Assessing Walkability

Using built environmental variables and population distribution to estimate and model walkability conditions around suburban GO Transit Stations

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Executive Summary

This report documents the development and testing of several measures to assess walkability around GO Transit stations. The work was conducted in several distinct phases. First, we conducted a widespread scan of the entire network, creating an inventory of basic demographic and walkability conditions around each station. Then using GIS, we modeled the pedestrian environment around several test stations to determine how the built environment affects walkability. Based on some basic qualities of the built environment, we developed the route quality factor (RQF), which weighted travel based on the quality of the route. We also developed a pedestrian weighted network accumulation value, which estimated how many people were likely to walk along different routes based on the distribution of population around stations and the configuration of the pedestrian network. By combining these two, we identified 'hot spots' of poor quality and high usage, and identified areas and strategies for improving conditions. Overall, we found that it was both reasonable and feasible to improve conditions along main commercial roads, and that there could be better pedestrian facilities within GO Transit parking lots. Additionally, we modeled the impacts of some types of new infrastructure improvements to increase connectivity.

Introduction

This report addresses the question of **how can walkability be effectively measured within station areas using basic characteristics of the built environment?** Walkability is an important quality to have in cities: it promotes good health through reducing automobility, increasing physical activity, activating the pedestrian realm through enhanced street life, and supporting more sustainable compact development. Walkability in conjunction with transit is especially important as it can encourage users to walk to the station, which can either result in a modal shift from automobile use to walking, reducing parking demands, or it can bring additional ridership.

However, walkability around many GO Transit stations is poor, owing to a variety of land use, infrastructure, and connectivity issues. This is unsurprising, since many of GO Transit's stations are located in post-World War Two suburban residential, commercial, or industrial areas with low population densities, little land use mix, and disconnected street networks. Conditions around each station are variable, however, some potential walking routes having missing sidewalk segments, requiring long walks along busy arterial streets and difficult street crossings, and other negative conditions that may discourage people from choosing to walk to transit. Other routes are more benign with complete sidewalks, largely on streets with low traffic volumes, and other more supportive conditions. This project seeks to develop a methodology to capture variations in walking conditions, identify areas where conditions can be improved, and explore strategies to do this.

Project Overview

The project was conducted over two years, and can be divided into two phases.

Phase One: Scanning and Mapping

- This phase took place during the first year of the project, and examined the entire system at once, including all GO Transit stations, and Mobility Hubs.
- The scanning element calculated several broad metrics for all of the stations: population density, pedestrian shed access, and land use mix.
- Some basic metrics and correlations were computed between these variables in order to develop some typologies.
- The mapping element created a full map series of all stations and Mobility Hubs (see Appendix).

Phase Two: Station Area Analysis

- This phase took place during the second year of the project and is the focus of this report, were we conducted a more in depth examination of walking conditions around GO Transit Stations, which were selected based on the results of phase one.
- A methodology for assessing walkability in these station areas included modeling the pedestrian network in each selected station area, and assigning variables to each link in the network based on adjoining land uses, the type of pedestrian facility present, and the class of roadway (local, collector, arterial) on which a link was located.
- Walkability was assessed in a of variety ways: by examining the area reachable within a 10 minute walk, by seeing what routes most people were likely to use, and by examining the quality along common routes. Maps of each of these analyses were produced for each selected station area (see Appendix).
- The impact on the size of a station area's walking shed by building new pedestrians links was also modeled, and summary metrics developed.

The Walkablity Literature

Walkability is a measurement of how conducive an area is to walking. It is a broad concept, comprised of both quantitative and qualitative factors, such as having a sense of comfort and safety, having a variety of destinations within walking distance, and having a certain level of visual interest along the journey (Southworth, 2005). Ewing, Handy, Brownson, Clemente, & Winston (2006) provide a helpful breakdown of walkability into three categories: physical features of the built environment, urban design qualities, and individual reactions to walkability conditions.

At the most objective end of the scale are physical features of the built environment, sometimes referred to as built environmental variables, or simply environmental variables. These are quantifiable 'facts' about the environment, such as sidewalk presence, or traffic speed. While there is no strict numeric relationship between built environment variables and absolute walking behaviour, environmental variables tend to have a more uniform effect across a variety of populations. For example, sidewalk presence has been shown to increase walkability in multiple studies (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009; Cerin, Saelens, Sallis, & Frank, 2006; Cervero & Kockelman, 1997; Forsyth, Hearst, Oakes, & Schmitz, 2008; Lee & Moudon, 2006; Leslie et al., 2005).

Urban design qualities are based on objective elements of the built environment, but the unique ways in which they interact with each other and other elements determines their impact. For example, the objective values of street width and building height come together to create the urban design quality of 'enclosure', with greater enclosure promoting walkability. Some other common urban design qualities related to walkability are 'human scale', 'complexity', and 'imageability'. However, these qualities are more subjective, and the way that they are interpreted can change how they affect walkability. For example, Leslie et al. (2005) found residents of different neighborhoods had different reactions to aesthetic urban design qualities.

Finally, individual reactions are how people interpret and react to both physical features, and urban design qualities, based on both these environmental variables along with the individual's subjective history. As such, they can vary greatly from population to population, and have a much looser relationship with quantifiable walkability. For example Painter (1996) found that perceptions of safety provided by street lights differed by gender.

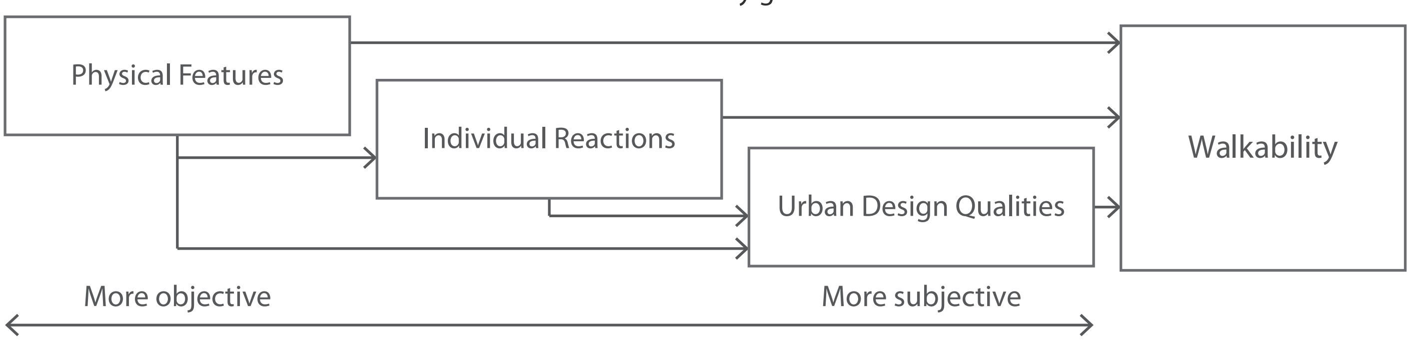


Figure 1: Conceptual framework for examining walkability, based on Ewing et al. (2006).

Using the Built Environment to Assess Walkability

Because of the difficulty in evaluating the impacts of the more subjective elements of walkability, this project uses objective built environment variables to assess walkability. There are three main reasons for this:

- Built environmental variables tend to have large and uniform effects on walkability.
- Assessing built environmental variables is easy and quick.
- Collecting or creating data for built environment variables requires a lower time investment.

The project does not measure urban design qualities directly, but we believe that we largely capture them through our typology of physical features. This is because most of the suburban environments addressed in the study are composed of fairly simple and similar patterns of built form. For example, built form elements such as shopping centres, strip malls, and arterial roadways across the study areas are both fairly similar in form, but also combine in a limited number of predictable patterns. Because of this, we believe they map well to urban design qualities such as complexity and enclosure, even though these are not directly measured. The project does not address individual reactions, although we discuss how these might be incorporated in to some analyses.

Since this project largely seeks to assess walkability through built environment variables, it is important to understand some of the basic relationships between them and walking that is identified in the research literature. It should be stressed that these relationships are *relative*, not *absolute* ones, meaning that while researchers have found correlations between different variables and walkability, there is no formula to directly relate the two. For example, studies have shown that greater sidewalk coverage is related to increased walkability, but there is no formula that states that for every x meters of sidewalk, there will be y people walking. Nevertheless, we can still use the relative relationships between different factors and walkability as a rough estimation of walkability.

From the existing literature, we selected three variables to use: land use, pedestrian facility type, and standard hierarchical road classifications. These were chosen because they are easy to assess and have a large and relatively uniform impact on walkability.

Land Use refers to what the main land use is next to where an individual is walking, and has been shown to have the largest impact on overall walkability, with land uses that create a high density of potential destinations and mixed land uses found to be most important (Agrawal & Schimek, 2007; Clifton, Livi Smith, & Rodriguez, 2007; Lee & Moudon, 2006; Leslie et al., 2005). It is important to note that land use may differ on different sides of the same street, and in order to capture this, this project examines pedestrian travel on both sides of a street. We also treat land use as impacting the experience of the walking environment, where, for example, strip malls, with multiple driveways crossing the sidewalk and the potential for moving traffic, is seen as having a negative impact on walking conditions compared to traditional main-street retail, that creates a street wall with many shops along a sidewalk, and is seen as creating positive walking conditions. Few research studies examine land use in this manner.

Pedestrian Facility refers to the type of surface that pedestrians have to walk on. Largely this refers to whether or not there are sidewalks, but it also encompasses other conditions, such as off street pathways, informal pathways, or if pedestrians have to walk through parking lots. Pedestrian facilities tend to have a large impact on walkability, but generally less than that of land use (Cerin et al., 2006; Cervero & Kockelman, 1997; Clifton et al., 2007; Forsyth et al., 2008; Hoehner, Ramirez, Elliott, Handy, & Brownson, 2005; Lee & Moudon, 2006; Leslie et al., 2005; Saelens, Sallis, & Frank, 2003).

Road Classification refers to the municipal designation of the adjacent roadway as a local street, a collector street, or an arterial street. Road Classification is used as a proxy for traffic speed and volume as well as the urban design qualities of the pedestrian environment. The latter, in most suburban contexts in the study area exhibit few features associated with good walkability, such as enclosure, complexity, or human scale. Additionally, this category encompasses the effects of street crossings. Based on the literature, roadway classification is assumed to have the smallest relative impact of the three variables on walkability (Clifton et al., 2007; Lee & Moudon, 2006; Leslie et al., 2005; Olszewski & Wibowo, 2005).

It is also important to note that this project conceptually assesses walkability by combining measures of walkability across a defined geographic area with measures of the quality of a particular route. The existing literature tends to ascribe walkability using either one or the other of these methods. For example, most research studies measure walkability in area around some defined point, often a neighbourhood defined around the residence of each respondent in a survey, or around some important destination such as a school. These areas are determined by either defining a simple linear buffer at some set distance around the point, often one-half mile or 800 metres, or by a buffer determined by a set distance from the point measured along the street or pedestrian network. As describe below, the later method is generally adopted for this study. Measures such as population density, land use mix, sidewalk system completeness, and street system connectivity are then measured within each defined buffer.

A second method inventories features along routes, such as measuring the presence and width of sidewalks, the presence and width of buffers between sidewalks and the roadway, the number of street crossings necessary, the surrounding type of land use, etc. This produces a large amount of very detailed data about walking conditions along specific routes. Such inventories, however, have proven difficult to use in correlational studies that link environmental conditions to rates of walking (Clifton et al. 2007).

In studying walking to transit stations, we are able to use elements of both approaches. The distribution of population density across the study area remains important in affecting the likely volume of pedestrians. However, as the destination of the walking trip is assumed to be to the transit station, measures like the density of destinations are less applicable. A defined destination does, however, allow for the conditions along routes to this destination to be captured and measured. We believe that by thinking through and using elements of both geographic, buffer-based measures of walkability, and more linear route inventories, this project contributes an unique and important approach to conceptualizing walkability for planning purposes that could be extended to correlational studies in some contexts.

Methods and Analysis: Phase One

For the first phase of this project, we performed an inventory of stations across the entire GO Transit rail network, and Mobility Hubs. The primary purpose behind this work was to get a general sense of what conditions were like across the network, in order to inform the more detailed analysis performed in Phase Two.

