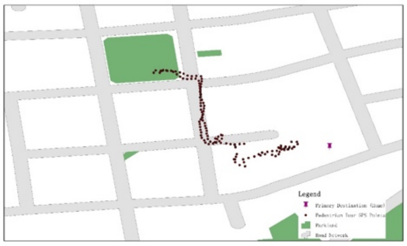
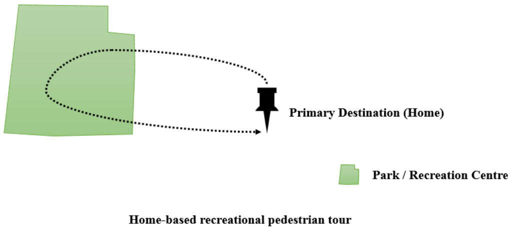
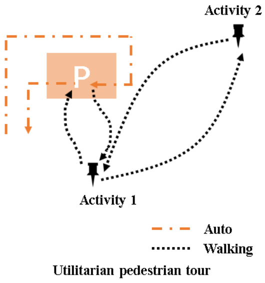
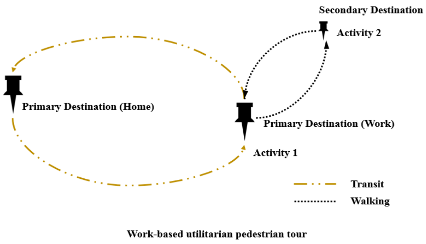
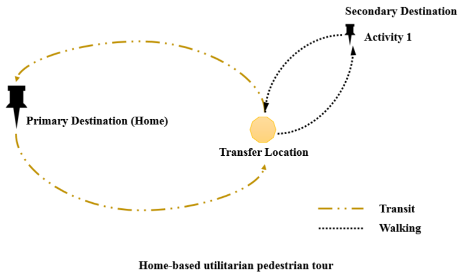
<tr><td>3
Unimodal
Home-based
Recreation</td><td></td><td></td></tr>
<tr><td>4
Unimodal
Non-home based
Utilitarian
Long Pedestrian Tour</td><td></td><td></td></tr>
<tr><td>5
Unimodal
Work-based
Utilitarian</td><td></td><td></td></tr>
<tr><td>6
Intermodal (transit-walk)
Home-based
Utilitarian
Long Pedestrian Tour</td><td></td><td></td></tr>
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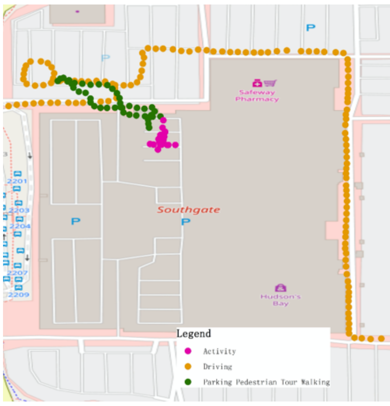
7 Intermodal (car-walk) Home-based Utilitarian Short Pedestrian Tour		

