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Accessibility to Employment Activities in the GTHA

Haoyang (Andre) Li
James Vaughan
Eric J. Miller

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UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

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1. Introduction

This report presents an overview of the accessibility to employment activities in the Greater Toronto-Hamilton Area (GTHA). Two measures, including the isochrone measure, and another random utility-based measure, are used to compute the accessibility. A scaling procedure, introduced in Yang (Luna) Xi's thesis, is further implemented to compare the random utility-based accessibility. The next section of the report provides a literature review to discuss the conceptual background of accessibility, which highlights the definition of accessibility, the importance of accessibility, and accessibility axioms. Moreover, an overview of different accessibility measures is also included in section two. Section three discusses the methodology of the research by introducing the two accessibility measures used in this study and the scaling procedure of the random utility-based accessibility. That is followed by section four, which describes the study area, sources of data and data processing methods of the research. Then, section five presents the results of the accessibility computation and provides a detailed analysis of the results. Section six concludes the report, while section seven highlights the possible steps for future studies.

2. Literature Review

This section provides a brief literature review of the fundamental concepts of accessibility as well as an overview of different accessibility measures.

2.1 Conceptual Background of Accessibility

Accessibility is defined as the "potential of opportunities for interaction" that measures the spatially distributed activities for a specific location considering the abilities and desires of travellers (Hansen, 1959) in the transportation context. Based on the proposition that "the primary role of a transportation system is to provide people and businesses with access to other people and businesses so that they can physically engage in spatially and temporally distributed activities of all kinds, and so that they can physically exchange information, goods and services" (Miller, 2018), it demonstrates that accessibility has huge importance to transportation planning and modelling. More importantly, from a socio-economic perspective, applying accessibility measures in transportation engineering, it helps to improve social equity (Miller, 2019).

It is also widely agreed that there is a set of axioms existing for accessibility, as mentioned in Miller (2018). They are listed as follows:

1. Accessibility varies from one point in space from another.
2. Accessibility is activity specific.
3. Accessibility intrinsically combines the concept of travel impedance with attractiveness and/or magnitude of opportunities.
4. Accessibility involves the integration or summation over the space of opportunities, weighted by their travel impedance.

The term "activity" in the second axiom can be interpreted as the purpose of a trip. For example, the purpose of the trip includes but is not limited to employment, community services, health care, and education. The term "travel impedance" in the third axiom refers to the ease or difficulty for one to interact with other locations in space. Usually, travel distance or time is applied to measure travel impedance. The term "attractiveness" in the third axiom is related to the concept of desirability. Two common ways to evaluate attractiveness are the size and location of a particular type of opportunity.

It is also worth noting that it is a common practice in accessibility research to divide the study area into spatial units, such as traffic analysis zones (TAZ). With that being said, a point-to-point accessibility analysis can be simplified to a zone-to-zone analysis, which helps to greatly reduce the number of O-D pairs involved and saves computation time (Meyer & Miller, 2001). In addition, accessibility is more specific. That means that when time is used to evaluate travel impedance, the accessibility for different trip modes, for example, auto, transit, and cycling, should be evaluated separately. However, such an approach is not required for multi-modal accessibility analysis, where all modes are considered in one accessibility measure (Miller, 2019).

2.2 An Overview of Accessibility Measures

Various measures are available for accessibility analysis. One extremely simple but somehow restricted accessibility measure is the distance to the nearest location measure, in which accessibility is defined as the minimum travel distance or time to the nearest location of a particular type of activity.

Meanwhile, the isochrone-based accessibility measure, where accessibility of a place to a particular type of activity is defined as the numerical sum of opportunities of that type of activity that lies within a maximum travel distance or time from that place, is another simple and intuitive accessibility measure. The isochrone-based measure is the most used accessibility measure in transportation planning. Nevertheless, it has several theoretical and methodological issues, for example, the arbitrariness of the threshold travel distance and time, the assumption of the indifference of travel distance or time to activities within the threshold, and another assumption of the irrelevance of accessibility for activities located beyond the threshold (Miller, 2019).

Gravity measures are also a common accessibility measure in practice, as first proposed in Hansen (1959). In this approach, a place's accessibility for a type of activity is equal to the sum of opportunities for that type of activity available weighted by their travel impedance. It resolves some of the latter two limitations of the isochrone-based approach; however, the measure's analogy to the concept in physics is somewhat doubtful.

Random utility-based measures are another major type of accessibility measure. They are derived from random utility theory, extending from neo-classical microeconomic theory (Manski, 1977). The most common random utility-based measure is the multinominal logit (MNL) model. This model defines accessibility for an individual as the expected maximum utility for a particular type of activity (Ben-Akiva & Lerman, 1985). This expected maximum

utility is the so-called "logsum" or "inclusive value" term defined by the natural logarithm of the logit model denominator. It should be noted that this accessibility measure has a very strong theoretical background. However, since this approach is more complicated and disaggregate, and requires a substantial amount of data to complete the computation, it is not widely used in transportation engineering practices (Koenig, 1980).

A more in-depth discussion of the accessibility measures used in this research will be included in sections 3.1 and 3.2 of this report.

3. Methodology

This section presents a detailed discussion of the two accessibility measures used in this study, which are the isochrone measure and the GTAModel PoRPoW model. In addition, an introduction of the scaling procedure is included in the last subsection of this section.

3.1 Isochrone Measure

As mentioned in section 2.2, isochore measure is a simple, intuitive, and widely used accessibility measure, but with noticeable theoretical and methodological issues. The accessibility at a place to a particular type of activity is defined by the following equation:

$$A_i^p = \sum_{j \in J_i^m} X_j^p \quad [1]$$

Where:
A_i^p = Accessibility of zone i to activity type p
X_j^p = Size of activity type p in zone j
J_i^m = Set of zones that lie within the threshold distance or time m from zone i

Moreover, the location choice model that determines the chance of choosing a particular type of activity in a zone is defined by the following equation:

$$P_j^{ip} = \begin{cases} \frac{X_j^p}{\sum_{j' \in J_i^m} X_{j'}^p} & if \quad j \in J_i^m \\ 0 & otherwise \end{cases} \quad [2]$$

In the context of this study, employment activity is the type of activity being focused. The employment activity can be further differentiated into four different employment occupation types, including general office, manufacturing, professional, and sales and services. Within each employment type, the nature of the activity can also be differentiated by the metric of full-time and part-time employment.

The measure of threshold time, also known as cut-off time, is used for this research. Although no universal or optimal threshold time has been defined for accessibility research, 30 and 45 minutes are two very common choices of cut-off time (Xi, Miller & Saxe, 2018), and they are

used in this study. Also, it is worth mentioning that travel time is mode-specific and varies by time of day. Hence, analyses will be specified based on transportation mode and time of the trip.

3.2 PoRPoW Model

The Place of Residence – Place of Work (PoRPoW) model is a random utility-based, doubly-constrained, MNL model that lies within the GTAModel framework (Travel Modelling Group, 2021). The accessibility at a place to a particular type of activity is defined by the following equation:

$$A_i = log \sum_{j'}^{N} e^{\alpha f_{ij'} + \log K_{ij'} + logB_{j'} + logEMP_{j'}} \quad [3]$$

Where:
A_i = Accessibility of zone i to employment
EMP_j = Employment (number of jobs) located in zone j
N = Number of zones
f_{ij} = Impedance function for travel from zone i to zone j
α = Scaling factor of the impedance function
K_{ij} = Calibration "K-factor" for O-D pair i-j (default value is 1.0)
B_j = The other "balancing factor"

In this case, the impedance function f_{ij} is defined as follows:

$$f_{ij} = log \sum_m e^{\beta^T X_{ijm}} = \log\left(e^{\beta_{aivtt} aivtt_{ij}} + e^{\beta_{Transit} + \beta_{tptt} tptt_{ij}} + e^{\beta_{Active} + \beta_{dist} dist_{ij}}\right) \quad [4]$$

Where:
β = Column vector of parameters
X_{ijm} = Column vector of explanatory variables characterizing the systematic utility of travel by mode m from zone i to zone j
β_{aivtt} = Weight for auto in-vehicle travel time (aivtt)
$aivtt_{ij}$ = The expected auto in-vehicle travel time between zone i to zone j
$\beta_{Transit}$ = A constant for the transit branch
β_{tptt} = Weight for transit perceived travel time (tptt)
$tptt_{ij}$ = The transit perceived travel time between zone i and zone j
β_{Active} = A constant for the active transportation branch
β_{dist} = Weight for the distance
$dist_{ij}$ = The walking distance between zone i and zone j

It is worth mentioning that the explanatory variables are based on the AM-peak hour (7:00 AM) travelling conditions. As such, the only accessibility available from this model is the AM-peak hour accessibility. Also, the PoRPoW accessibility is in the unit of utils; a higher util indicates a greater level of accessibility.

In this model, both A_i and B_j act as balancing factors. B_j is defined by the following equation:

$$B_j = 1/\sum_{i'}^{N} A_{i'} ELF_{i'} e^{\alpha f_{ij'} + \log K_{ij}} \quad [5]$$

Where:
ELF_i = Employed labour force (number of workers) living in zone i

Moreover, both A_i and B_j need to satisfy the following constraints:

$$\sum_j^N T_{ij} = ELF_i \quad \forall\, i = 1, N \quad [6]$$
$$\sum_i^N T_{ij} = EMP_j \quad \forall\, j = 1, N \quad [7]$$

Where:
$$T_{ij} = \frac{ELF_i B_j EMP_j e^{\alpha f_{ij} + \log K_{ij}}}{\sum_{j'}^{N} B_{j'} EMP_{j'} e^{\alpha f_{ij'} + \log K_{ij'}}} \quad [8]$$

The purpose of the balancing factors is to consider the competition of employment opportunities. It is important to account for competition in accessibility analysis since an individual living in an area that has a large number of employment opportunities but with many other individuals living nearby may not have a high level of accessibility due to any potential competition (Miller, 2019). In the PoRPoW model, a B_j value less than one will reduce the utility of a zone, which makes the zone less attractive for individuals looking for jobs. Nevertheless, a B_j value less than one will increase the utility of the zone, making the zone more attractive.