The outputs of this phase were:

- General urban form and demographic statistics for all station areas
- Full map series detailing generalized pedestrian sheds
- A station selection criteria and methodology

To carry out this inventory relevant geospatial data was assembled using GIS (geographic information systems) software to create, analyze, and map spatial information. The ArcGIS platform was used for this purpose during both Phase One and Phase Two. For this first phase, we obtained the following metrics:

- Population Density
- Network Efficiency
- Land Use Diversity

Population Density

Population density was found by examining all census dissemination blocks falling within a zone defined around the stations/hubs. This zone was determined by buffering out 800 linear metres from each station entrance (as identified using aerial photography). A census dissemination block is simply the smallest unit of the Canadian Census, roughly equal to a residential block or small subdivision. This project used population data from the 2011 Canadian Census. In order to determine population density, the population of the blocks within the buffer zone was simply divided by the area of the zone.

Network Efficiency

Service area analysis was used to model how much area is serviceable from a defined point traveling along a network, which in our analysis is the area reachable within 800m of the station access points. We termed this area the station pedestrian shed. The pedestrian shed is always smaller than the 800 metre straight-line buffer, as defined above, because travel networks are perfectly direct between all points (see Figure 2). Thus, network efficiency was defined as the relative difference in size between the 800 metre straight-line buffer zone

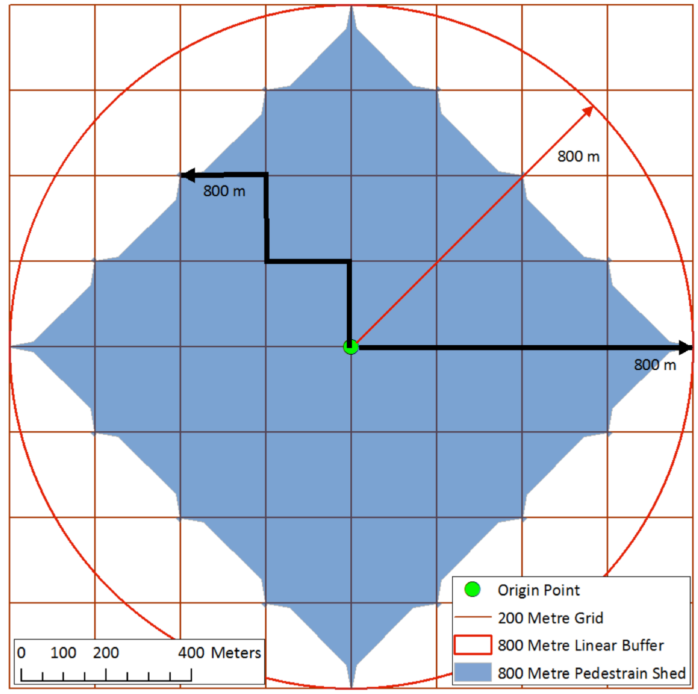


Figure 2: Even with a tight grid layout, the pedestrian shed will always be less than the theoretical linear buffer distance.

and pedestrian shed. It was found by dividing the total area of parcels reachable by the network within the pedestrian shed by the area of the straight-line buffer. Classified land use parcels from Sorensen & Hess (2013) were used for this analysis.

Note, an important distinction between the service area analysis for defining pedestrian sheds in Phase One and Phase Two, is that the service area analysis in Phase One uses the road network centre-lines as a basis for analysis, while in phase two we modeled the more complex pedestrian net-work, including pathways along both sides of roadways, street crossings, and walkways through schools and parks.

Land Use Diversity

Land use diversity was found by using the Shannon Diversity Index and the classified land use parcel data. The Shannon Index is a measure of diversity that examines the proportion of each land use, relative to the total land use. For any defined area and number of land uses, the highest score would be achieved if there were an equal proportion of each defined land use. Theoretically scores can range from 1 (highly diverse or mixed land uses) to 0 (lack of any mix). In the context of urban planning, higher values are an indicator of mixed-use development, which is generally correlated to greater walkability. Values near one are rarely encountered in cities, but single use areas

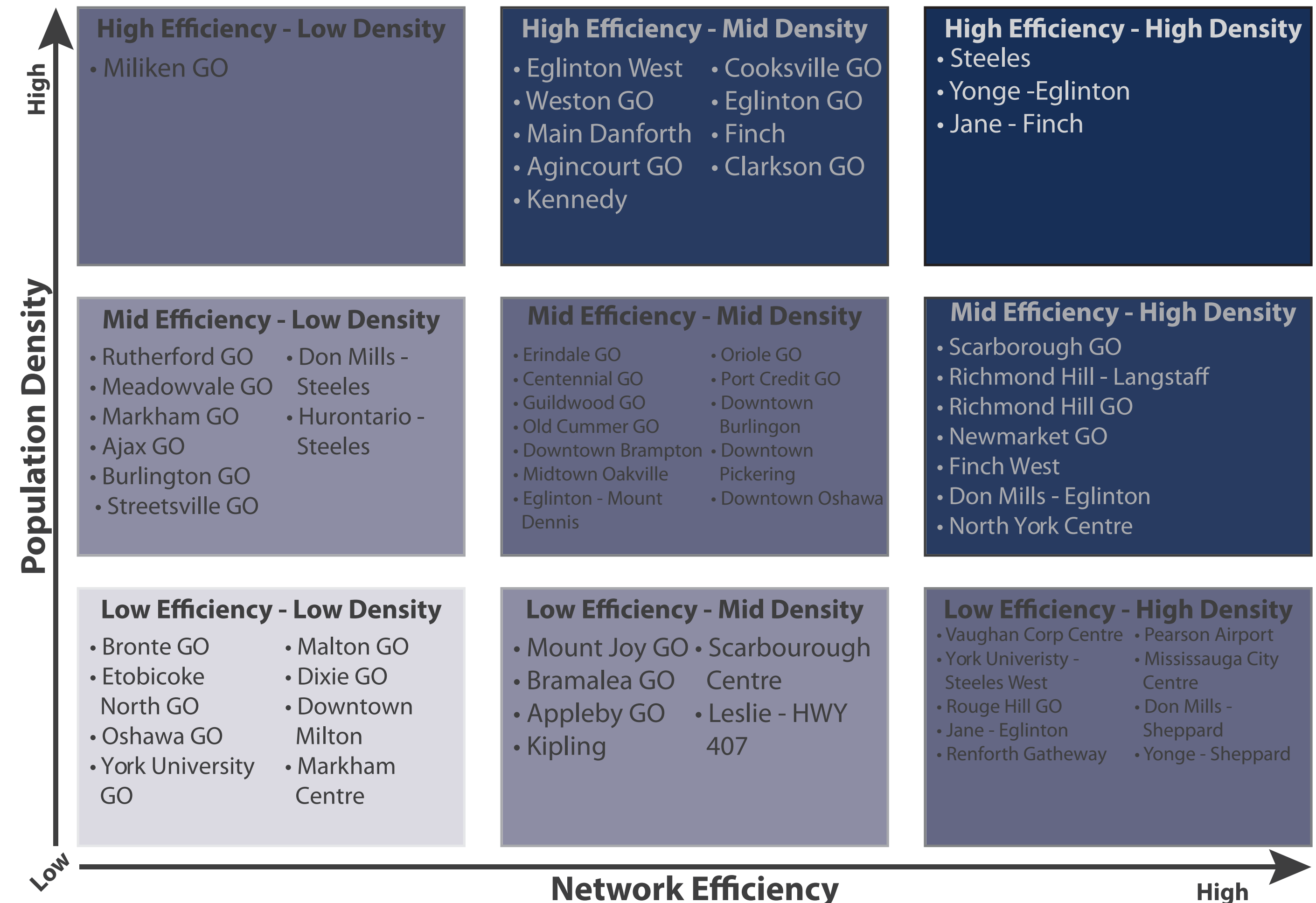


Figure 3: Cluster matrix of population density and network efficiency. This project mainly targeted stations that were in the middle of the matrix.

can be found that score 0. Although this measure has clear limitations (see Hess, Moudon, and Logsdon, 2001), it is widely used in the transportation literature and is employed here.

Classification

Once all of the stations and hubs were analyzed and mapped, stations and hubs were classified into various categories and typologies. Based on the distribution of each of the three variables, each station was classified based on their standard deviation (σ) from the mean score as high (> +0.5 σ), medium (> -0.5 σ < +0.5 σ), or low (< -0.5 σ). See Figure 3.

In addition to the categories based on the values from the analysis above, stations were also categorized into typologies based on their urban form and transportation function.

Analysis

A cluster analysis was then run between all of the stations and hubs inventoried, creating a matrix, of increasing population density, and increasing network efficiency. This was used to inform the selection of stations used for future analysis. Stations with already high efficiencies and population densities that likely have good walking conditions were excluded from selection, as were stations with very low efficiencies and densities that would require so much intervention that they are cost prohibitive, relative to potentially smaller gains. This includes, for example, stations surrounded by large areas of very low-density employment lands that would require substantial redevelopment, land use change, and restructuring of the street network to substantially improve walking conditions. Stations with more typical suburban conditions including medium population density and street connectivity were targeted for further study.

In addition to this general clustering, correlations were performed between the two variables, as can be seen in Figure 4. While there was a correlation between efficiency and density, it was very weak with r2 = 0.13,

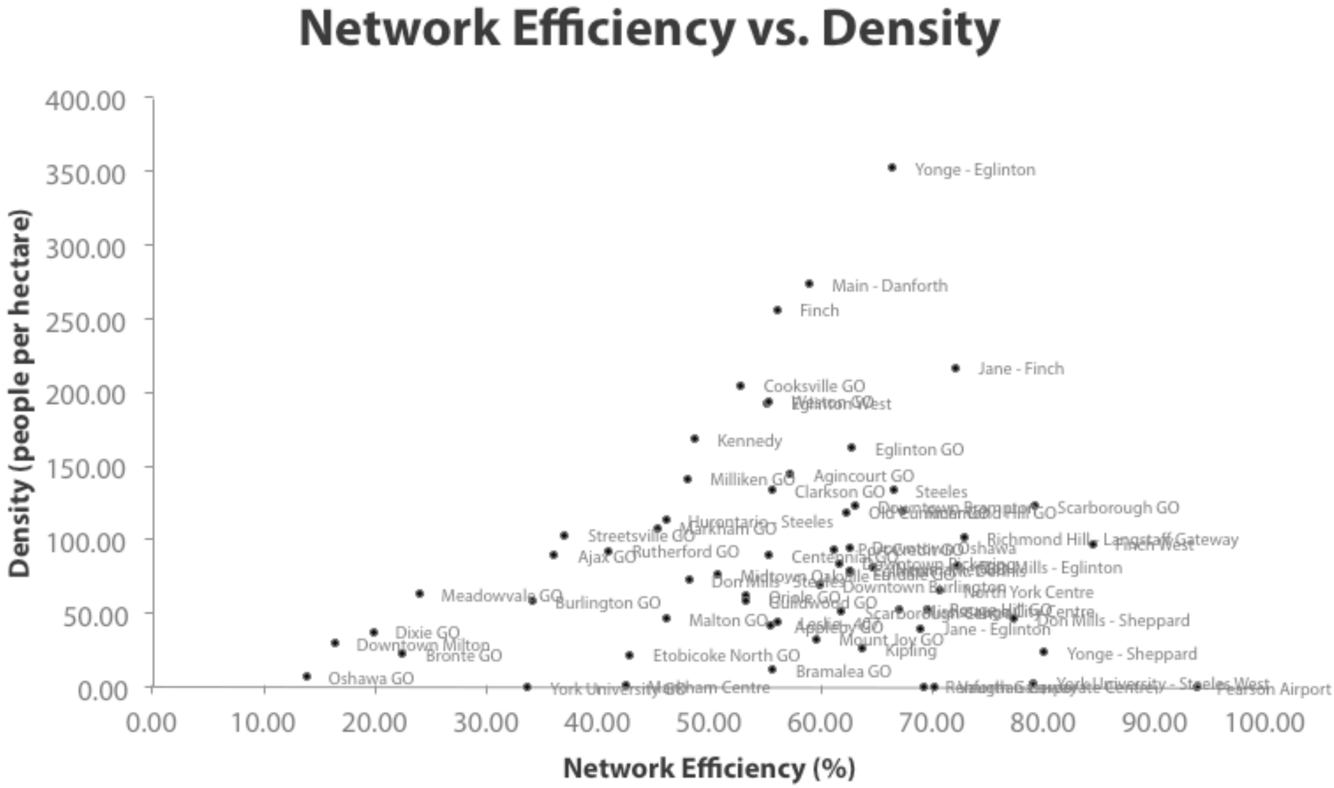


Figure 4: Correlation between population density and network efficiency. No statistically significant correlation was observed.