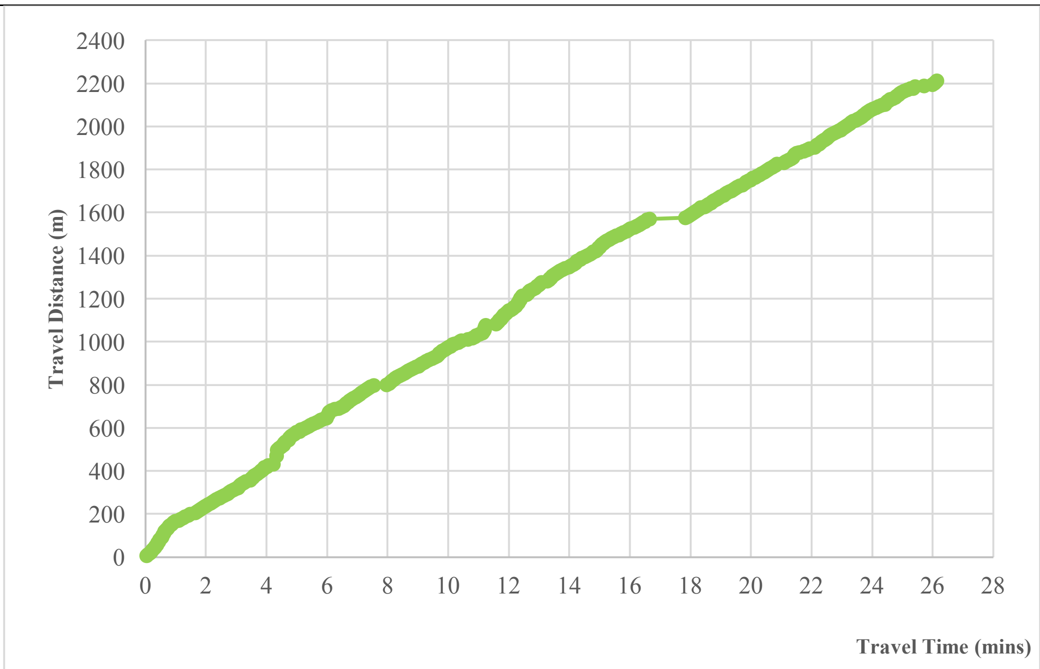
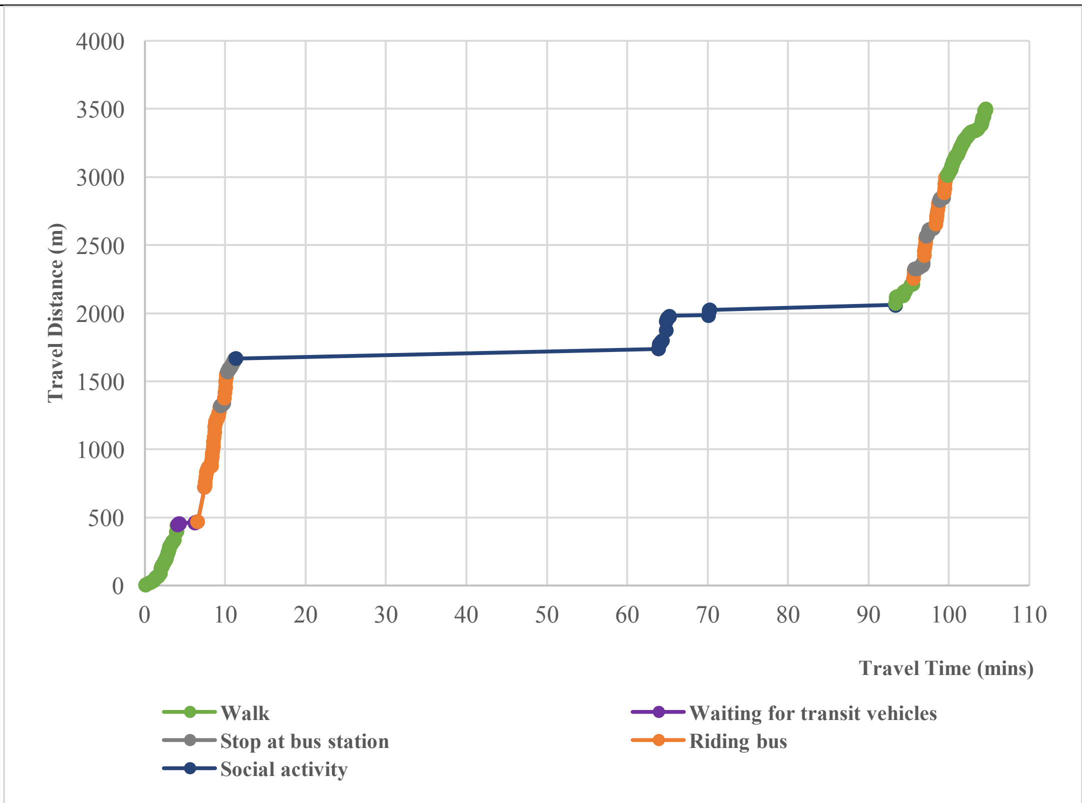
Pedestrian tours are classified into unimodal or intermodal tours based on the whether or not the observed tour was made exclusively as a pedestrian, or if the tour involved multiple modes. Similarly, the tours are classified as simple – single activity – or complex – multi activity – based on the number of activities observed. We also define recreational tours as a unique case of a simple or single activity tour, where there are no utilitarian activities and the trip purpose is either the trip itself or recreational activity like relaxing in a park. Like in most travel forecasting work, we also define the trip tours based on their point of origin, for example home-based or work-based tours. Lastly, we further classify a tour based on the travel purpose including shopping, social, recreation etc.