Furthermore, the location choice model that determines the chance of choosing a particular type of activity in a zone is defined by the following equation:

$$P_{j|i} = \frac{T_{ij}}{ELF_i} = \frac{B_j EMP_j e^{\alpha f_{ij} + \log K_{ij}}}{\sum_{j'}^{N} B_{j'} EMP_{j'} e^{\alpha f_{ij'} + \log K_{ij}}} \quad [9]$$

Where:
$P_{j|i}$ = Conditional probability that a worker living in zone i works in zone j

As with the isochrone accessibility analysis, the PoRPoW analysis breaks down employment occupation type into eight categories. A more detailed documentation of the PoRPoW model can be found on the website of Travel Modelling Group (TMG) at the University of Toronto.

3.3 Scaling Procedure

A major issue of the PoRPoW model and all random utility-based accessibility measures is that the outputted accessibility values are ordinal. This means that accessibility values from two different models (say, for two different occupation groups) are not directly comparable (Miller, 2019). In addition, the unit “utils” for PoRPoW accessibility has no physical meaning. Different individuals perceive this unit in very different ways, and it is hard to classify “utils” into desirable and undesirable ranges (Miller 2019; Xi, 2019).

A scaling procedure is required to resolve these issues by converting the unit "utils" to common units of "minutes" or "dollars" using a series of simple procedures. Dong, Ben-Akiva, Bowman, and Walker (2006) propose a procedure to scale the random utility-based accessibility. This scaling procedure is further investigated by Yang (Luna) Xi (2019). The overall procedure can be mathematically represented as below:

$$\alpha_i = \frac{A_i(\Delta z) - A_i(base)}{\Delta z \sum_j P_{j|i} z_{ij}} \quad [10]$$

$$\widetilde{A_i} = \frac{A_i}{|\alpha_i|} \quad [11]$$

Where:
α_i = Scaling factor (in the unit of utils/minutes or utils/dollars)
$A_i = A_i(base)$ = Accessibility of zone i based on current explanatory variables
$A_i(\Delta z)$ = New accessibility of zone i after changing one of the explanatory variables by a fraction amount of Δz
$\widetilde{A_i}$ = Scaled accessibility of zone i (in the unit of minutes or dollars)

For this study, the aivtt variable is adjusted by increasing its value by 10%, which also implies that the scaled accessibility is in the unit of minutes, and a lower value indicates a higher level of accessibility. The mathematical operation of the scaling factor can also be visualized on a Cartesian coordinate system as below:

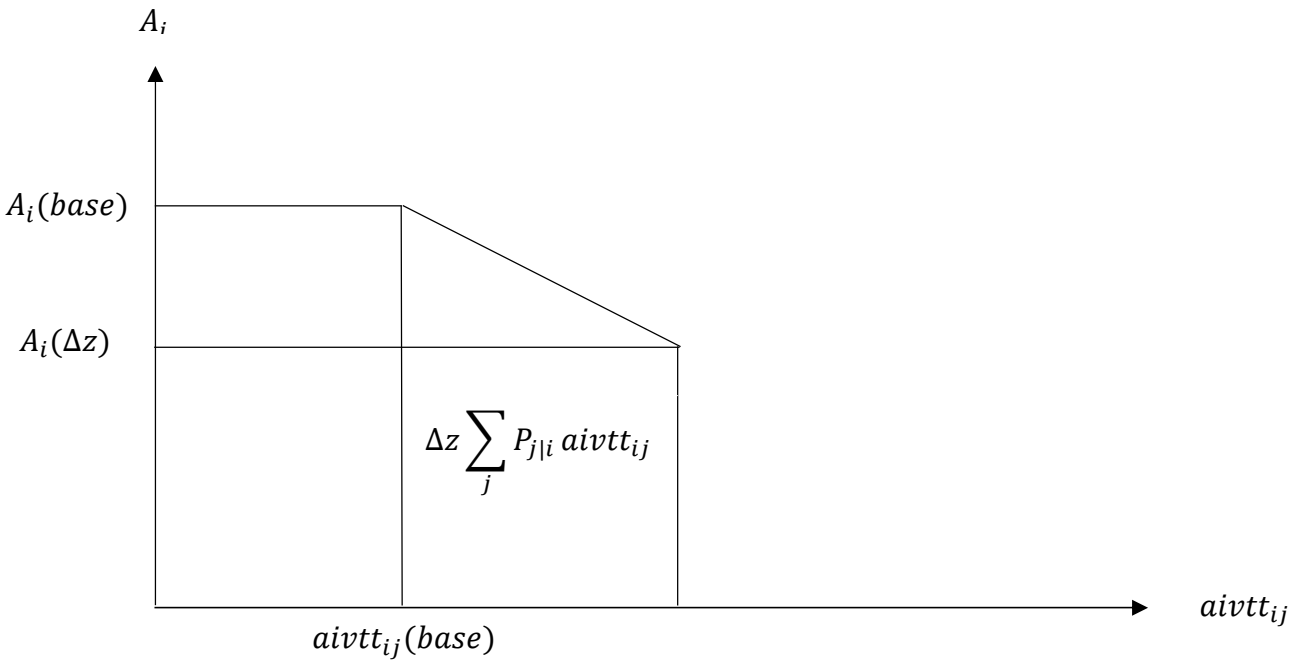

Fig. 3.3.1 – Visualization of Scaling Factor Operation

As figure 3.3.1 demonstrates, the scaling factor is the slope of the accessibility-aivtt function, assuming that there is a linear relationship between them. The purpose of the probability term in the denominator act as a "weight" term to compute the weighted average of all aivtt in zone i. Note that the level of accessibility is decreasing by an increasing of aivtt. It makes intuitive sense since a longer trip duration will make the trip less "attractive" or "desirable", and it eventually reduces the "utils" level of the activity.

4. Study Area, Data Sources and Data Processing

The first part of this section introduces the study area of this employment accessibility research. The second part of this section presents the sources of data used for this employment accessibility study. The last part discusses the two softwares, the eXtensible Trave Modelling Framework (XTMF) and ArcGIS Pro, used for the data processing procedures of this research.

4.1 Study Area

The study area of this accessibility research is the GTHA, which includes the Cities of Toronto and Hamilton, the Regional Municipality of York, Peel, Durham, and Halton. In 2016, GTHA had a total population of 6,954,433, which accounted for 51.71% of the provincial population, and 19.78% of the national population. GTHA has a land area of 8244.42 km^2 (Statistics Canada, 2021). In the GTAModel, all zones located in GTHA have a zone ID smaller than 6000; these zones are the focus of this study (Travel Modelling Group, 2017).

4.2 Data Sources

All employment, population, and network data, as well as the PoRPoW model parameters used, are from the GTAModel V4.1.1 database, including the Level of Service (LoS) data.

Employment and Population Data

Both employment and population data of the GTHA are available in the database based on the 2016 statistics. For the general employment data, it can be further narrowed down to eight occupation types, include general office full-time (GF), general office part-time (GP), manufacturing & other full-time (MF), manufacturing & other part-time (MP), professional full-time (PF), professional part-time (PP), sales and services full-time (SF), and sales and services part-time (SP). This breakdown is consistently applied within both isochrone and PoRPoW accessibility analyses. Note that for PoRPoW analysis, working at home and working at areas external to the GTHA employment and population are excluded from the total employment and population.

Network Data

The network data, including the travel time and distance data, is also available in the GTAModal database. They are categorized as the LoS data. Since the travel time varies by time of a day, the LoS data divides a day into five periods to account for this variation. The five periods are AM

(6:00-9:00), MD (9:00-15:00), PM (15:00-19:00), EV (19:00-0:00), and ON (0:00-6:00). While isochrone accessibility is available for all five periods, PoRPoW analysis is only available for AM. Moreover, travel time varies by modes, so auto travel time and transit travel time are considered separately. While auto travel time only consists of auto in-vehicle travel time (aivtt), for isochrone measure, transit travel time is the sum of transit in-vehicle travel time (tivtt), transit walking time (twalk), and transit waiting time (twait). In contrast, for PoRPoW model, transit travel time only consists of transit perceived travel time (tptt), which is the weighted sum of the various transit travel time components.

PoRPoW Model Parameters

The GTAModel database also includes the parameter vector and K-Factor values for the PoRPoW model. Table 4.2.1 below presents the parameter vector used for the analysis of each occupation type.

Table 4.2.1 – Vector Parameter Used for PoRPoW Model Analysis

Parameter	GF	GP	MF	MP
β_{aivtt}	-0.298418	-0.2998326	-0.2495778	-0.2945731
$\beta_{Transit}$	-0.1136036	-0.8700591	-0.444736	-0.1007776
β_{tptt}	-0.01395946	-0.00863043	-0.03107527	-0.02936452
β_{Active}	0.5639797	-0.457964	-1.051485	-2.177834
β_{dist}	-0.0552581	-0.05421526	-0.07972697	-0.1205801
α	1.787468	2.592111	1.178371	0.9817105
Parameter	PF	PP	SF	SP
β_{aivtt}	-0.2925624	-0.2999898	-0.1088905	-0.2965416
$\beta_{Transit}$	-0.3030214	-1.64042	-1.8689	3.876954
β_{tptt}	-0.01892142	-0.003902744	-0.007260611	-0.2887224
β_{Active}	-0.2476287	-0.4793607	-0.4699099	0.5767689
β_{dist}	-0.04738925	-0.05322143	-0.1016599	-0.2806954
α	1.494841	2.330561	1.750935	0.5226743

Table 4.2.2 below presents the non-default K-Factor values used for the analyses.

Table 4.2.2 – Non-Default K-Factor Values Used for PoRPoW Model Analysis

Employment Category	Origin Zone ID	Destination Zone ID	K-Factors
GF	35	35-36	1.4
MF	33	1-16	1.3
MF	34-36	1	2.3
MF	35	33-34,36	1.3
MF	36	33-35	1.3
PF	2-4, 6	36	0.9
PF	33-36	33-36	1.3
PF	34-36	1	0.9
SF	34-36	1-16	0.91
SF	33	33	1.3

SF	35	35	1.3

4.3 Data Processing

XTMF V1.8 is used to compute both the isochrone and PoRPoW accessibility. It takes inputs of the employment, population, and network data, as well as the parameter values. Then, by processing the accessibility equations expressed under the built-in ODMath framework, it enables the output of the zonal accessibility results in vector form in CSV files.