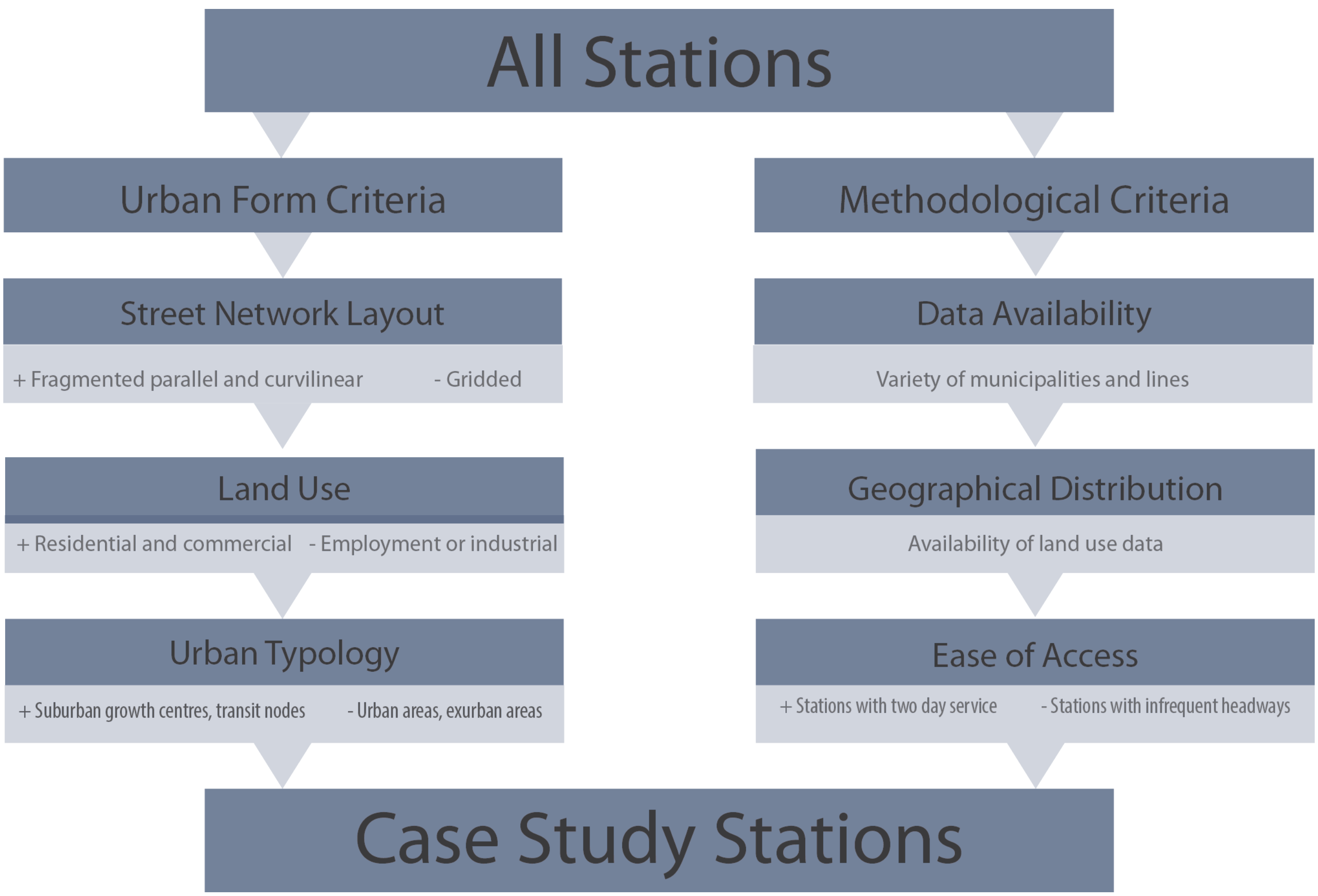


Figure 5: Station Selection criteria.

indicating that there is little relationship between density and network efficiency. This is simply because there are so many different land use typologies and built forms around all the different stations and hubs that no one relationship can clearly be observed. Thus, stations were selected to capture a variety of conditions.

Finalized Selection Criteria

From this first phase, we developed a detailed selection process for selecting case studies for further analysis in Phase Two. This process, seen in Figure 5, takes into account several of the factors involved in Phase One, as well as some additional methodological criteria.

On the Urban Form side of the selection process, we selected stations with the following characteristics:

- Located in inefficient network areas, characterized by fragmented grid, or curvilinear street layouts, rather than older street grid layouts.
- Located in areas that include substantial residential land uses, rather than almost exclusively industrial or commercial areas, to screen out stations where there are little to no people within walking distance.
- Suburban areas with residential populations, where there is potential for growth, such as urban growth centres (UGCs), rather than urban areas that are already well developed.

On the Methodology side of the process, stations were selected with:

- Good geographic distribution across different parts of the GTA.
- Have available land use data based on Sorensen & Hess (2013) that only covers the GTA.
- Good accessibility. Since there was some field work involved, we selected stations that researchers could easily reach, which were generally ones with two way service, or ones closer to Toronto proper.

Metrolinx staff was also consulted on final station selection.

Audit

One of the final stages of Phase One was an audit of two GO Transit Stations, Eglinton GO, and Oriole GO. This methodology was based on the Pedestrian Environmental Data Scan (PEDS), (Clifton et al. 2007). PEDS is a detailed audit based tool used to document specific environmental and urban design details of the pedestrian environment. This was able to reveal many specific details about the different pedestrian environments. Some of the findings of these audits include:

- Many pedestrians chose to create their own informal pathways through fields and parking lots in order to reach the station.
- •Specific infrastructure deficiencies and barriers were identified in each area.
- Pedestrian environments along arterial roadways were very unpleasant, owing to large commercial parking lots and reverse frontages.
- Pedestrian permeability was significantly reduced within apartment properties, owing to numerous fences.

Although this audit methodology was able to obtain very detailed data, the necessary fieldwork was too resource intensive to replicate across further station areas. It was also not clear how to process and aggregate the data to compare station areas. As a result, Phase Two of the research sought to develop more efficient and comparable methods of assessing walkability.

Methods and Analysis: Phase Two

The second phase of this project built on the scanning and high-level analysis in phase one by developing methods to measure and analyze walkability that were tested in nine stations; eight test stations in areas with intrinsically poor walkability, and one control station in an older, more walkable neighbourhood. Stations used in the study are shown in Table 1. The control station allowed us to ensure the results of analysis were capturing basic differences in environments.

Station	Municipality	Rail Line	Typology
Agincourt	Toronto	Stouffville	Suburban Transit Node
Burlington	Burlington	Lakeshore West	Emerging Urban Growth Centre
Clarkson	Mississauga	Lakeshore West	Suburban Transit Node
Cooksville	Mississauga	Milton	Suburban Transit Node
Eglinton	Toronto	Lakeshore East	Urban Transit Node
Erindale	Mississauga	Milton	Suburban Transit Node
Milliken	Toronto	Stouffville	Suburban Transit Node
Pickering	Pickering	Lakeshore East	Urban Transit Node
Danforth	Toronto	Lakeshore East	Urban Transit Node

Table 1: Summary of GO Transit Stations included in study.

The general outputs of this phase were:

- Detailed built environment, demographic, and walkability measurements, analyses, and maps for eight test stations.
- Generalized, evidence based observations about factors that impact walkability.
- Typologies of how to improve connectivity through infrastructure investment.
- Step-by-step technical documentation for how to perform this analysis for other locations.

The goal was to develop an efficient method of measuring walkability, not to measure all of the stations in the GO network . However, the detailed methodology included with this report should allow anyone with GIS skills to replicate this analysis.

Modeling the Pedestrian Environment

Built environment characteristics related to walkability were modeled within a GIS environment. Basic to this effort was modelling the pedestrian network, as other built environment features were treated as attributes of the links in the network. Existing network datasets that rely on street centrelines were not adequate for this task, as pedestrian conditions may differ from one side of a street to the other and these networks do not allow modelling of street crossings. Thus, we built a custom pedestrian network file.

The pedestrian network was created in a spatially referenced GIS environment, both following existing property lines, and tracing satellite imagery. If satellite imagery was unclear, Google Street View was used. Travel lines were created along both sides of all streets, along formal off-street pathways such as through school sites and parks, along visible informal paths on pedestrian 'desire lines,' and through GO Transit station facilities. Crossings were modeled at all intersections and formal crosswalks, even if they were not located at intersections. Informal street crossing locations are possible almost anywhere along the network and were not modelled.

All links in the pedestrian network were then assigned values based on three variables:

- Land Use. This classification was based on the classified land use parcels from Sorensen & Hess (2013). The full classification scheme was both collapsed and expanded to capture relevant typologies as shown in Table 2.
- Pedestrian Facility Type. No existing geographic data set was found with adequate and complete data on pedestrian facilities, so this was assigned manually based on satellite imagery, and Google Street View. The classification of facilities used is shown in Table 3.
- Classification of adjoining roadways. This classification was based off of existing road network data (DMTI Spatial Inc., 2013). Non-street adjacent segments (i.e. pathways) were not assigned a value. This classification scheme is shown in Table 4.

Any change in any one of the three variables along a segment of the pedestrian network caused the network line to be split into different segments. For example, if a sidewalk along an arterial roadway moved from being located next to apartments to being next to a strip mall, the network link would be split to record this change. This was done to ensure that there was never any more

	Land Use	Description	RQF
Predominant Uses	Residential		0
	Single Detached	Free standing residential building comprised of a single dwelling unit.	0
	Duplex	Free standing residential building with two attached dwelling units.	0
	Townhouse	A series of attached residential buildings with multiple dwelling units, with individual entrances.	0
	Apartment/Condominium	A residential building with a common entrance, and multiple floors of dwelling units.	0
	Commercial		
	Traditional retail	Traditional main street character retail with smaller store fronts. Buildings extend to the property line, and there is no parking in front.	0.15
	Small scale strip mall	More automobile oriented retail, still with smaller store fronts. Buildings do not extend to the property line, and have small parking fields in front of them.	-0.25
	Big box retail, power centre, enclosed mall, etc.	Large scale, stand-alone retail locations with large format stores, and large parking fields. In the case of malls, it would be large parking fields with an enclosed shopping centre.	-0.5
	Mixed Use (commercial-residential)	Mixed commercial and residential buildings of all formats.	0.25
	Employment/Industrial	Designated employment areas, containing a variety of employment uses, ranging from offices to industrial.	-0.25
	Institutional	Institutional related land uses, including schools, emergency services, government facilities, etc.	-0.1
Minor Uses	Community Facilities	Community land uses, including community centres, cultural centres, and arenas.	0
	Parkland	Publically accessible green and open space.	0.1
	Parking	Parking areas, including surface and parking structures.	-0.5
	Rail/Highway Corridor	Major highway and rail corridors.	-0.25
	Utility	Utility corridors.	-0.25
	Undeveloped Land	Undeveloped land/unutilized land.	-0.1

Table 2: Description of land uses, and RQF Values.

Pedestrian Facility	Description	RQF
Sidewalk	Paved pedestrian facilities that are adjacent to, but not separated from, the street.	0
No Sidewalk	The side of any roadway without a sidewalk.	-0.15 to -1*
Off-street Pathway	Paved pedestrian facilities that are not adjacent to the street.	-0.05
Informal Pathway	Unpaved, informal pathways which pedestrians use. These were only digitized when there was clear evidence from satellite imagery or Street View.	-0.25
Parking Lot	Paved automotive parking facilities. These were only considered in cases of GO Station parking lots where pedestrians would have to walk through the lot to reach the station.	-0.15
Crossing	The crossing of any vehicular roadway. Crossings were digitized only at intersections, or where other crossing facilities existed.	-0.25 to -1*
* Specific RQF values varied based on the road classification of the crossing or lacking sidewalk.		

Table 3: Description of pedestrian facilities, and RQF values.

Road Classification	Description	RQF
Expressway/Highway	A high-speed thoroughfare with controlled points of entry/exit and no pedestrian access.	N/A
Arterial	A major thoroughfare with medium to large traffic capacity.	-0.2
Collector	A minor thoroughfare with low to medium capacity.	-0.1
Local	A low-speed thoroughfare dedicated to accessing the front of properties.	0
Laneway	A low-speed thoroughfare dedicated to accessing the rear of properties	0.1

Table 4: Description of road classifications.