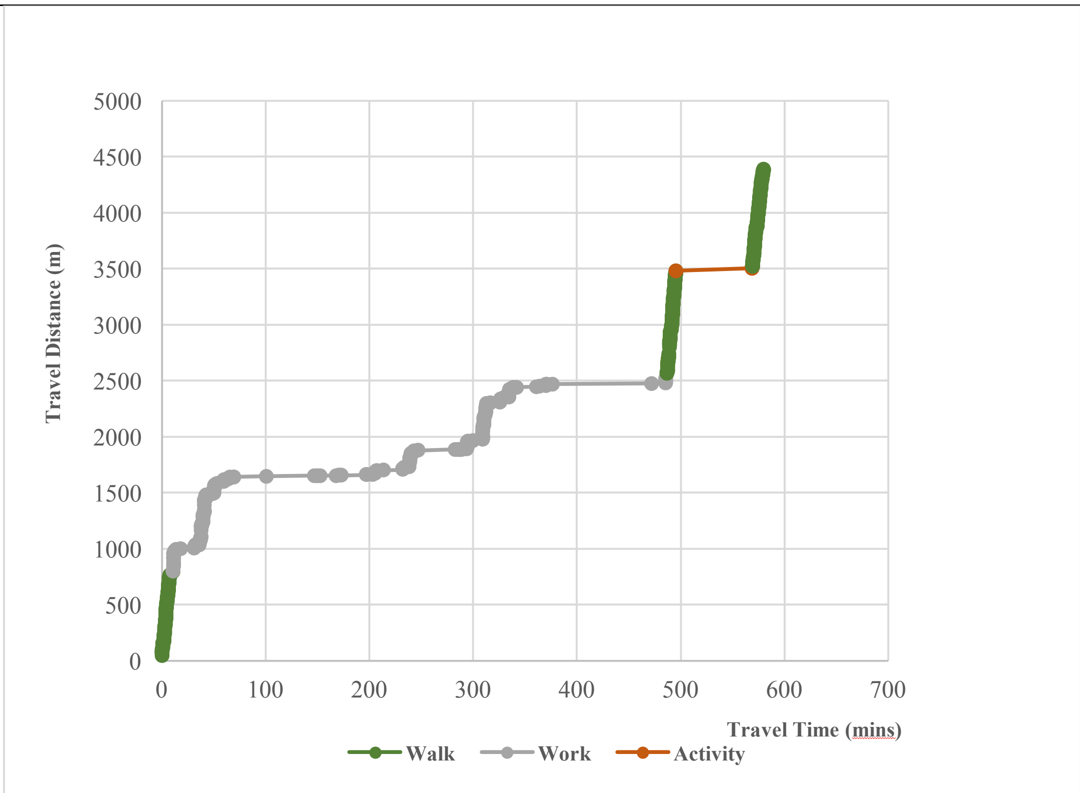
Returning to the examples in the previous table, Model 1 represents a home-based utilitarian unimodal pedestrian tour. This individual starts walking from home, ends at their workplace, conducts a work activity at this primary location, then walks home at the end of the day. Model 2 represents a unimodal recreation tour. This individual starts and ends at their workplace, and no intermediate stops or activities accomplished during the tour. Model 3 also represents a unimodal recreation tour. However, this pedestrian tour has a stop at a park or recreation centre.