ArcGIS Pro is used to visualize the accessibility results. This is achieved by adding a GTAModel V4 shape file into the ArcGIS Pro interface and then joining the zonal accessibility result CSV files with the shape file. Eventually, the accessibility level of each zone can be visualized on a map.

5. Results and Analysis

This section of the report presents the results of the isochrone and PoRPoW accessibility analyses. It starts with the isochrone accessibility results, followed by the PoRPoW accessibility results. In the last part of this section, the scaled PoRPoW accessibility results are discussed.

5.1 Isochrone Accessibility Result and Analysis

The isochrone accessibility result and analysis are presented in this section of the report. Note that the focus of the presentation is on the AM accessibility results, although the accessibilities for other time periods of the day are also available for the isochrone measure. This is because only AM-peak hour accessibility is available for PoRPoW accessibility and doing so ensures the comparability between the results. It is also because AM period is the time when most of the working population go to work, and the result is more meaningful.

AM Accessibility by Occupation Types

This part of section 5.1 presents the spatial distribution of the AM accessibility for the eight different occupation types using a cut-off time of 45 minutes. The scale used for each map is an equal-interval scale dividing accessibility values into ten intervals. However, the scales used between the maps are different due to the huge difference in employment statistics between occupation types. Note that the AM accessibility for the eight different occupation types using a cut-off time of 30 minutes is included in the appendix.

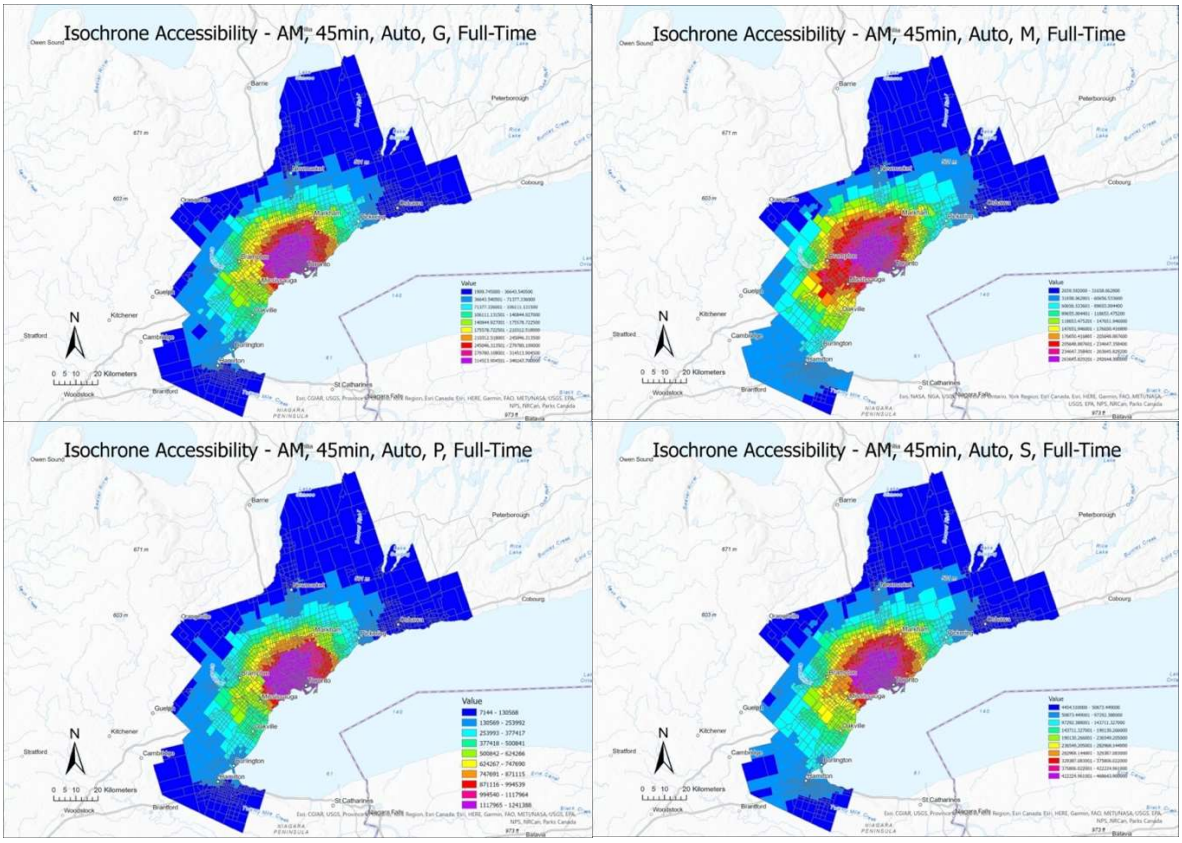

Fig. 5.1.1 – AM 45 min Full-time Auto Isochrone Accessibility by Occupation Types

The figure above reveals the spatial distribution of the AM auto accessibility to all four full-time occupation types using a cut-off time of 45 minutes. The ranking of the auto accessibility based on occupation type is professional, sales and services, general office, and manufacturing. The table below includes the highest and lowest accessibility value being recorded for the four occupation types.

Table 5.1.1 - Accessibility Extremes of AM 45 min Full-time Auto Isochrone Accessibility

	GF	MF	PF	SF
Maximum	349247.4	292644.3	1241388	468643.9
Minimum	1909.745	2659.592	7143.61	4454.51

The relative spatial distribution of the general office, professional, and sales and services accessibility are very similar, where there is a monotonic decrease of accessibility from the central and west side of the city of Toronto toward the boundary of the entire GTHA. The reason for the high auto accessibility in that area is due to the proximity to a large number of those three types of jobs located in downtown Toronto and near the Lester B. Pearson Airport, plus the existence of various highways, including Queen Elizabeth Way (QEW), Gardiner Expressway, Highway 401, and Highway 427.

However, for accessibility to manufacturing employment, there is a slight shift of the "hotspot" to the northwest, meaning that the region near the Etobicoke and North York segment of highway 401 and the east side of Pearson Airport have the greatest accessibility. That different distribution is mainly because manufacturing employments are concentrated in widespread locations within GTHA, including Pearson airport, York University, the MacMillan Yard, Highway 401 East corridor near Oshawa and Pickering, and QEW corridor near Oakville-Burlington-Hamilton. Located next to the highway, northern Etobicoke and central-west North York can have higher accessibility to manufacturing employments. Also, the rate of decrease of manufacturing accessibility is slower than the other three types of accessibility. That indicates a more even distribution of auto accessibility to manufacturing jobs.

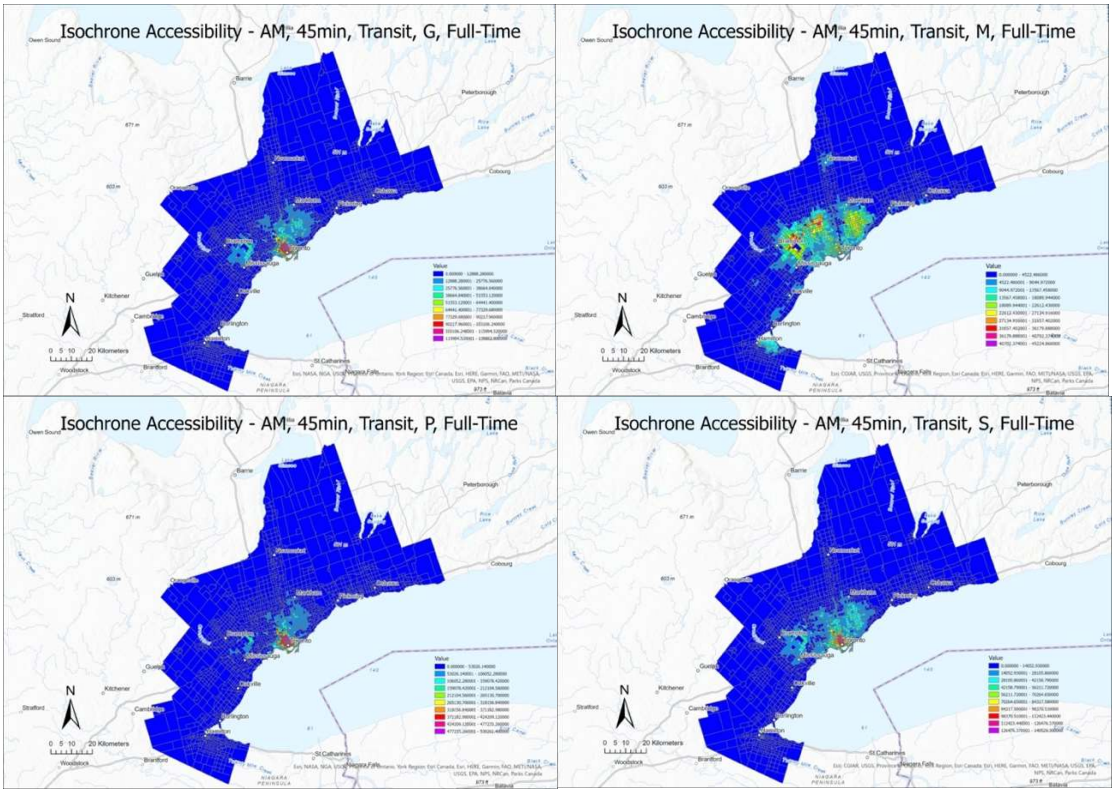

Fig. 5.1.2 – AM 45 min Full-time Transit Isochrone Accessibility by Occupation Types

The figures above reveal the spatial distribution of AM transit accessibility to all four full-time occupation types using a cut-off time of 45 minutes. The ranking of the transit accessibility based on occupation type is professional, sales and services, general office, and manufacturing. The table below includes the highest and lowest accessibility value being recorded for the four occupation types.