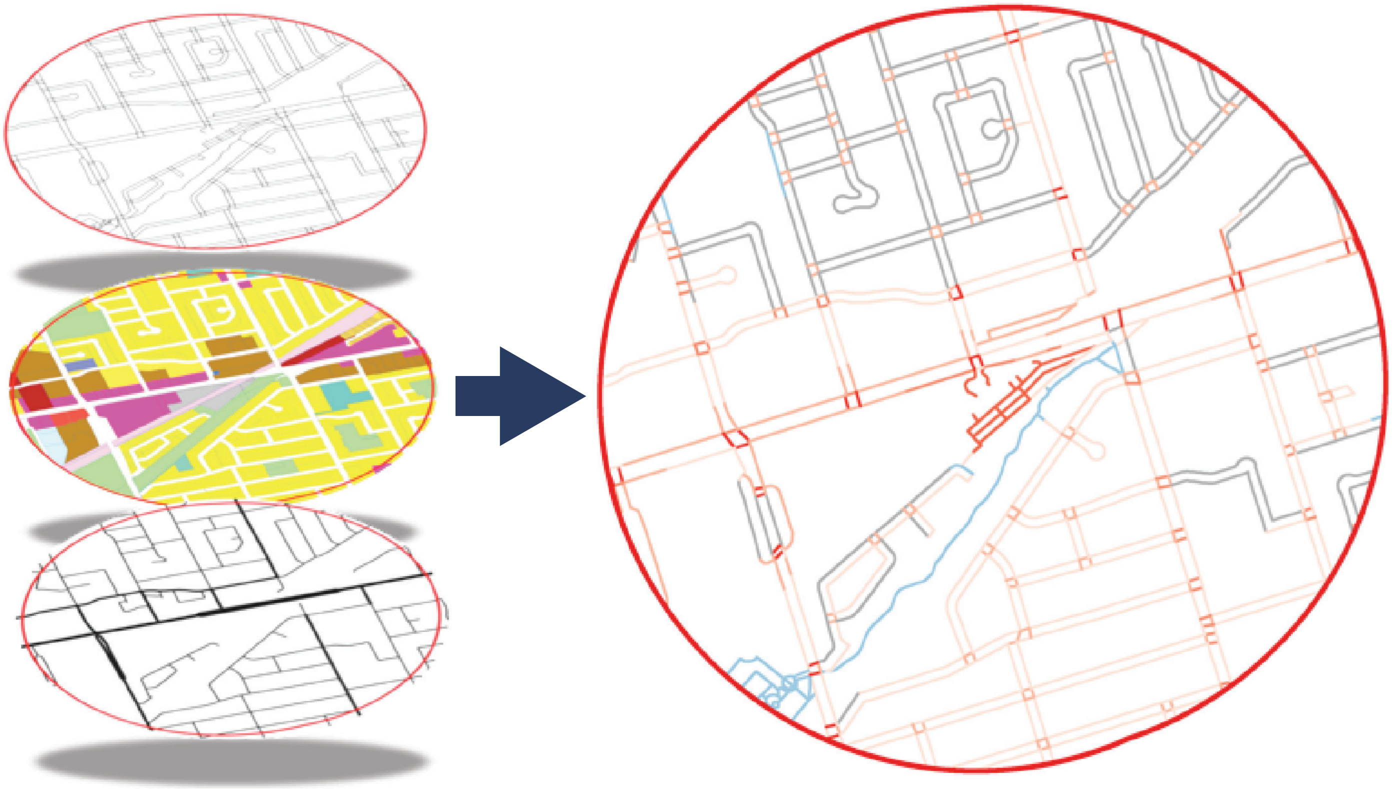


Figure 6: 'Layering' of built environment variables to create a single GIS layer for analsyis.

than one variable adjacent to each segment. Thus, each link on the network would have one code for land use type, one code for facility type, and one code for street classification type. Figure 6 conceptually shows what all these variables look like when layered on a pedestrian environment.

Route Quality Factor

The Route Quality Factor (RQF) was developed using these variables – land use, pedestrian facility type, and street classification type – to uniquely assess how the built environment affects pedestrian travel along a route, as well as be able to evenly assess station areas throughout the GTA. The RQF is a conceptual measurement, and not meant to empirically evaluate the absolute effects or differences of the built environment on walking. Instead, it assigns relative values to different variables based on what has been found within the literature. It is neither meant to estimate pedestrian trip generation, nor has it been calibrated to known walking levels, a step that would require substantial behavioural datasets based on micro-geographic sampling that are simply not available. However, the RQF allows for a high level assessment of walkability that can be used for sketch planning and to explore where future, more detailed studies make sense.

The general premise of the RQF is based on the notion of perceived cost. RQF treats environments associated with poorer pedestrian conditions as a cost to walking, and environments associated with better conditions as a benefit to walking. These costs are translated into distances, with the assumption that people are willing to walk further along routes with favourable conditions, and willing to walk less far along unfavourable ones. This assumption is implicit in much of the walkability literature, but has not been explicitly tested.

The RQF operates by assigning a positive, neutral or negative value to each segment, based on each built environment attribute connected to that segment:

- Positive values were assigned to variables that add to the pedestrian experience and make walking pleasant. Some examples include walking along sidewalks in traditional street oriented retail (Figure 7A), or through parks.
- Neutral values were assigned to variables that neither added to, nor subtracted from the pedestrian experience, and were rather base conditions. An example would be walking along a residential street with a sidewalk (Figure 7B).
- Negative values were assigned to variables that subtract from the pedestrian experience and make walking unpleasant. Some examples include walking along automobile oriented commercial arterials, through parking lots, or along roads with no sidewalks (Figure 7C-D).

RQF values are show in Tables 2-4.

Figure 7: Representative images of different RQF values. From top right; A a positive value along a traditional main street, B a neutral value in a residential neighbourhood, C a negative value along a busy road with no sidewalk, D a negative value through a parking lot.

Measuring Station Area Walking Sheds

Eglinton Station area is used in examples below to explain the methodology. The first stage in our analysis was to define the walking shed or pedestrian service area around each station. In each, we defined the area reachable from any of the transit station access points with an 800-metre walk in any direction along the network (see Figure 8). This translates into about a 10 minute walk for the average person. We call the result of this *unweighted travel* using simple network distance (*dn*), as it does not take into account the effects of environmental quality (RQF) on how far someone might be willing to travel.

This analysis was then re-run using an impedance value that incorporated the RQF. We call the results the *weighted distance* (*dw*) and calculate it as:

$$dw=dn*(1+(-RQF))$$

This inverts positive and negative RQF costs into impedance values (i.e. it converts negative environmental values into longer distances and vice versa), and adds one so that RQF values are computed as an additional percentrage of unweighted (*dn*)network values. Putting this all together, a segment with a unweighted distance (*dn*) of 100 metres and an RQF of -0.1, for example, would have a weighted distance (*dw*) of 110 metres.

Re-running the service area analysis using dw as the impedance value generally reduces the overall size of the service areas due to the prevalence of poor walking conditions in the transit station areas (Figure 9). In other words, impedance values converted from RQF translate into shorter distances people are assumed to be willing to walk. Again, its important to stress that this is a conceptual measurement of how the built environment may impact walkability and not an empirical measurement of how much less people are willing to walk. Such a measurement would require calibration of RQF values based on behavioural data that is not available.

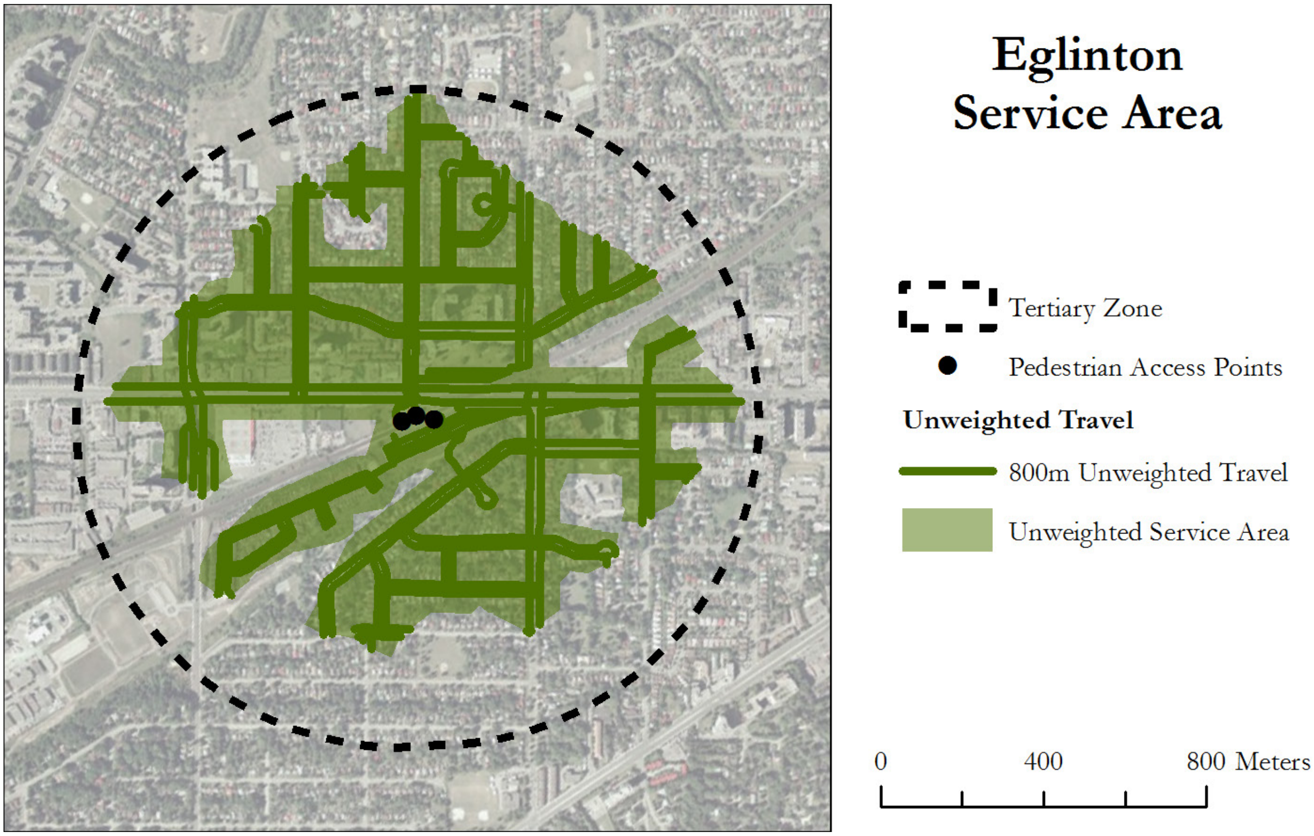


Figure 8: Unweighted service area for Eglinton Station. The green lines represent 800m of unweighted travel from the pedestrian access points along the network. The green shading represents the area reachable within that 800m walk.

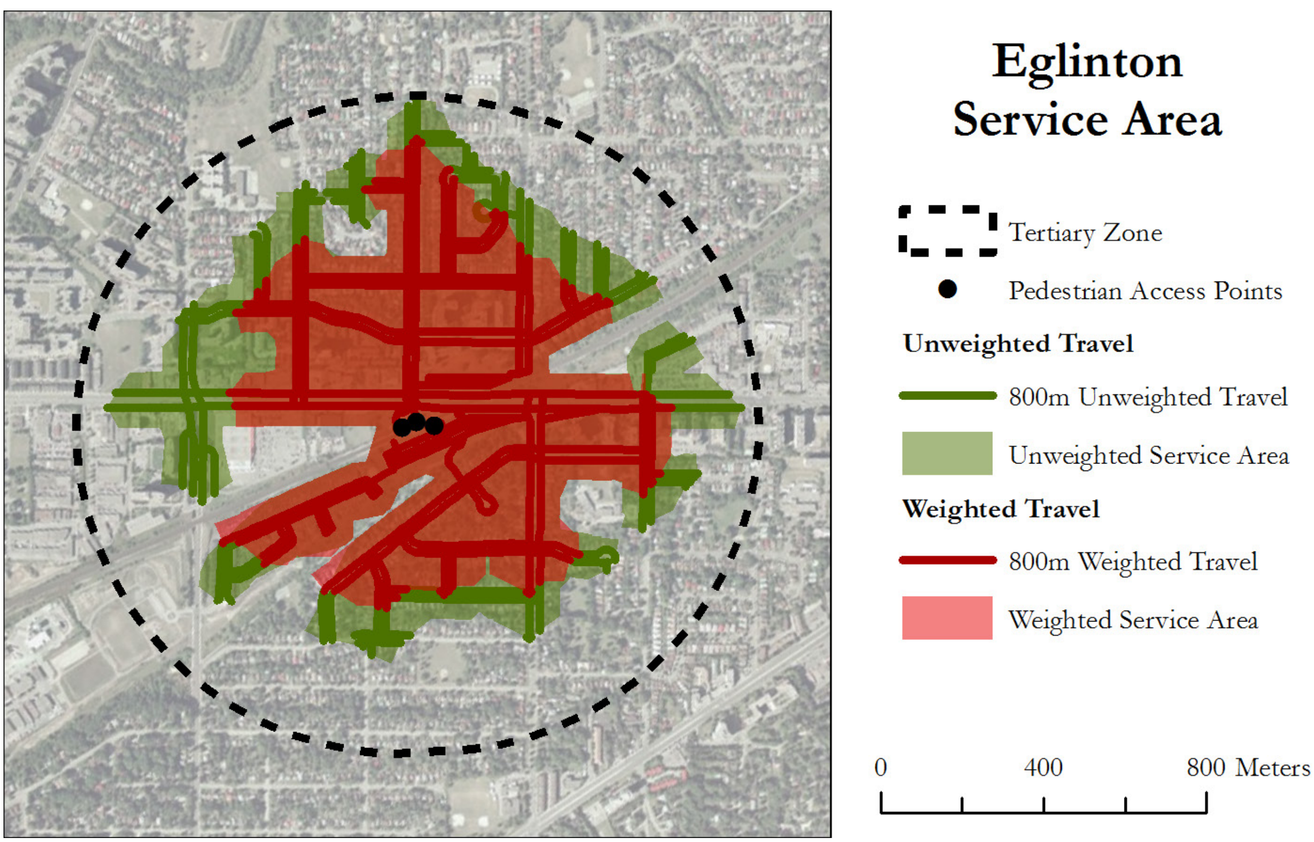


Figure 9: Both unweighted and weighted service areas of Eglinton Station. The green service area is the same as that in Figure 8, but has been overlain with the red service area, which represents weighted travel.