Models 4 and 5 are long pedestrian tours from activity 1 to activity 2. Models 6 and 7 are intermodal pedestrian tour with access modes by auto or transit. The differences between type 4 and type 7 are the duration of walking and start and end location. Model 4 model has an activity location as the start and end location, while Model 7 has a parking lot as the start and end location. We consider the parking lot as the transfer location for modes from car to walk or walk to car. Hence, Model 7 is classified as intermodal since the major travel mode might be driving. However, the longer pedestrian tour Model 4 can be distinguished from Model 7 since multiple activities can be accomplished by walking at different destinations. For example, a person may drive to a shopping mall to buy clothes, but may also walk to a dining out lunch at a second place, the return to shopping. The dining out tour is accomplished only by walking. Similarly, Model 5 has primary/activity location which can separate the previous tours, but Model 6 has transit station as the mode transfer location. This typology of pedestrian tour can not only capture the connectivity within the trips, but also capture the sequence of pedestrian activities.

Quantifying Activities

Our next objective is to develop and apply methods to determine the number and duration of activities that a traveller conducts as part of a pedestrian tour. To this end, we have developed general examples of the kind of speed profiles we observed, and how they can be interpreted to quantify activities.

Type	Time-Distance (mins-meters)
Unimodal Recreation	
Intermodal (Walk-Transit-Walk) Utilitarian Single activity	

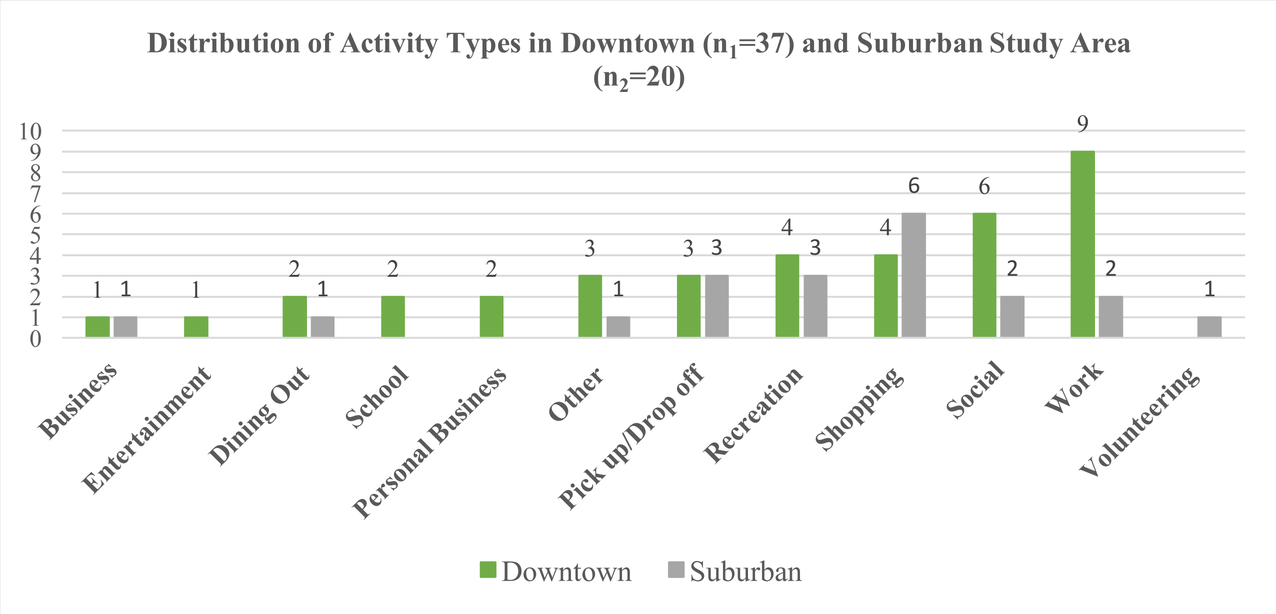
Unimodal Utilitarian Multiple activities	

The first graph shows a pedestrian walking at a relatively constant speed for just over 16 minutes. At that point, the speed profile changes to a nearly constant, nearly zero speed. This reflects an activity. When one analyzes the location of this activity and finds that there is no structure present, it becomes clear that this is a recreational pause.