Table 5.1.2 - Accessibility Extremes of AM 45 min Full-time Auto Isochrone Accessibility

Max/Min	GF	MF	PF	SF
Maximum	128882.8	45224.86	530261.4	140529.3
Minimum	0	0	0	0

The relative spatial distributions of the general office, professional, and sales and services accessibility demonstrate that downtown Toronto has the highest transit accessibility. That is not surprising more transit services are being provided in downtown Toronto, and the number of employments is also high in that region. Moreover, the accessibility to these three types of employments is relatively higher in the region near Lester B. Pearson Airport, midtown Toronto, and centre Scarborough, and the accessibility near York University is slightly higher than the adjacent areas. In other words, the transit accessibility is usually higher at a place where is next to a rapid transit line. Besides, for the sales and services transit accessibility, it happens to have a slightly higher level in the district of Etobicoke. The accessibility is generally low in most of the suburban and rural areas.

For transit accessibility to manufacturing employment, unlike the distribution of all other occupation types, the accessibility level is similar across most parts of the cities of Toronto and Brampton, with the region near York University and Northwest of Lester B. Pearson Airport having the highest accessibility. Besides, the centres of towns of Newmarket and Oakville, and cities of Hamilton and Burlington have a slightly higher level of accessibility than adjacent regions. Very surprisingly, the northern part of the Young Street corridor, in which Toronto Subway Line One is built, is recorded with the lowest level of accessibility in the city of Toronto. That is also due to the widespread distribution of manufacturing employments, as mentioned in the auto accessibility discussion above.

In general, the four part-time accessibility distributions are very similar to their respective full-time distributions. However, for all transit accessibilities, the distributions are more scattered, and that is mainly because of the more even distribution of the part-time opportunities than the full-time ones within the GTHA. The accessibility values are much lower due to the lower number of part-time jobs. However, in terms of the ranking, sales and services has the greatest level of accessibility instead of professional, and that is due to the larger number of this type of employment for part-time. The highest accessibility value of each occupation type of auto and transit mode is in the table below. The part-time accessibility maps are included in the appendix.

Table 5.1.3 – Accessibility Extremes of AM 45 min Part-time Isochrone Accessibility

Mode	Max/Min	GP	MP	PP	SP
Auto	Maximum	69815.56	23693.89	118519.8	246081.4
	Minimum	1140.755	426.9495	1534.968	4027.19
Transit	Maximum	20755.46	4213.95	45344.64	67314.56
	Minimum	0	0	0	0

Effect of 15 min Cut-Off Time Increase on Total Employment Accessibility

This part of section 5.1 provides a brief analysis of how a 15-minute increase of cut-off time improves accessibility. The analysis is based on the total employment auto and transit accessibility. The scale used for maps for the same transportation mode is the same.

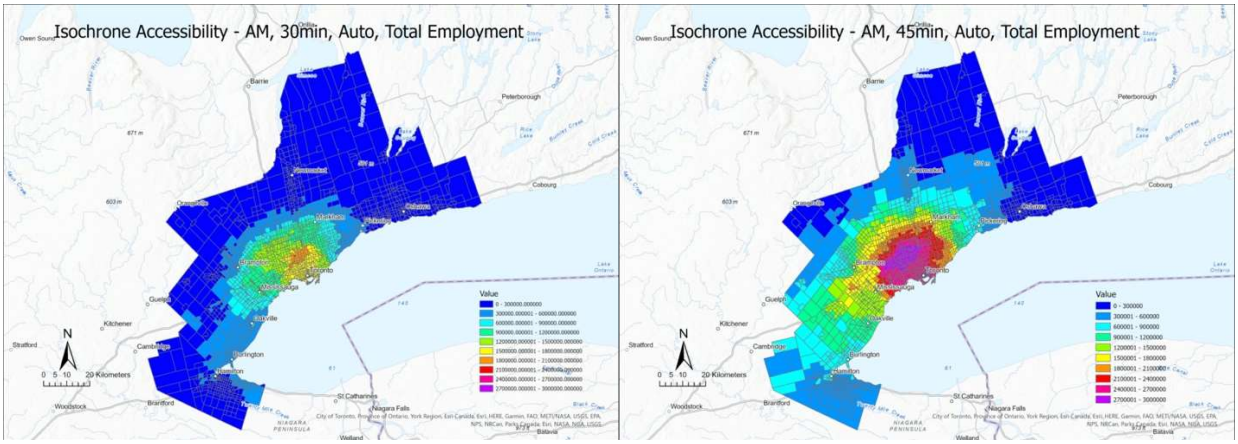

Fig. 5.1.3 - AM 30 min and 45 min Auto Isochrone Accessibility of Total Employments

The figures above are two auto isochrone accessibility maps. Based on the spatial distribution of accessibility, it demonstrates that the increase of auto accessibility is very significant by a 15-minute increase of cut-off time. The drastic colour changes indicate a doubling or tripling of accessibility levels in some regions of GTHA. Like all auto accessibility maps above, the auto accessibility of total employment has a monotonic decrease from the central-west region of GTHA toward the boundary of the area.

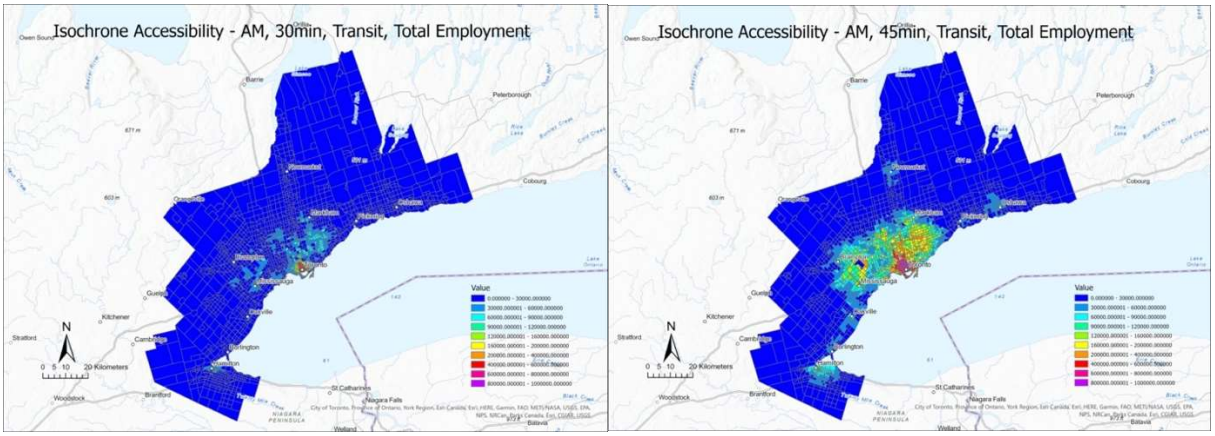

Fig. 5.1.4 – AM 30 min and 45 min Transit Isochrone Accessibility of Total Employments

The increase of transit accessibility of the major population centres in GTHA by the cut-off time increase is also significant. Though the change is not huge in downtown Toronto, it is evident that the accessibility level of Scarborough, North York, Etobicoke, the city of Hamilton, and the area near Lester B. Pearson Airport is tripled after the cut-off time change. In the centre of the town of Oakville and Newmarket and the cities of Oshawa and Burlington, the level is doubled. There is also a trend that the accessibility level is higher in the places that are adjacent to a rapid transit line, which is similar to all other transit accessibility maps above. However, it is interesting that many zones in Scarborough and next to the Sheppard Avenue East demonstrate a better level of accessibility than adjacent zones. This phenomenon is interesting since there is no rapid transit line present under the Scarborough segment of Sheppard Avenue East.

PM Accessibility Using Reversed Travel Time

The last part of section 5.1 provides the result of the investigation on PM accessibility using reversed travel time from destination zone to origin zone. The purpose of the investigation is to supplement and mirror the AM accessibility since it examines how long it takes for the large number of workers who go to work on AM to return home on PM. The investigation is based on total employment and a 45-minute cut-off time. The scale used for maps for the same transportation mode is the same. Maps for 30-minute cut-off time are included in the appendix; they can reveal the same effect but are not as detailed as the 45-minute maps.

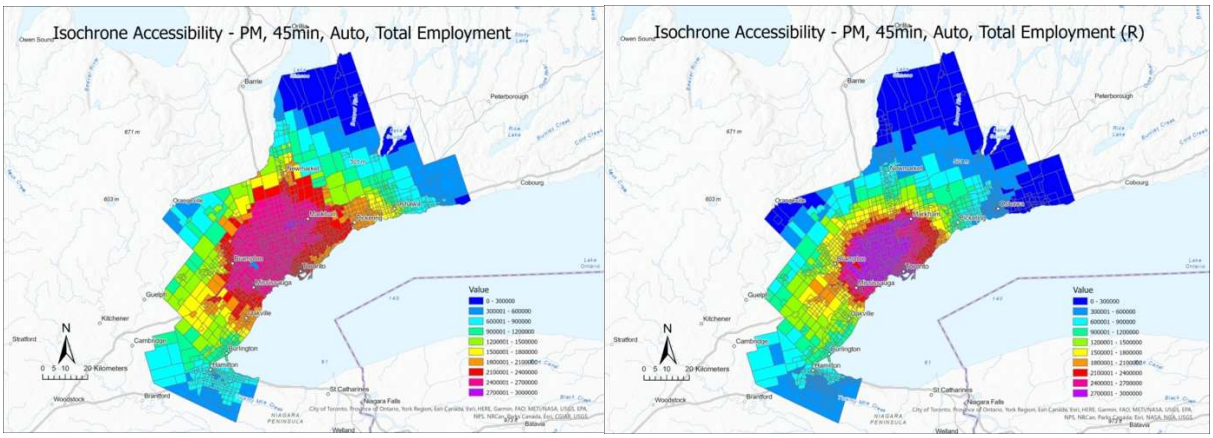

Fig. 5.1.5 – PM 45 min Auto Isochrone Accessibilities of Total Employments

The right-side figure shows the PM auto accessibility using reversed travel time. The reversed time map better reveals the effect of congestion than the normal time map on the left. Besides, compared to the previous AM 45min auto accessibility map, there is a larger red and purple area in the PM reversed travel time map, which indicates a higher level of accessibility. That reveals lower road congestion on average during PM.