Once the two service area analyses were performed, the area and population within the weighted and unweighted service areas were measured. These values were then expressed as a proportion of all of the area and population within the 800 metre tertiary zone, in order to gauge the efficiency of the network.

Area efficiency was calculated as:

$$Ea=adn/a$$
$$Eaw=adw/a$$

and population efficiency was calculated as

$$Ep=adn/pa$$
$$Epw=adw/pa$$

where;

Ea is the unweighted network efficiency by area

Eaw is the weighted network efficiency by area

Ep is the unweighted network efficiency by population

Epw is the weighted network efficiency by population

adn is the area of the un-weighted service area

pdn is the population within the un-weighted service area

a is the area of the tertiary zone

pa is the population within the tertiary zone

As these proportions near 1, the service area or population nears those of the area defined by the 800 metre buffer, suggesting efficient networks. The analogous comparisons using the weighted service area measures the effect based on network quality. While this project just used total population for the sake of simplicity, it would be possible to perform additional demographic filtering to try and isolate people that more fall into GO Transit's user demographic.

Measuring Route Walkability Within Station Areas

A second type of network analysis examined pedestrian travel along routes to stations using a GIS routine known as closest facility analysis. Route usage was weighted based on population density distributions using census dissemination block data. In effect, the analysis uses the equivalent of a simple pedestrian trip generation rate, with more trips generated from high-density blocks than from low-density blocks. The technique is intended to estimate relative use of different route segments, and should not be interpreted as estimates of actual use. From each block, trips were assigned to the nearest segment of the pedestrian network, and routes were generated using a shortest network distance calculation to the nearest station access point. The results display the "accumulation" of trips along the network. Network segments that adjoin blocks with dense populations create more accumulation (are estimated to have more travellers) than low-density blocks. Also, segments near to the station that are shared by many routes, will have the highest accumulation values, as all pedestrians must use them to reach the station (see Figure 10).

Accumulation values were assessed simultaneously with route quality by comparing the aggregate distance of all walkers as measured with and without RQF as follows:

$$D\Delta=((1+RQF)*A)-A$$

where:

DΔ is the change in relative quality

RQF is the sum RQF value of the segment

A is the population weighted network accumulation, or simply the number of people walking along a segment. See Figure 11.

The formula adds one to the RQF to convert it from a relative percent to a constant value. This is then multiplied by the accumulation value to give a weighted accumulation, and the product of this is then subtracted by the unweighted accumulation value. The outcome of this is a relative value that shows how much the characteristics of the built environment subtract (negative DΔ) or add (positive DΔ) to the pedestrian experience. The greater the absolute magnitude, the more severe the condition is, and/or the more people experience it. For example, a segment with a RQF of -0.1, and an accumulation value of 10, would have a DΔ of -1. Again, like RQF, DΔ is a conceptualization of walkability, not an empirical measure. It is still useful, however, in identifying network links that have potentially high usage and poor quality. We noted, therefore, where segments of particular high negative DΔ occurred, and what types of built environment variables were found there.

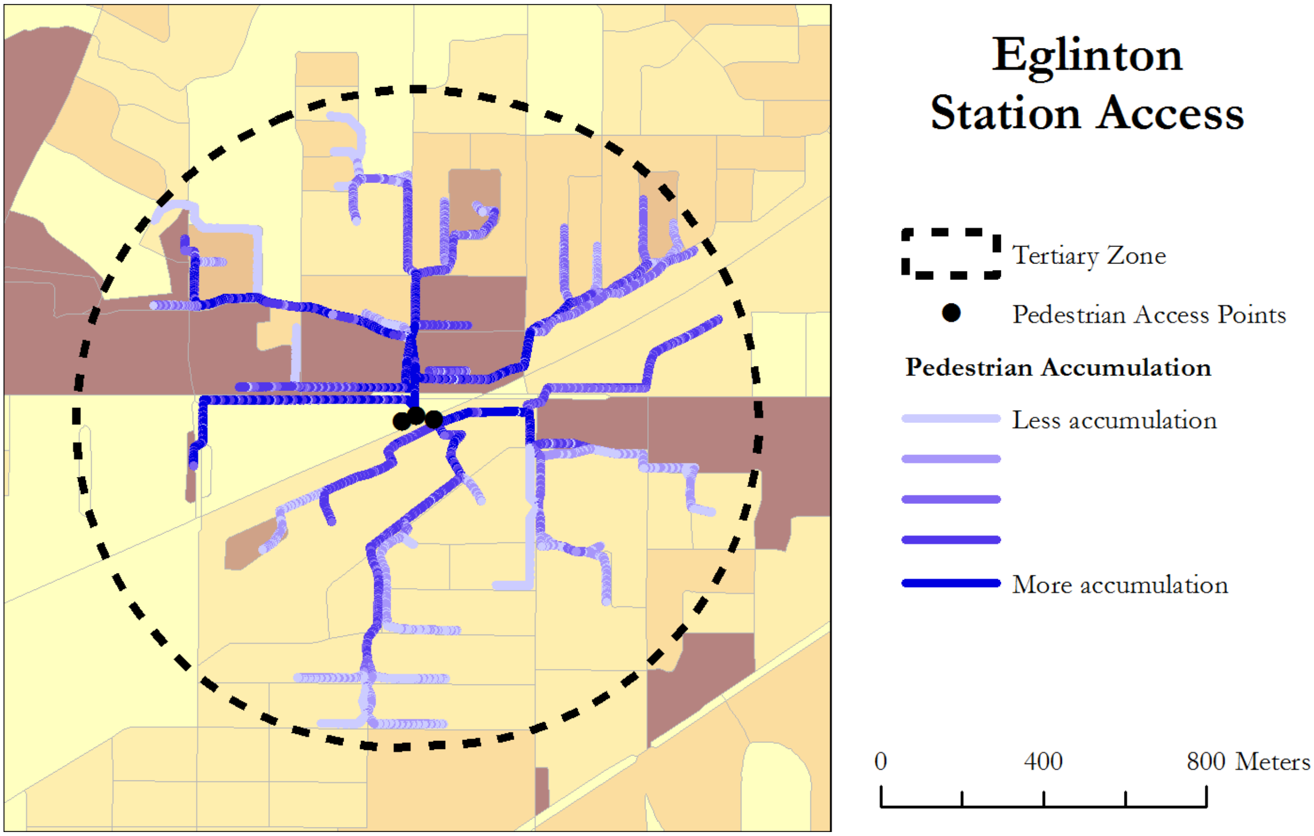


Figure 10: Pedestrian accumulation from each census dissemination block to nearest station access point. Pedestrian accumulation value is determined by both the population density of the origin block, and the amount of overlap along the routes. Accumulation values are ordinal

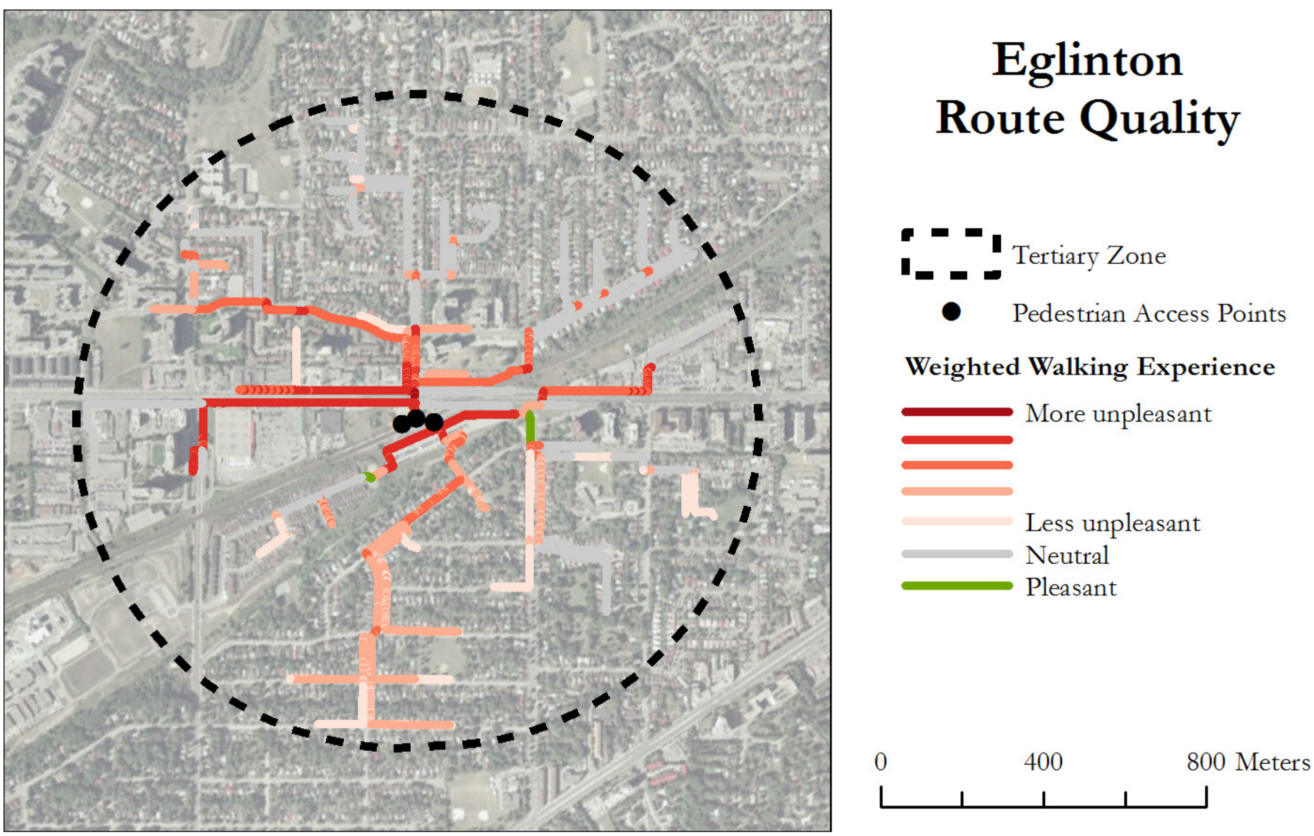


Figure 11: Walking experience along routes to the station. Darker red indicates a higher intersection of poor quality and high usage, while light red indicates a less severe condition, and gray is neutral. Green, when is does occur, represents an intersection of usage and good quality.

Basic Findings: Walkability Assessments and Improvements

Based on the exploratory work performed in Phase One, and the more detailed analysis work performed in Phase Two, we were able to determine, develop, and implement a methodology for assessing walkability around station areas. The following section summarizes principle findings and how conditions might be improved to both increase connectivity and quality.

GIS Analysis Results

The results of the GIS analysis from Phase Two confirm that walkability was indeed poor around the eight test stations, and good around the one test station. Overall, the causes of poor walkability were:

- Auto-oriented built form especially the prominence of arterial roadways, and some lack of pedestrian facilities.
- Inefficient network layouts. This refers to the variety of non-gridded street layouts (fragmented parallel, curvilinear, etc.), natural and infrastructure based barriers, and general lack of crossings.
- Non-supportive land uses immediate to the station. This refers to land uses such as employment or industrial, which do not serve the pedestrians in the area. These uses are not conducive to GO Transit's primary current use by commuters travelling to and from central Toronto, and as such limits current walkability.