The second graph is more complex. In this case, a traveller begins by walking at a constant speed, then engages in a short period of no movement. Again, when this stop location is mapped against land uses, one can see that the traveller's pause took place where a bus stop is located. The next set of points indicate a relatively low speed fairly constant trajectory. When these data are combined with the knowledge that the transition took place at what appears to be a bus stop, it is logical to assume that these points reflect travel by bus. The bus trip is followed by a long activity that land use data suggests is social. Finally, the return trip follows a similar path as the earlier part of the tour, suggesting the traveller is returning to the origin by the same mode, bus.

The last graph shows a very common phenomenon of a very long, nearly 500 minutes or eight hours, activity with some movement, but no utilitarian trajectory. The traveller begins the tour with a constant speed and trajectory towards a destination. For eight hours, the travellers' motion is circuitous, and limited in the x,y plane to a constrained physical space, presumably the confines of the workplace. At the end of the work activity, a similar, purposeful trajectory is observed at a speed that suggests walking. That walking segment is interrupted by an activity, likely a stop on the travellers return from work trip.

These examples demonstrate how the combination of GPS travel data, land use data, and analyses of motion patterns can be used to separate travel from activity. From the empirical data, we are also able to determine the distribution of activity types and present these results as a function of the area in which the tour took place. The following Figure summarizes the findings.



From the distribution of activities in different urban forms, 37 activities accomplished by pedestrian tours in Downtown, 20 activities in suburban. In Downtown, 24% of the activities are work, then 16% are social, 11% for recreation and recreation purpose. In Suburban, 30% of the activities are shopping, 15% as pick-up/drop-off and recreation. 10% for working and social.

The diagram suggests that there are similar distributions of activity types between downtown and suburban areas with several notable exceptions. Shopping activities constitute a much higher proportion of suburban tours than in the downtown. On the other hand, work and social activities are much more prevalent among downtown tours compared to suburban areas. These outcomes are logical and expected given the land use definitions for these areas.

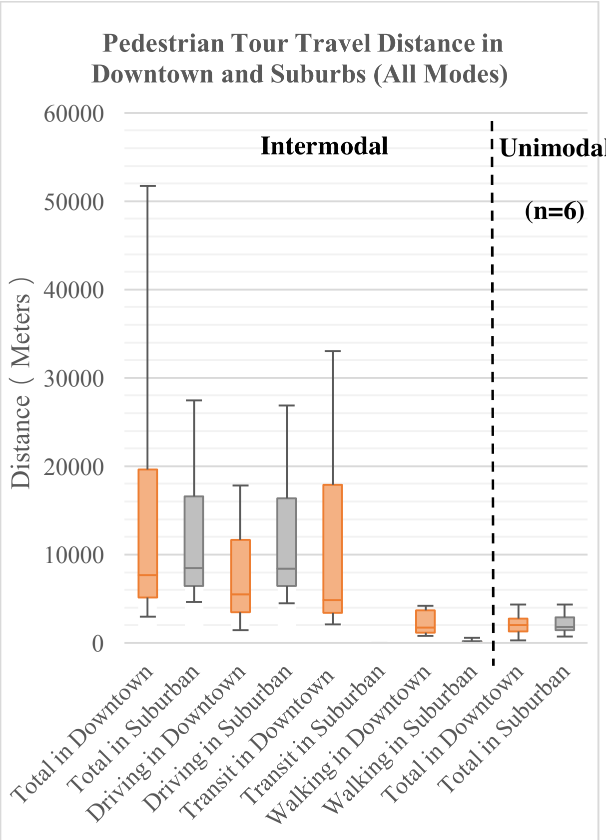
Distribution of Duration and Distance in Downtown and Suburban Area