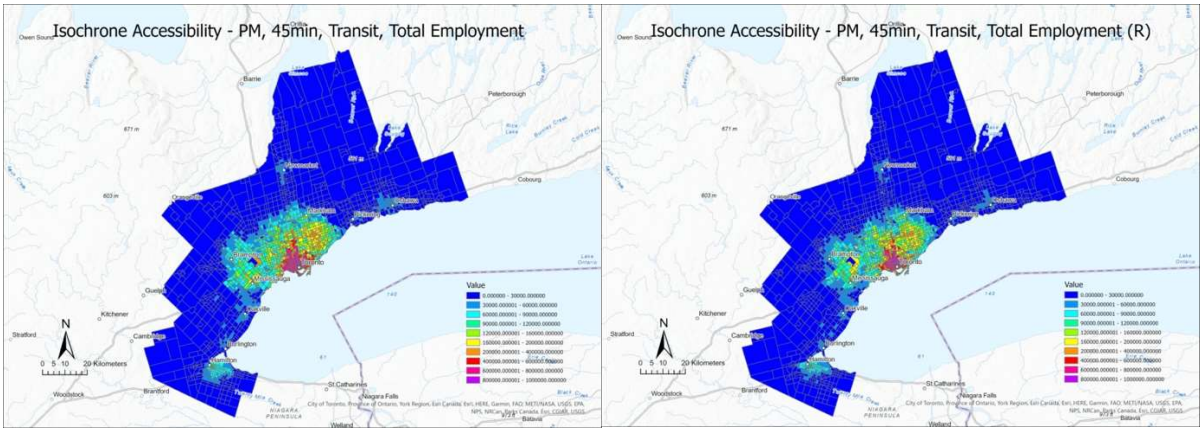

Fig. 5.1.6 – PM 45 min Transit Isochrone Accessibilities of Total Employments

The right-side figure shows the PM transit accessibility using reversed travel time. However, unlike the auto accessibility maps, the two maps show a similar accessibility distribution. The cause of that may be the lower congestion effect on rapid transit lines than the road traffic during rush hours.

5.2 PoRPoW Accessibility

Section 5.2 discusses the PoRPoW accessibility results and analysis. Besides, a short analysis of the results of the balancing factor is provided.

PoRPoW Accessibility by Occupation Types

The first half of the section includes the PoRPoW accessibility results of the eight occupation types. The scales used for all maps are the same

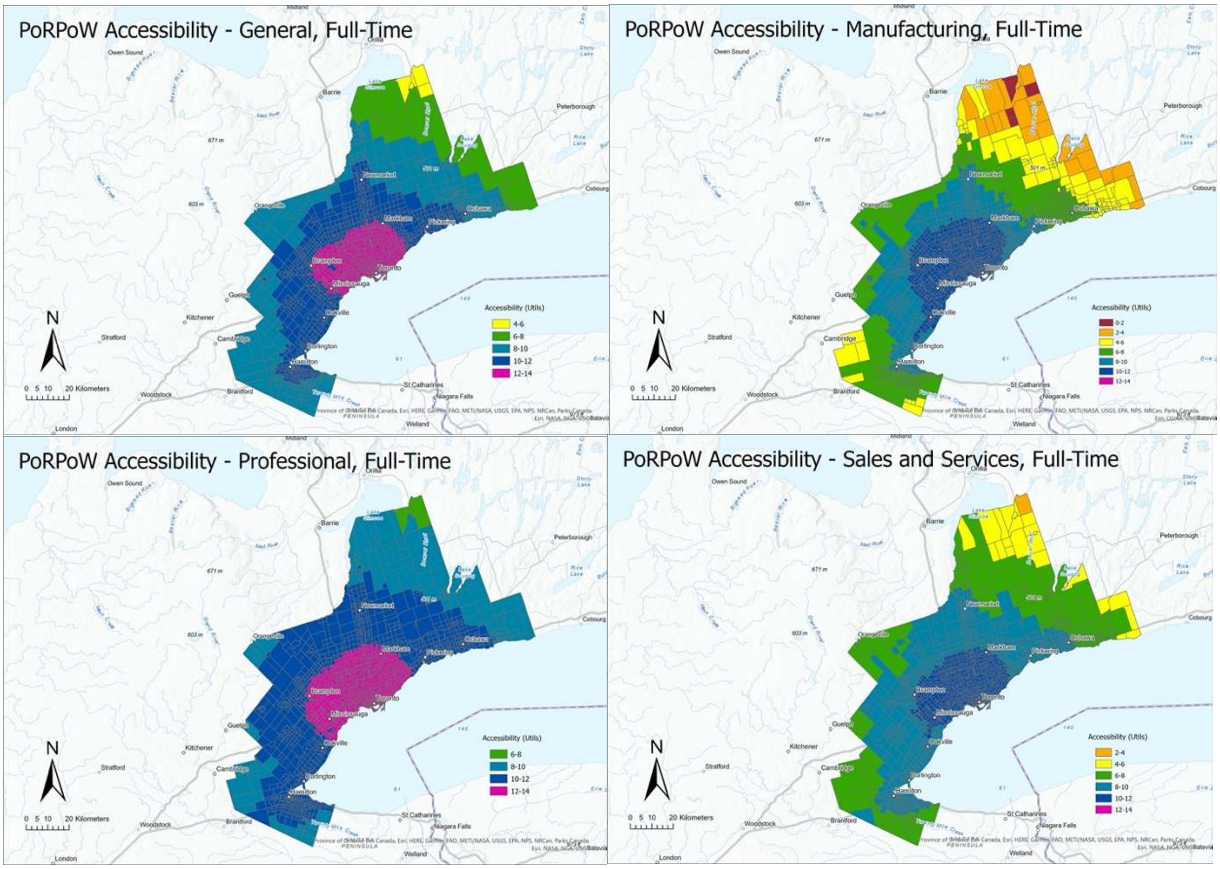

Fig. 5.2.1 – PoRPoW Accessibility of Full-time Occupation Types

The figure above shows the PoRPoW accessibility of the four types of full-time employments. It is found that the accessibility for professional employment is the highest, followed by general, sales and services, and manufacturing. The highest and lowest accessibility values recorded for the four occupation types are in the table below.

Table 5.2.1 - Accessibility Extremes of Full-time PoRPoW Accessibility

	GF	MF	PF	SF
Maximum	13.51409	11.95714	13.72931	11.67583
Minimum	5.395808	1.69858	7.690216	3.938526

It is not surprising that professional employment has the best level of accessibility since it has the greatest number of opportunities among the four types of occupations. Similarly, the number of opportunities available for manufacturing employment is the smallest, and that leads to the worst level of accessibility for that occupation type. The main reason that general office employment has a better level of accessibility than sales and services in the PoRPoW analysis is that there is a greater working at home and working at areas external rates for sales and services employment. Though the number of employments of sales and services is higher, subtracting the portion of the individuals working at home and working out of GTHA, it results in lower accessibility for sales and services compared to the general office.

The spatial distribution of the accessibility reveals that there exists a monotonic decrease of accessibility from downtown Toronto to the boundary of the GTHA region, except for the accessibility in the northern part of the Durham Region. Moreover, the accessibility to manufacturing employment has the greatest variance between urban and rural areas, while variance for professional employment is the smallest. The accessibility level of variance for general office and sales and services employments is similar.

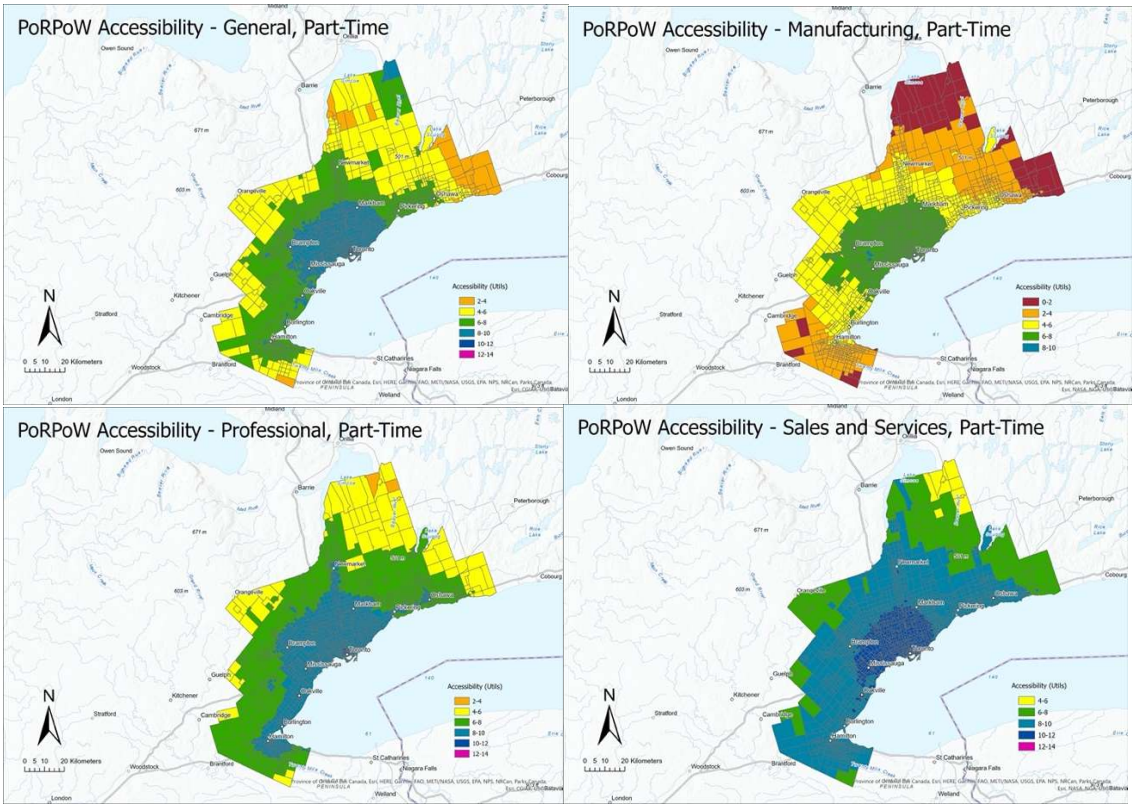

Fig. 5.2.2 – PoRPoW Accessibility of Part-time Occupation Types

The figure above shows the PoRPoW accessibility of the four types of part-time jobs. In this scenario, it is found that the accessibility for sales and services employment is the highest, followed by professional, general office, and manufacturing. The highest and lowest accessibility values recorded for the four occupation types are in the table below.