Table 5 shows a summary of these general issues, along with their associated evidence.

Poor Quality Built Environment

Poor quality built environments were by far the leading cause of poor walkability, being found at six of the eight test stations examined. Our analysis showed that these stations tended to have more automobile oriented streetscapes, with travel concentrated on a small number of larger roads. As a result, pedestrians are often forced to travel along these routes with poor environments (with high traffic exposure, lack of enclosure, lack of human scale, lack of complexity) in order to reach the station.

Land use was the primary element of poor quality, mainly coming in the form of commercial or industrial uses that generally detract from the pedestrian environment. Land use impacts walkability by creating poor, neutral, or positive pedestrian environments, and also by determining how much exposure the pedestrian has to

Station	Issue			Evidence			
	Built Environment	Network Layout	Land Use	Large change in service areas	High RQF	Inefficient Network	Non-residential land use
Agincourt	X			X	X		
Burlington	X	X	X	X	X	X	X
Clarkson	X			X	X		
Cooksville		X				X	
Eglinton	X						
Erindale		X				X	
Milliken	X	X	X	X	X	X	X
Pickering	X	X	X	X	X	X	X
Danforth (Control)							

Table 5: Summary of walkability issues and supportive evidence.

these environments. Thus, low density residential uses comprise the largest geographic component of station areas, but do not have a large impact on walkability because: (1) they are fairly benign walking environments; and (2) streets with low-density residential uses generally do not accommodate many trips to stations as evidenced by low accumulation values. This latter point is both because low-densities do not generate much travel, but also because of the limited role that local, residential streets play in the overall pedestrian network.

Non-residential land uses, on the other hand often create large, negative pedestrian impacts. Again, this is because: (1) these uses, including employment uses, and auto-dominant environments such as big box centres, shopping centres, and strip commercial often create poor conditions such as high exposure to moving vehicles, lack of enclosure, etc.; and (2) they are often located along higher-order streets that are important links in the overall network, and thus have high accumulation values with many pedestrians using them on route to stations. The ways that land use environments combine with their location with in the pedestrian network is illustrated in Figure 12.

For similar reasons, poor quality pedestrian facilities were found to have mixed impacts on walkability depending on their location. One of the areas of largest

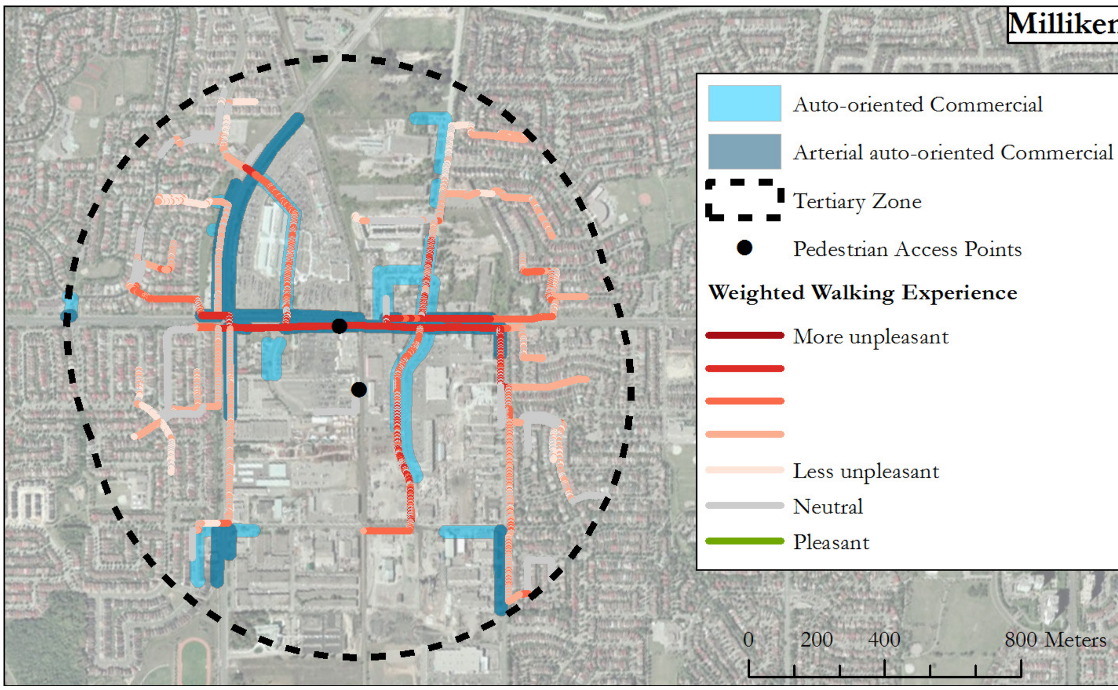


Figure 12: Auto-oriented commercial and arterial auto-oriented commercial typologies and weighted walking experience. Note how there is a large amount of unpleasant travel through these typologies.

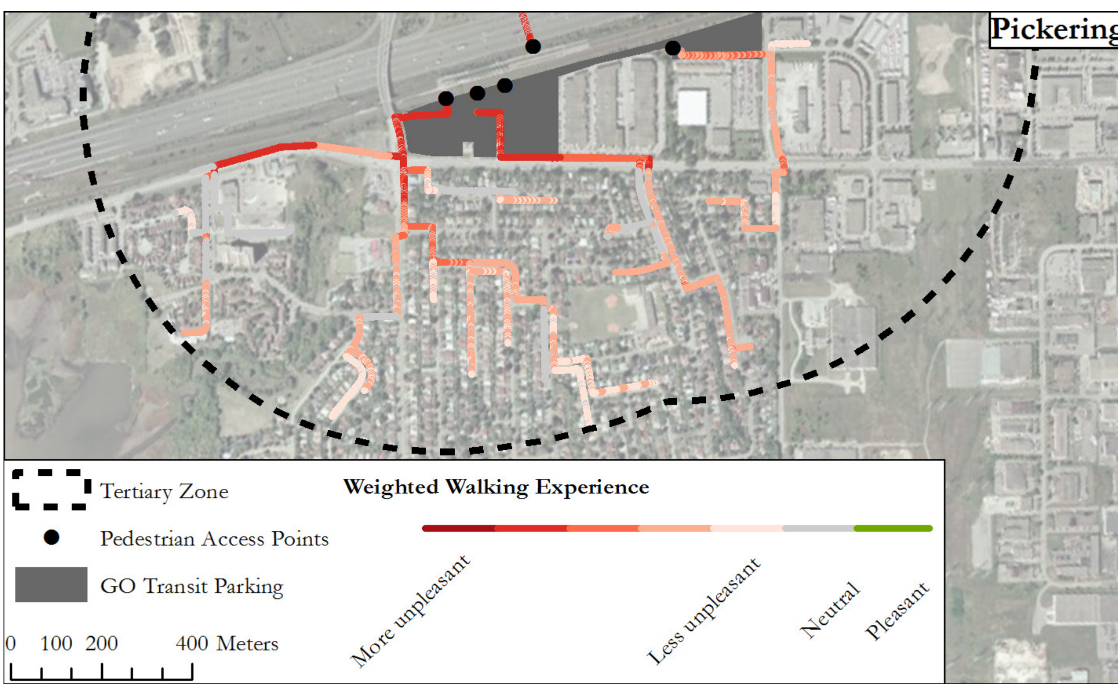


Figure 13: The impacts of walking through parking lots on pedestrain travel. In this example, all pedestrains arriving at the station from the south are forced to walk through the parking lot in order to reach the platform.

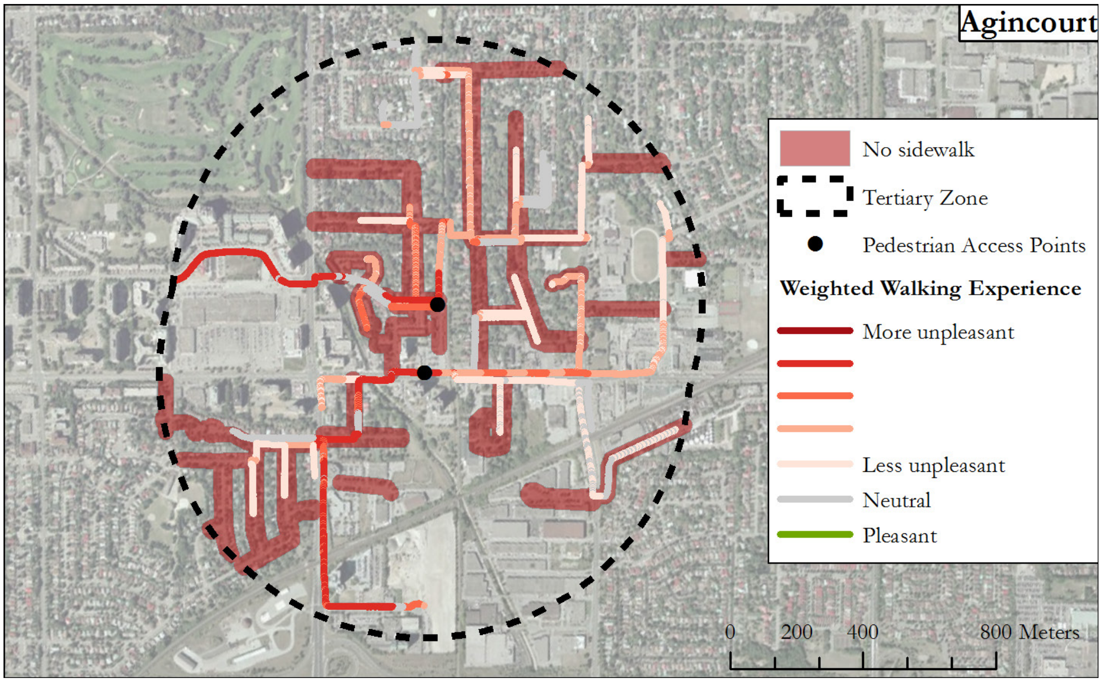


Figure 14: The impact of a lack of sidewalk facilities is less than may be expected. Notice how the areas without sidewalks mainly have travel that is within the first categories of less unpleasant walking experience, while the conditions along the main roads have travel that is more in the unpleasant range.

negative impact are the GO Transit stations areas themselves, which often lack any dedicated pedestrian facilities, and are also used by all pedestrians using the stations. In many stations the platform is only accessible via the parking lot, where literally *everybody* arriving at the station will have to traverse the parking lot. This includes, of course, those who walked to the station, but also those who drove, exited their vehicles, and are now pedestrians as well (Figure 13).

At the other end of the trip, residential areas without sidewalks may have fewer impacts than we hypothesized, or is reported in the research literature. In principle, we believe that all streets should be provided with sidewalks. In terms of our modelling to transit stations, however, these streets otherwise provide reasonable pedestrian environments, with relatively light, slow moving traffic as well as reasonable enclosure, human scale, and other positive environmental attributes. They also play a relatively minor role in station trips, with low accumulation values (See Figure 14). For other trip purposes, the modelling assumptions may not hold. For example, these streets may play a much more important role for travel to local schools. The impact of not having a sidewalk is also likely much greater for young children.

The impact of the final element of the built environment analysed, street classification was also mixed, mostly because of the weighting of RQF values. The largest negative impact was from arterial roadways, which also generally had large accumulation values, with many pedestrians walking to stations exposed to these environments. The environmental impact of the roadway itself, however, was assumed to be less than that of adjoining land use or pedestrian facility type (especially with sidewalks rarely missing from arterial streets). This assumption was based on our interpretation of the literature as we applied research findings to our methodology. We do not have high confidence that this weighting is correct, and walkability may be more influenced by the environments associated with different roadway classifications than assumed. However, given the conceptual nature of this research, we believe that this is a good starting point to assess the issue, with further empirical evaluation possible in subsequent studies.

Network Connectivity

Poor network connectivity was another leading cause of overall poor walkability, by increasing walking distances, and decreasing the size of a station's pedestrian service area. Based on a comparison of service areas based on an 800 metre walk to an 800 metre Euclidian buffer, we found that five of the eight test stations had relatively low connectivity. However, station access also depends on the distribution of population living around stations, and area based analysis alone was not always a useful metric for measuring the effectiveness of the pedestrian network. In an additional piece of analysis we tested increasing the efficiency of networks in station areas by modelling the addition of new pedestrian links. This is discussed below under "Improving Conditions." Here we discuss network efficiency.