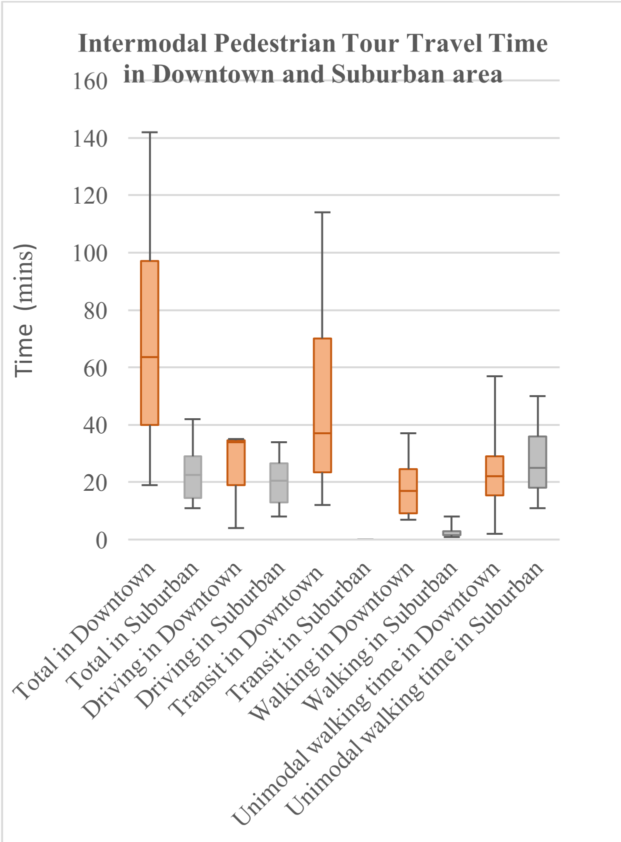
To help with establishing typologies of pedestrian behaviours, we were also interested in the duration (in time) and length (in distance) of observed pedestrian tours. The following figures present the data gathered in Edmonton using a box plot approach. The shaded central area for each category represents the range from the 25th to the 75th percentile of observations, with the horizontal line indicating the 50th percentile or median. The lines that extend above and below the shaded areas present the 95th and 5th percentile boundaries (respectively).

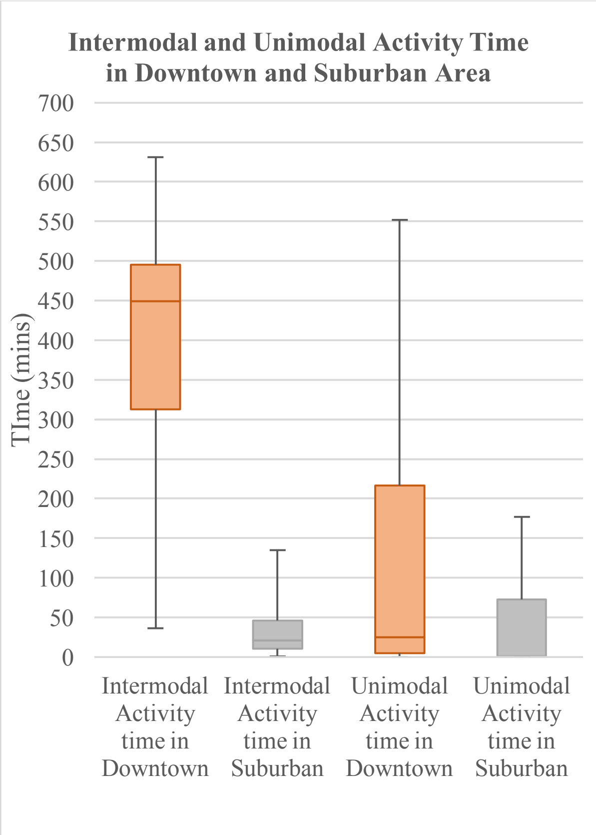
From the first chart, the following observations can be made. Generally, tours in the downtown tend to be longer in distance than those made in suburban areas. One can posit an explanation that the downtown lends itself to longer tours due to the improved environment for walking and as a result of the presence of utilitarian destinations. In other words, people make longer pedestrian tours in the downtown because there are destinations to access whereas in the suburban area, fewer destinations exist.