Table 5.2.2 - Accessibility Extremes of Part-time PoRPoW Accessibility

Max/Min	GP	MP	PP	SP
Maximum	10.44371	8.235681	10.65747	11.39195
Minimum	2.249315	0.1551474	3.579188	4.911879

Similar to isochrone accessibility, it is not surprising to see that part-time sales and services accessibility is the greatest. That is because of the greater number of this type of employment.

The spatial distribution of the accessibility reveals that there is a monotonic decrease of accessibility from downtown Toronto to the boundary of the GTHA region in general. However, there is more non-uniformity of accessibility level in rural areas. For example, the level of general office accessibility in the northern part of the Durham Region is much higher than the adjacent areas, yet no significant local employment opportunities are being observed. Likewise, the region near Port Perry and Lake Scugog is also observed with a somewhat greater level of accessibility than the nearby area. The accessibility to general office and manufacturing employment has a faster decrease of accessibility from urban to rural areas. The speed of decrease for professional and sales and services accessibility is similar.

Balancing Factor by Occupation Types

The purpose of the balancing factor is to take into consideration the competition for jobs among workers for the PoRPoW analysis. The second half of section 5.2 provides a brief overview of the level of competition of employment opportunities within the GTHA. The scale used for all the maps is the same. A red zone indicates a balancing factor greater than one, which indicates a more “attractive” zone due to the lower level of competition. In contrast, a yellow zone indicates a balancing factor less than or equal to one, which indicates a less “attractive” or an “unadjusted” zone.

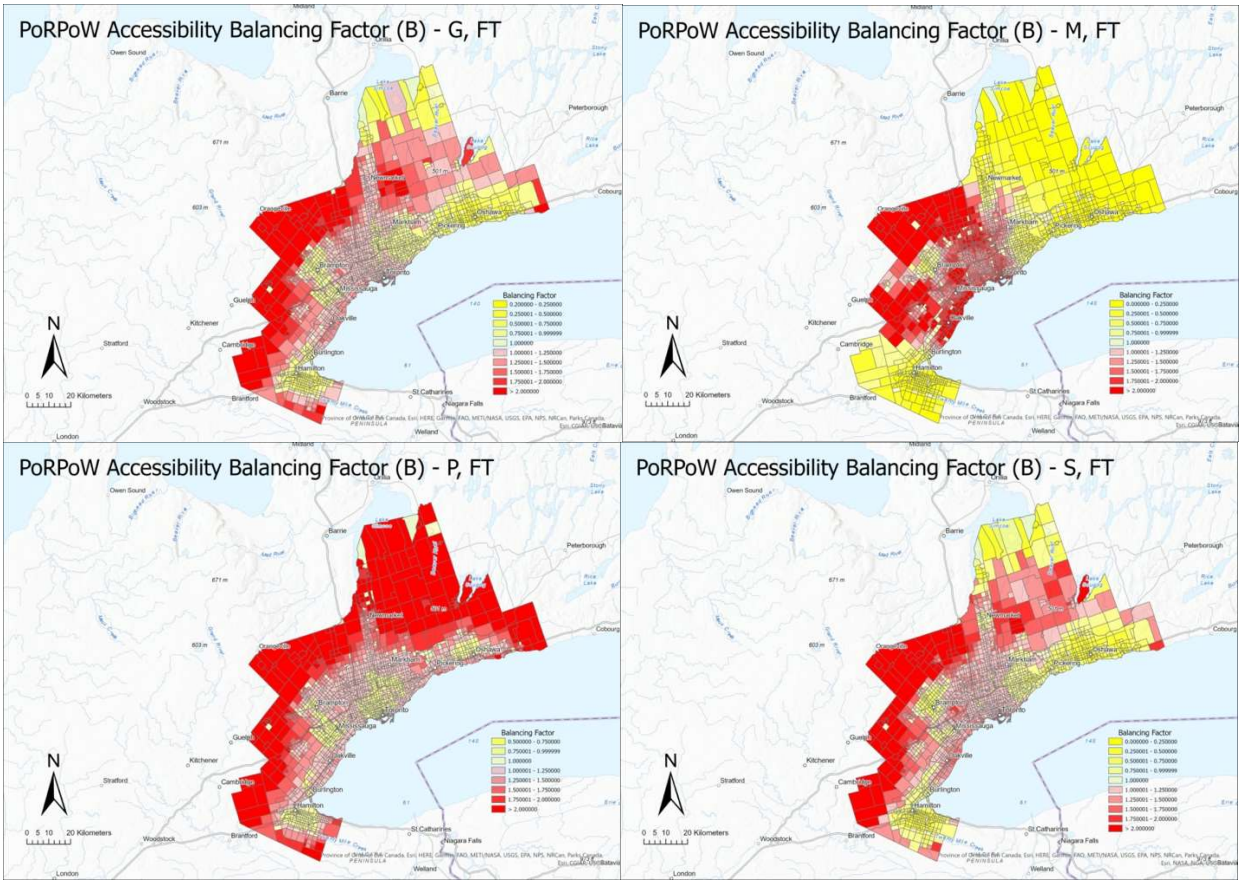

Fig. 5.2.3 – Balancing Factors of Full-time Occupation Types

The figure above is the spatial distribution of the balancing factor of the four full-time occupation types. The spatial distribution of the full-time general office balancing factors above demonstrates that the level of competition is generally high in Scarborough, cities of Pickering, Oshawa, Brampton, Mississauga, and Hamilton. The competition level is somewhat low in downtown Toronto, Etobicoke, towns of Oakville, Aurora, and Newmarket, and the city of Burlington. In other places, the competition level is extremely low. For manufacturing, the competition level is either very high or very low. The high competition region includes the east half of Scarborough, the entire Durham Region, the north half of the York Region, and the cities of Brampton and Hamilton. All other areas within GTHA have low competition levels. For professional, the competition is very low in all rural areas and somehow low in suburban areas, yet there is a high-level competition in the cities of Toronto, Mississauga, Hamilton, and Oshawa. Lastly, for sales and services, the spatial distribution of the competition level is similar to general office.

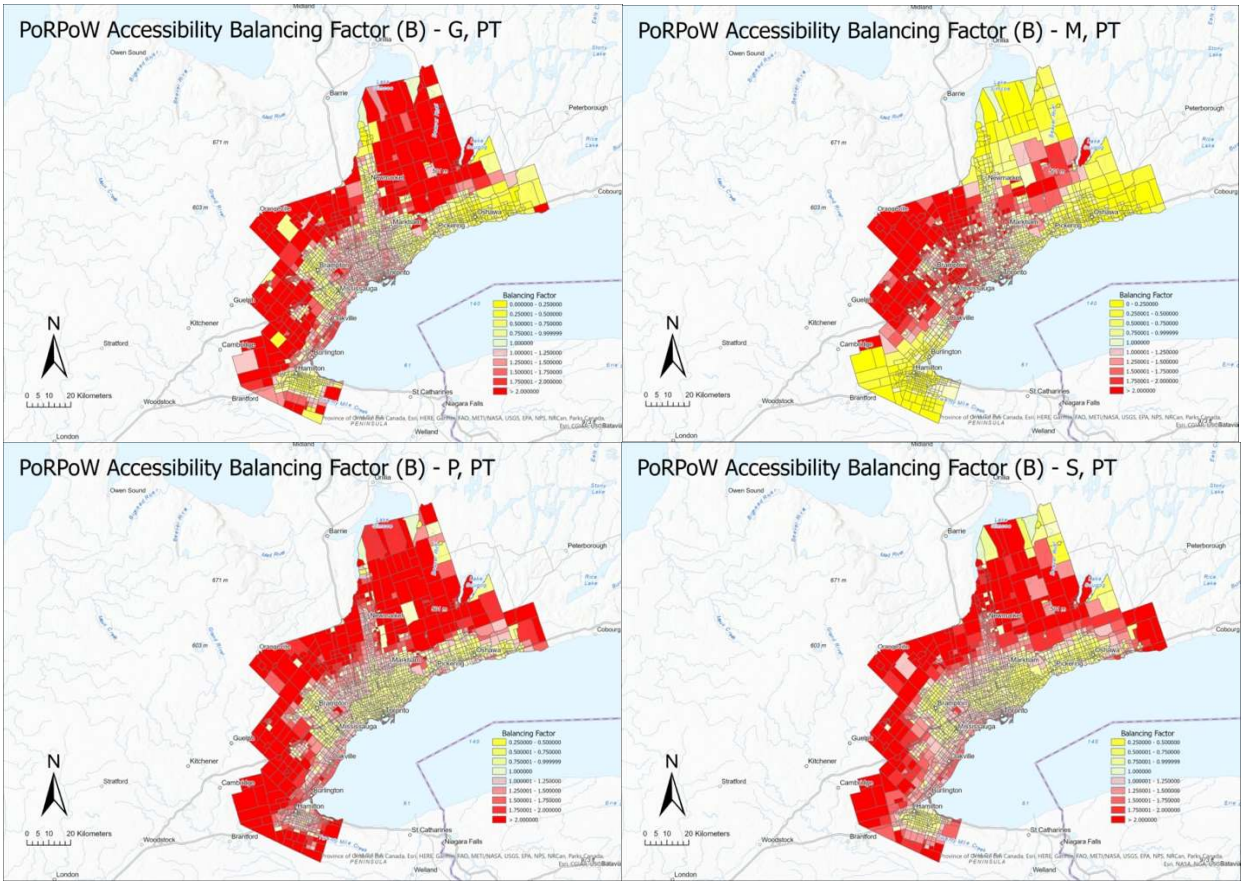

Fig. 5.2.4 – Balancing Factors of Part-time Occupation Types

The figure above is the spatial distribution of the balancing factor of the four part-time occupation types. In general, the spatial distributions are somewhat like their respective full-time distributions, but with more variation and scatteredness between zones. The distribution of the balancing factor for part-time manufacturing employments has the greatest difference to the full-time distribution, where the competition level near Uxbridge and Port Perry is instead low.