Our two measures of efficiency – area and population – showed different results. Stations with higher percentage of area coverage indicated a more connected network, while lower area coverage indicated less connected networks. This poor connectivity was generally caused either by curvilinear network layouts, or low street density immediate to the station itself. Higher population coverage indicated that there were more people living close to the station and/or that there was good connectivity into the neighbourhood, while lower values indicated the opposite. See Figure 14.

Interestingly, gridded street layouts are not *necessarily* required to have a lot of people within walking distance to the station, as this is also a function of the distribution of population density. High-density residential developments close to the station will boost the number of people within 800 metres, without the need to create new blocks or street layouts. This sort of transit-oriented development is also supported by existing policy.

Land Use

Land uses and built environment configurations that are not supportive of pedestrian activity were found in several station areas because they created limited zones of potential riders. For example, stations located in industrial parks or large commercial areas limited pedestrian access, offered few pedestrian friendly features, and reduced the number of pedestrians living

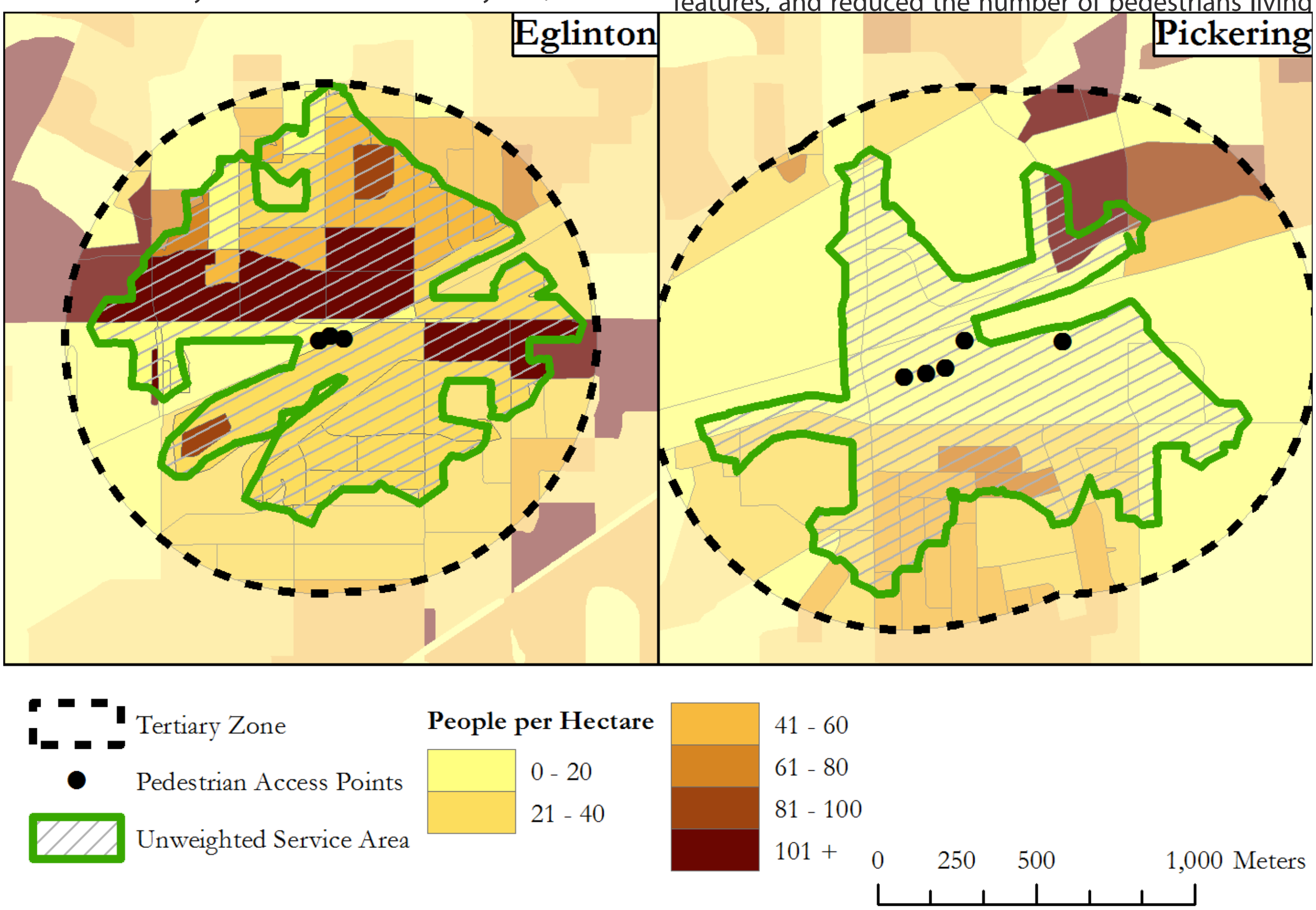


Figure 14: Illustration of population based network efficiency. The 800m service area in Eglinton reached several high density apartment blocks. Conversely, the same distance in Pickering mainly reached low density residential and failed to reach the high density units north of the station.

close to the station. Since 800 metres was used as a walkable distance, these designs severely limited the number of people that could even reach the station, much less the quality of their walking experience. The methodology we developed could be adapted to evaluate some of these zones as potential employment destinations. Given the current configuration of most GO service and the low employment densities of these zones, we did not undertake this evaluation.

Improving Quality

A goal of this project was to be strategic about where resources should be spent. We used the following criteria to identify locations for walkability improvements:

- **Need**. Existing conditions are relatively poor.
- **Relative impact**. These improvements would have to have a high relative impact, and affect many users.
- **Feasible**. Feasibility was largely based on planning concerns, such as the difficulty of redeveloping single family subdivisions. We did not look explicitly at fiscal impacts, but did isolated ourselves to areas were previous examples of modest investment can be found.

The two areas that should be the focus for improvements are:

- Along commercial arterials, where there is higher usage, often poor quality conditions, and land which could reasonably be planned for redevelopment.
- In GO Transit parking lots that are actually controlled by Metrolinx, and where there is extremely concentrated usage but often poor quality conditions.

The most improvement potential is along auto-oriented commercial arterials for a number of reasons. First, there is high accumulation along these arterial streets, as these higher order roads – by design – tend to be main routes for pedestrians once they leave areas of local streets in subdivisions. Second, the pedestrian environment is generally poor, with arterials designed around vehicular travel. Finally, it is broadly feasible in planning terms to redevelop these areas with higher density, more pedestrian-oriented uses. This is compatible with Provincial policy such as the Provincial Policy Statement (2014), The Growth Plan for the Greater Golden Horseshoe (2006), and the Transit Supportive Guidelines (2012). This support is re-iterated in various municipal planning policies and land use controls including Toronto's Official Plan. Although Metrolinx does not have the direct planning authority over these areas, they should work with local municipalities and land owners to create more transit supportive communities in their station areas.

GO Transit parking lots are the other area that clearly should be targeted for improvement, especially as they are under the agency's control. As discussed previously, these parking lots are an intersection of very high usage, and poor quality. By upgrading the quality of these segments, it would improve the experience of almost everyone arriving at the GO Station, including of course pedestrians, but also motorists who have exited their vehicle, and cyclists.

One caveat to note about this section on improving quality is that the methodology developed for this report is only capable of assessing current conditions, not predicting how changes to conditions will affect future walkability. Walkability is a very complex concept, and simply changing a variable from 'commercial' to 'mixed-use' in the model will not capture the nuances that come from such a change. For example, a mixed use land use classification in a downtown context is not the same as the identical mixed use classification in a suburban one. Such differences get into the specifics of urban design and pedestrian perception. As discussed, the model assumes a fairly conventional suburban built environment, which such changes are intended to alter.

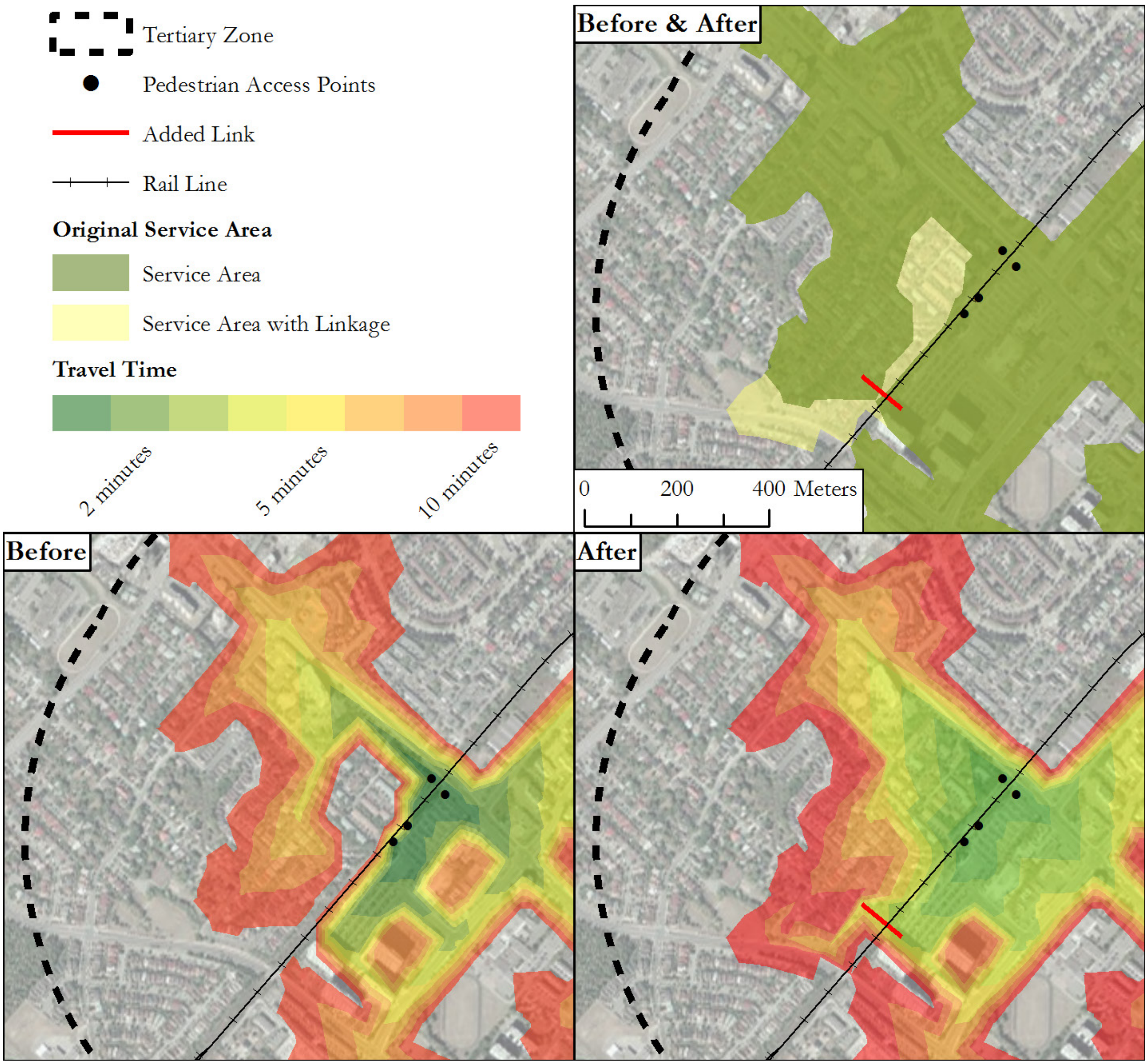
Improving Connectivity

The other aspect of improving walkability we explored was improving connectivity within the station area. We developed three typologies of connectivity improvements, modeled their impacts on pedestrian access, and provided some rough metrics about the benefits of these improvements. These typologies are: (1) the addition of a rail under or overpass; (2) the addition of a new pedestrian pathway along a rail corridor near a station; and (3), the provision of a pedestrian easement across private land to connect streets. The components of the analysis was speculative, based on testing a few hypothetical linkages in station areas, and no detailed feasibility analysis was conducted. The main goal was to create examples of the potential effects of adding network links.

Rail Under/overpass

One of the biggest barriers to mobility within the station area is the rail corridor itself. This infrastructure barrier limits pedestrian travel, often forcing people to take indirect walking routes in order to reach a crossing. Rail under/overpasses can remedy this situation by bridging the barrier, and allowing for more points of access.