On the other hand, intermodal tours involving driving and walking tend to be shorter in the downtown. We assume that this is a result of the density of activities. One is required to drive less to reach destinations in the downtown. Moreover, driving in the downtown is often more onerous in terms of convenience than in the suburban areas.

Transit-walking tours only exist in the downtown. These tours tend to be longer and have a larger range of distances travelled than auto-walking tours. This is understandable, given the length of the transit network and again the propensity to accomplish multiple activities.





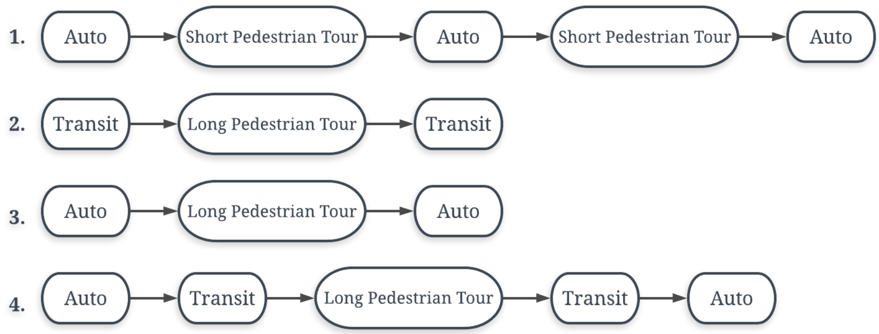


Considering the duration of observed tours, similar confirming evidence is seen. Downtown tours are much longer in time than those in the suburbs. Driving-walking tours are actually longer in time in the downtown but shorter in distance, reflecting urban congestion and greater walking components. Transit-walking tours again demonstrate a wide range of durations, presumably due to modal attributes and the number and durations of activities. The final interesting observation from these data are that suburban, unimodal walking trips tend to be longer in the suburban areas. We attribute this phenomenon to be indicative of suburban residents engaging in longer recreational walking trips as substitutes to the utilitarian walking that happens within downtown areas.

The final diagram above shows the duration of only the activities, as opposed to the total tour. Activities tend to be much longer in the downtown area, presumably because of many tours involving work activities that tend to span nearly 500 minutes. Activities in the suburban area are much shorter. We surmise that these durations are a result of multiple, short duration shopping and other activities.

Based on the typology of pedestrian tours, commonly observed pedestrian tours can be summarized as follow.

Commonly Observed Pedestrian Tours



Type 1: Multiple errands run with long auto trips followed by short pedestrian tours. For example, a person driving to parking lot then walk to the store, back to the vehicle. Commonly observed in suburban areas.

Type 2: Transit access from suburban areas to downtown; long pedestrian tour accomplishing multiple activities. For example, a person takes a bus to Downtown, accomplish multiple activities by walking, and then return home by bus.

Type 3: Auto access to parking - at destination in suburban areas, adjacent to core downtown area; long pedestrian tour accomplishing multiple activities. For example, a person driving to a parking lot near Downtown, walk within Downtown and accomplish multiple activities, and walk back to vehicle.

Type 4: Auto access from suburbs to transit; travel to downtown for work / other activities; return home by transit-to-auto. For example, a person lives in suburban where poor coverage of transit but works in Downtown.

Conclusion

This study identified pedestrian tours from the empirical data collected from a smartphone application; classified those tours by modes, number of activities, origins and purposes; quantified those tours' characteristics in terms of duration, distances, and accomplished activities. This study also correlated these attributes to different urban forms in terms of Downtown Edmonton and suburban area. Most of the activities accomplished by pedestrian tours vary as a function of different urban forms. In downtown, working is the major travel purpose in pedestrian tours. However, in suburban areas, the major travel purpose of a pedestrian tour might be shopping. Also in suburban areas, the most commonly observed walking type is long auto trips followed by short pedestrian tours. In downtown, the most commonly observed walking type is long pedestrian tours with multiple activities completed. In the future, this study can further explore the generalized cost function and route choice model based on the pedestrian tours identified from empirical data.

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