5.3 Scaled PoRPoW Accessibility

This subsection presents the results and analysis of the scaled PoRPoW accessibilities. The scale used for all the maps is the same. A greater value in minutes indicates a greater level of accessibility (i.e., the accessibility is higher measured in the "currency" of minutes). Note that the zones coloured in grey have no accessibility data since the ELF values are zero.

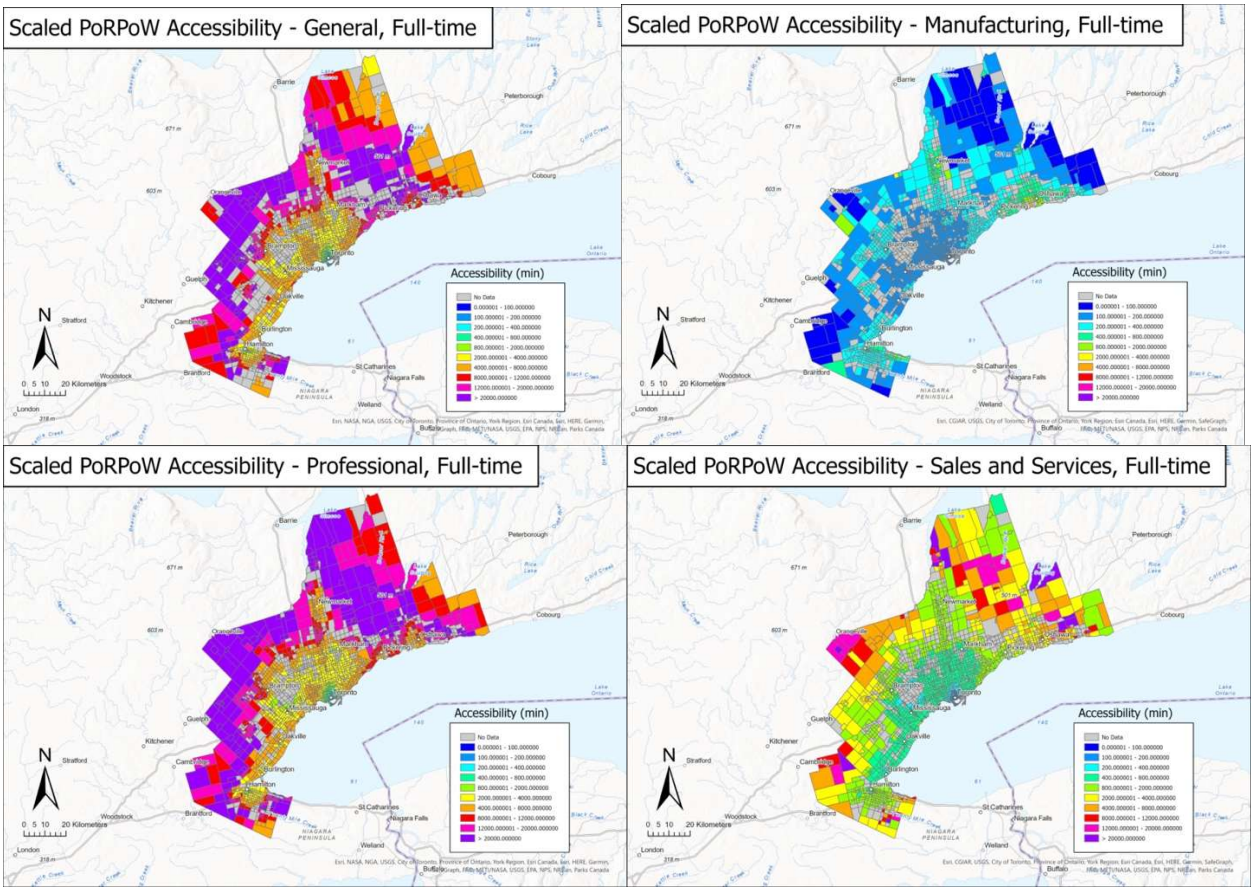

Fig. 5.3.1 – Scaled PoRPoW Accessibility of Full-time Occupation Types

As illustrated by the figure above, professional and general office have the greatest and a similar level of level across the entire GTHA, followed by sales and services, then manufacturing.

The spatial distribution of the scaled accessibility for full-time general office and professional employments is similar. Surprisingly, both occupation types have high accessibility in rural regions across GTHA, usually in the range of over 8000 minutes, whereas the accessibility level starts to decrease when moving towards the urban areas. Downtown Toronto has the lowest level of scaled accessibility, in the range of lower than 2000 minutes. The accessibility value maintains below the orange range (8000 min) in nearly all major population centres of GTHA.

Meanwhile, the spatial distribution of the scaled accessibility for full-time manufacturing employment looks very different. The city of Oshawa and the town of Newmarket have the greatest level of accessibility; most of the zones in these regions have a scaled accessibility value of over 400 minutes. Moreover, it is noted that there is an increase followed by a decrease in scaled accessibility values when moving away from downtown Toronto.

For the spatial distribution of the scaled accessibility for full-time sales and services employment, the accessibility is higher in rural regions across GTHA, usually in the range of over 2000 minutes. Downtown Toronto has the lowest level of accessibility; the accessibility

value in downtown Toronto is typically under 400 minutes. There exists a slow monotonic increase of accessibility values when moving away from urban areas to rural regions.

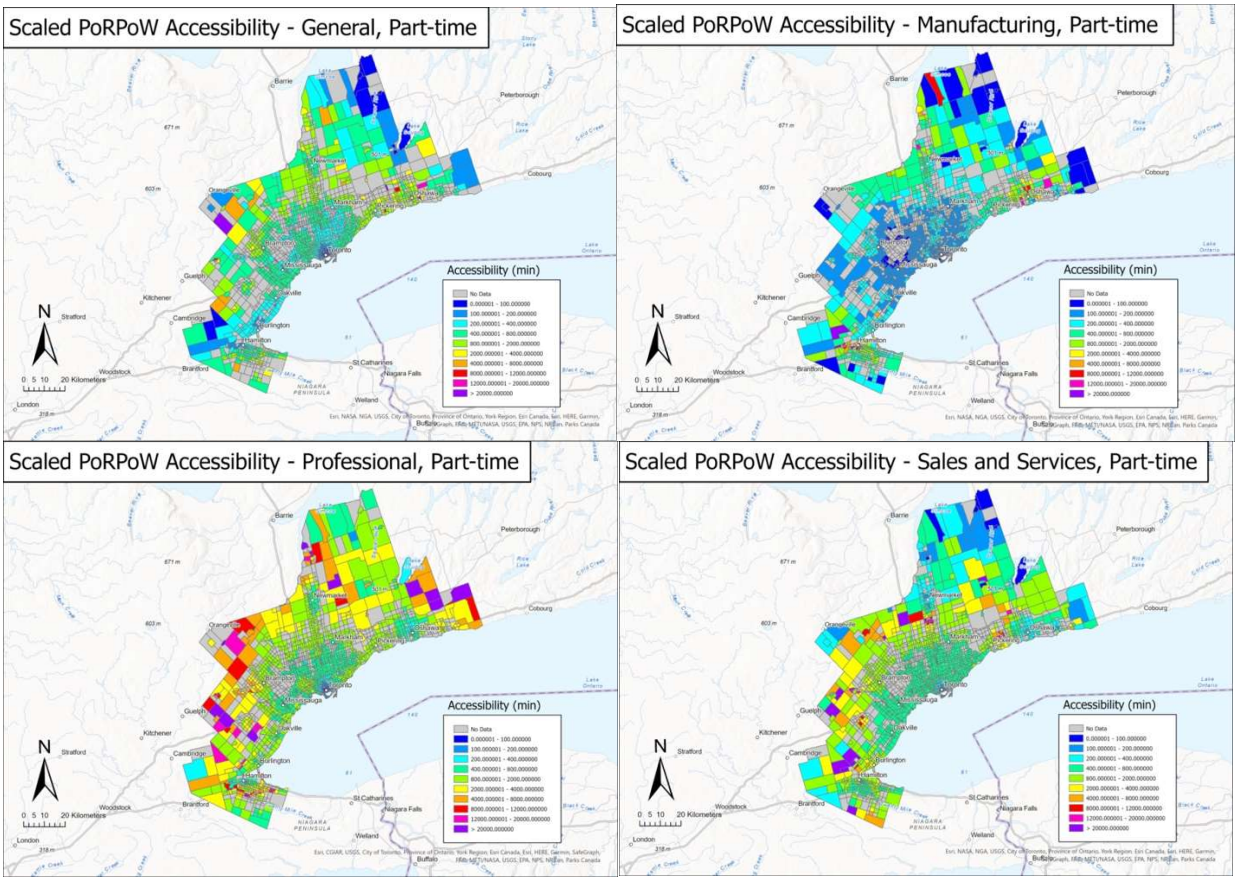

Fig. 5.3.2 – Scaled PoRPoW Accessibility for Part-time Occupation Types

The ranking of the scaled accessibility based on part-time occupation type is professional, sales and services, general office, and manufacturing, as illustrated by the figure above.

The spatial distributions of the scaled PoRPoW accessibility for part-time occupation types are different from their respective full-time distributions. All accessibility distributions are more scattered. The scaled PoRPoW accessibility for general office employment is the lowest in downtown Toronto and many zones next to the GTHA boundary. They are in the range of 0-200 minutes. The monotonic increase of accessibility level is slower for part-time general office employment when moving away from downtown Toronto; most of the zones have accessibility values under 2000 minutes.

For manufacturing, while accessibility distribution within the city of Toronto is like full-time manufacturing employment, the accessibility is higher in some of the rural zones in the York, Durham, and Halton regions. However, the general level of accessibility is still low for part-time manufacturing employments; most of the zones have accessibility values under 2000 minutes.

The way that professional and sales and services accessibilities distribute is somewhat comparable with the distribution of general office accessibility, but with a faster rate of increase when moving away from downtown Toronto. The accessibility values for zones located in the city of Toronto are generally under 800 minutes for both professional and sales and services, with most of the zones in GTHA having accessibility values under 20000 minutes.