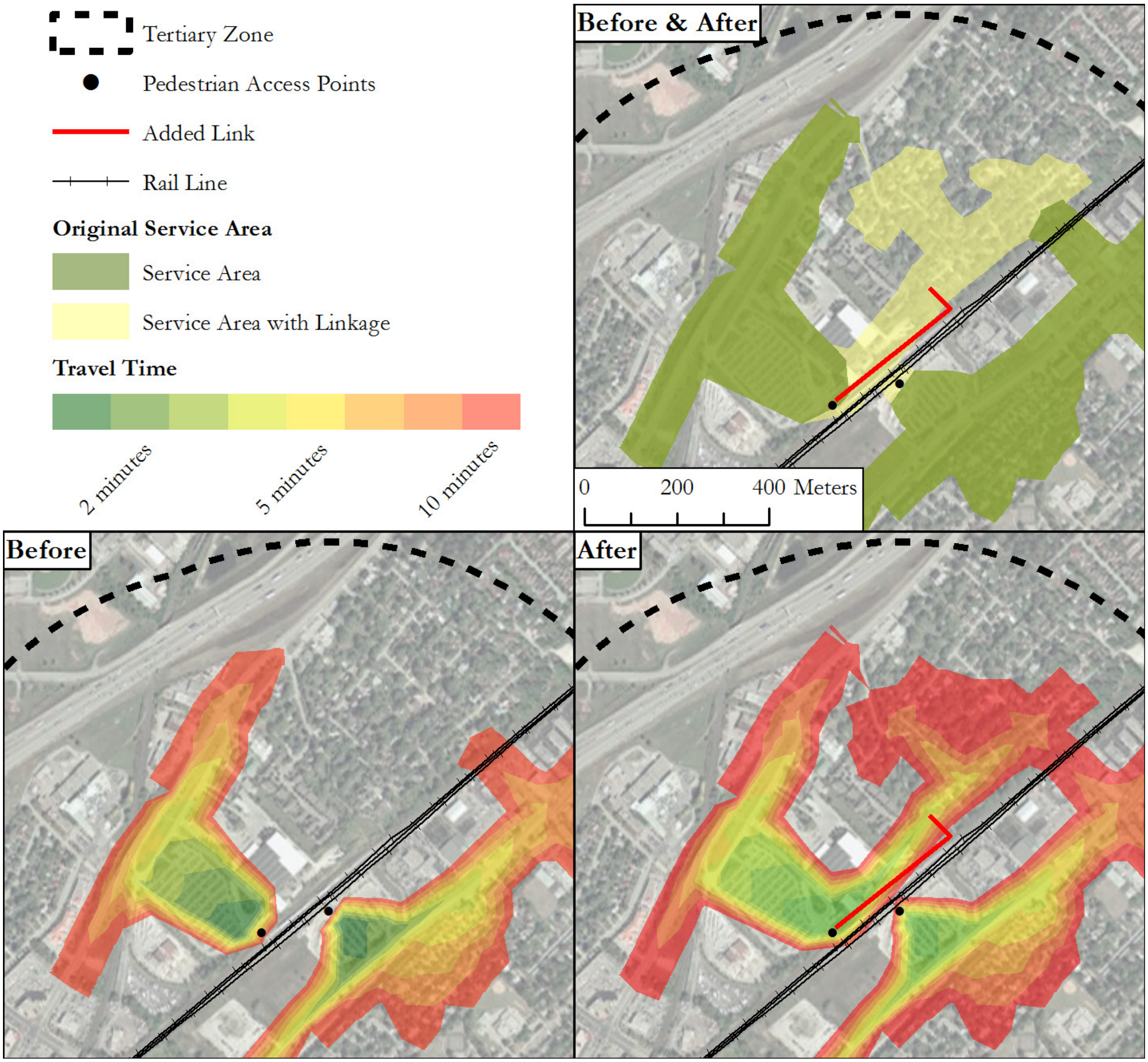
To demonstrate the effect on network connectivity, we modeled a new connection over the Milton Line rail track at Cooksville GO. This connection was approximately 80 metres long, and connected residents in the neighbourhood to the north of the station to the eastern portion of the station. This increased the walking shed to cover an additional 26% of the population, relative to the original shed. Additionally, it reduced travel time for existing residents by allowing more directly access the station, rather than walk around to Huronontario Road.



Rail Adjacent Pathway

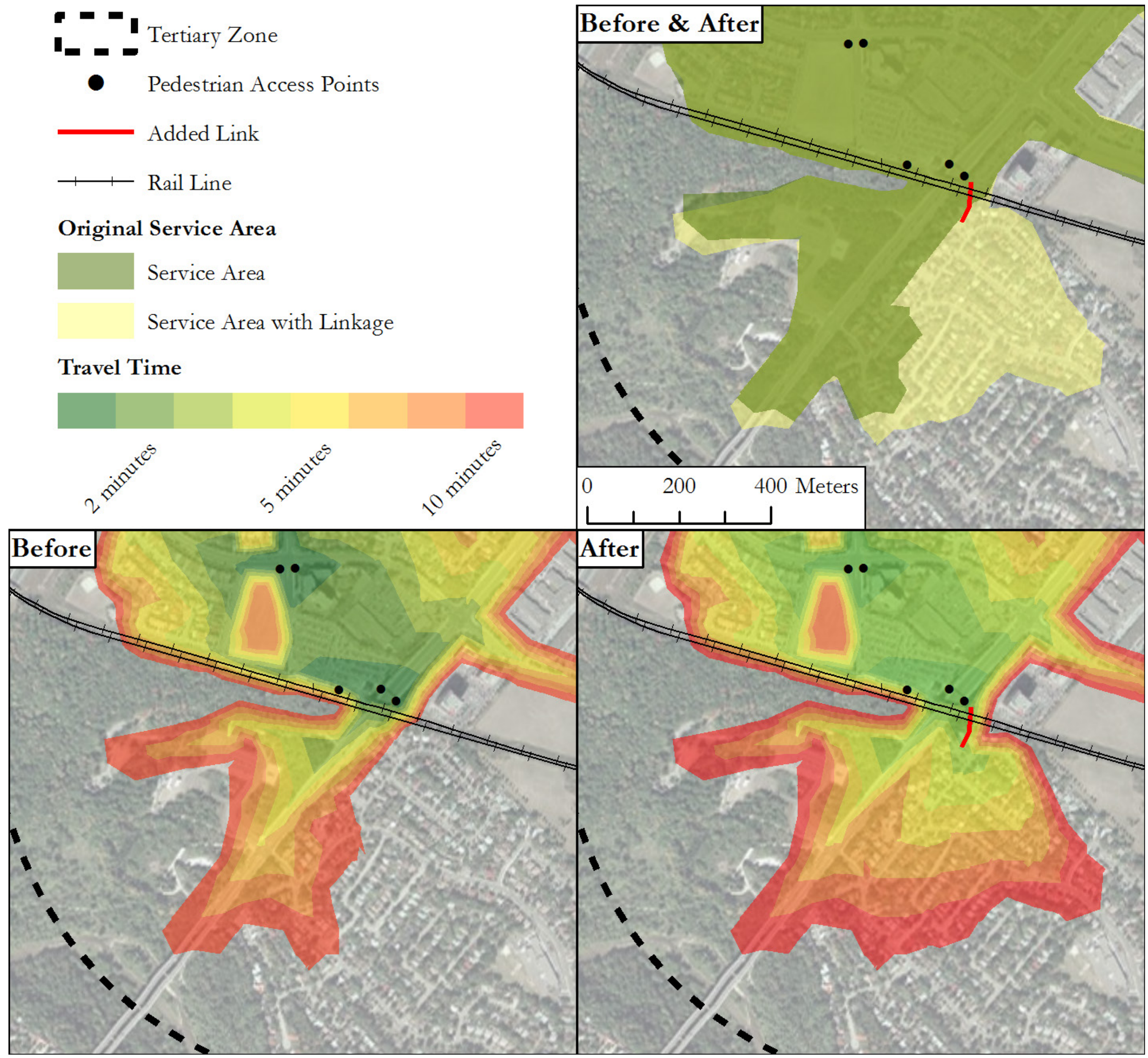
Adding links along rail corridors can bring new areas into walking distance to rail stations that, previously, would require indirect routes, often out to arterial roadways, and then back to the rail line. Such connections can also bypass the poor walking conditions on arterials (but may introduce other issues such as creating isolated pathways that do not feel safe).

To illustrate the effect of a new rail adjacent pathway, we modeled a new pathway to the north of the Lakeshore West Line near Burlington GO. This station area already has very poor connectivity due to its large parcel size and poor street layout. However, by adding a 400 metre pathway, a residential neighbourhood that is not currently served within an 800 metre walking shed was added to the service area, increasing overall population coverage by 10%.



Public Easement

Typical post-World War Two suburban street networks often have indirect walking routes. In some subdivision designs easements are used to connect loop streets and cul-de-sacs directly to school sites or to arterial roadways where bus stops are located, in order to decrease walking distances. Such easements are far from universal and are not typically set up to serve rail transit (although there are exceptions). In a final example, in Erindale Station we modelled a new easement, a small 50 metre pedestrian pathway and over/underpass to bridge the tracks, connecting residents of a local subdivision to the station. Because there was only one road leading out of the subdivision, approximately half a kilmoetre down the road, there was a vast amount of potential users in the area that were not within an 800 metre walk. In fact, there was some as close as 100 linear metres from the station that required more than 800 metres of travel to reach the station. By adding this new connection, the station would increase its population coverage by 55% and reduce the total time for others by removing the need to walk out to the main road and double back to the station.



Conclusion

This project was able to successfully take elements from both inventory and built environment methods, and combine them in an efficient way to assess walkability around GO Transit stations. The route quality factor (RQF) offers a potentially interesting and unique way to examine walkability in future studies. This, combined with the more empirical accumulation analysis, our methods provides planners and policy makers a way to easy get obtain high level overview of walkability in the station area, including where areas of targeted improvements can be made, and what the potential impacts of new infrastructure investment would be.

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Appendix

The following are some of the output tables of the model developed in Phase Two. These tables are meant to show the full breadth of analysis possible within the model, but rather to demonstrate some of the key outputs.

For full station and mobility hub maps from Phase One, and the full series of analysis maps from Phase Two, please consult the map books attached to this report.

Average RQF Values

Lower values indicate worse conditions, while values closer to zero indicate better conditions. Station average values are the distance weighted average of all segments in the network, while average route values are the distance weighted average of only the traversed segments of the network. Similar values indicate that the trip to the station is of similar quality to the entire network, while route values lower than average values indicate that travel to the station is of a lower quality than the network average.

Station	Average RQF Value Within Station Area	Average RQF Value Along Routes
Agincourt	-0.23	-0.23
Burlington	-0.26	-0.38
Clarkson	-0.20	-0.24
Cooksville	-0.16	-0.19
Eglinton	-0.16	-0.21
Erindale	-0.14	-0.14
Milliken	-0.25	-0.42
Pickering	-0.26	-0.34
Danforth (Control)	-0.11	-0.14

Network Efficiency Measures

Gross network efficiency by area indicates the area with the !! service area as a percentage of the area of the tertiary zone. Higher percentages are better, as they indicate that there is more area traversable within an 800m walk from the station. Effective walking efficiency is similar to the gross walking efficiency, except that it represents the area of the !! service area as a percentage of the tertiary zone. Higher values are better; as they indicate that there are more areas reachable within 800m of RQF weighted travel.

Station	Gross Network Efficiency		Effective Network Efficiency		Change in service area by area	Change in service area by population
	Area	Population	Area	Population		
Agincourt	42%	43%	29%	21%	-30%	-51%
Burlington	19%	24%	9%	8%	-50%	-66%
Clarkson	77%	54%	31%	32%	-35%	-41%
Cooksville	36%	35%	24%	32%	-33%	-9%
Eglinton	51%	65%	33%	41%	-36%	-37%
Erindale	37%	37%	30%	37%	-19%	0%
Milliken	31%	28%	13%	3%	-58%	-89%
Pickering	35%	13%	19%	5%	-45%	-60%
Danforth (Control)	60%	65%	54%	41%	-11%	-37%

Average RQF Values

Percent non-residential is the percent (by gross area) of the non-residential or greenspace, within various distances to the transit station. Within a 250m buffer was seen as a directly incompatible use as it indicted the station was in a non-residential location, while within the 800m buffer was used as a confirmatory measure. Non-residential use was determined to be everything except all residential typologies and mixed-use. Greenspace was also excluded because it was not considered an incompatible land use within this test. Since GO Transit currently operates as a mainly commuter service, non-residential uses were considered incompatible. Lower values for both columns are considered better, as there is less incompatible uses (such as commercial, industrial, etc.) around the station.

Station	Percent non-residential (250m)	Percent non-residential (800m)
Agincourt	26%	46%
Burlington	87%	59%
Clarkson	54%	44%
Cooksville	49%	27%
Eglinton	37%	20%
Erindale	44%	37%
Milliken	100%	64%
Pickering	94%	68%
Danforth (Control)	32%	22%