6. Conclusions

This report presents an overview of the employment accessibility in the GTHA using the isochrone measure and the PoRPoW model, a random utility-based measure. To improve the comparability of the PoRPoW accessibility results, they are further processed using a scaling procedure. Eight different occupation types, including full-time and part-time general office, full-time and part-time manufacturing, full-time and part-time professional, and full-time and part-time sales and services, are analyzed for this study. The employment, population, network, and model parameter data used for this study are all from the GTAModel V4.1.1 database. All the data processing works are finished using XTMF V1.8, while the accessibility visualizations are achieved using ArcGIS Pro.

There is a very clear trend that for the four types of full-time employments; the accessibility to professional employments is the best, and manufacturing employment is the worst. Accessibility to sales and services employments is ranked above general office employments when using the isochrone measure; however, their position is swapped in the PoRPoW and scaled PoRPoW results. That is clearly due to the large working at home and working at external area rates for sales and services employments. For part-time employments, the isochrone and PoRPoW accessibility yield similar results; the ranking of the overall accessibility level is sales and services, professional, general office, and manufacturing, which also reflects the ranking of their employment opportunities. However, for scaled part-time PoRPoW accessibility, professional is ranked ahead of sales and services.

For the spatial distribution status of accessibility, all auto isochrone and PoRPoW accessibilities demonstrate a monotonic decrease from the city of Toronto, with some minor differences and exceptions. However, there exists a monotonic decrease in general for all scaled PoRPoW accessibility when moving away from the city of Toronto. Most of the relatively high transit accessibility regions are usually with the presence of a rapid transit line. Two location exceptions are the Scarborough segment of Sheppard Avenue East and the region near Lester B. Pearson Airport. One occupation type exception is manufacturing, where the accessibility level is similar across most parts of the cities of Toronto and Brampton, but the accessibility is low in the Yonge Street corridor. For scaled PoRPoW accessibilities, the distributions for all occupation types have greater nonuniformity, with large variation usually occur in rural areas.

An increase of cut-off time by 15 minutes leads to huge increases in both auto and transit accessibility, with many zones observing a doubling or tripling of accessibility levels. Also, applying reversed travel time from destination to origin for PM analysis can be useful as it better reveals how long it takes for the large number of workers who go to work on AM to return home on PM.

The balancing factor distribution for all occupation types shows that the competition level is usually very low in rural areas, while in most of the urban and suburban areas the level is higher. One location exception is the city of Oshawa, where the competition is always high for all types of employments. One occupation type exception is manufacturing, where nearly all low competition areas are in the region between Toronto and Hamilton.

7. Future Steps

One possible step for future study is to have more statistical analysis, for example, analysis on the mean value, median value, skewness, and standard deviations, on the isochrone and PoRPoW accessibilities. Though it is possible to find the general trend of the accessibility and see the relative level of an area's accessibility within the GTHA from the accessibility maps, the results from the statistical analysis can provide greater precision for the study. Also, statistical analysis can help to explore any correlation of accessibility with other socio-economic factors, which potentially helps improve social equity.

In addition, more analysis can be provided on the isochrone accessibility during the other four periods of the day for the eight occupation types. Although the accessibilities for other time periods of the day are also available, to consider the comparability with the PoRPoW accessibility results, the accessibilities for those time periods are not the focus of the report. A separate report can be provided to only focus on the accessibility results for those four time periods using the isochrone measure. This analysis is also important since not all the workers, especially a considerable proportion of the part-time workers, go to work during AM period. Some occupation, like self-employed teachers, nurses, pilots, and firefighters, may not start their work shift during the morning. Hence, this separate analysis can provide a better overview of their actual employment accessibility level. Also, the cut-off time and reversed travel time analysis can expand to each of the eight occupation types.

Finally, for the scaled PoRPoW accessibility, another analysis can be done by increasing the transit perceived transit time (tptt) by 10% and comparing it with the current result. It is surprising that both full-time and part-time manufacturing accessibility is very high in this scaling analysis, which is opposed to the result of isochrone and PoRPoW analysis, so another scaling analysis of adjusting a different variable can help verify the results for this report. A separate analysis can be done by adjusting the distance variable. That allows the scaled PoRPoW accessibility to be in the unit of kilometres, which can provide a new perspective to the study.

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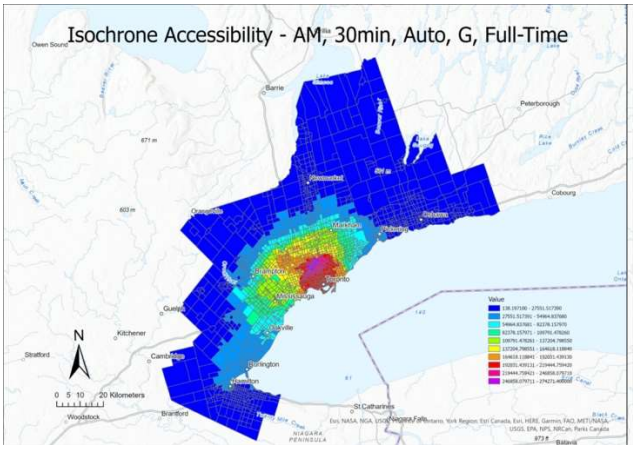
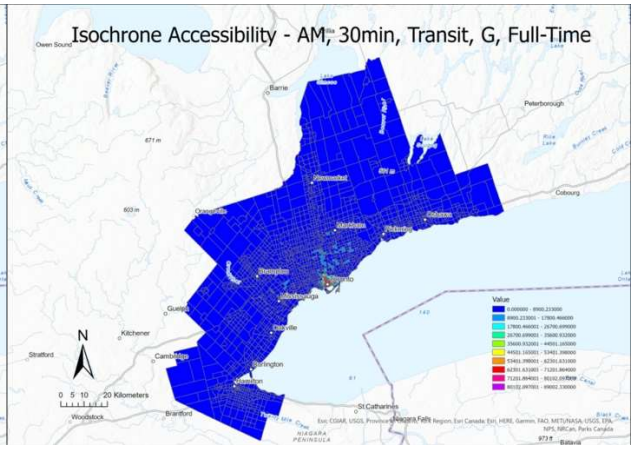
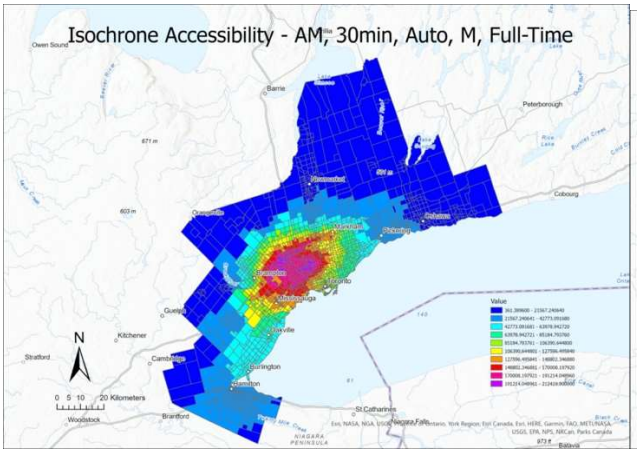
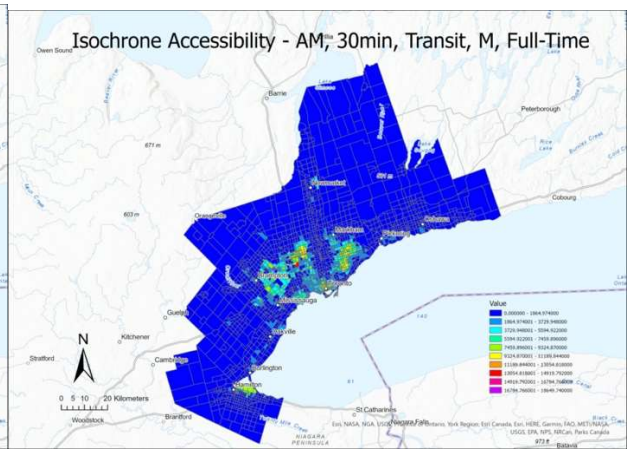
Appendix

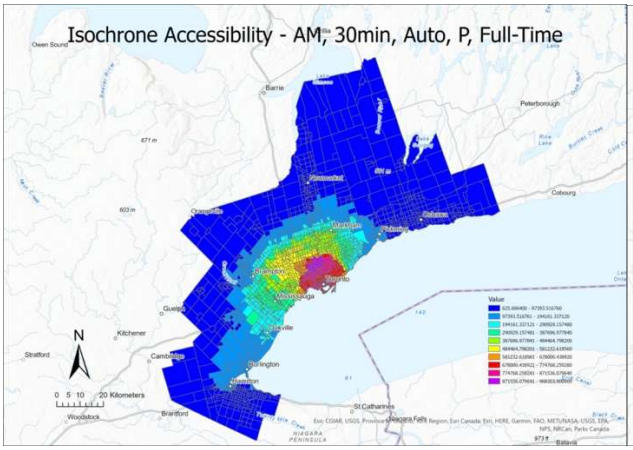
AM 30min Accessibility Maps for Different Occupation Types

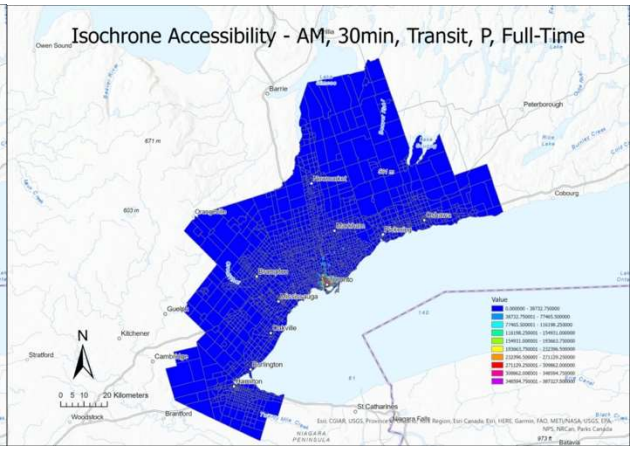


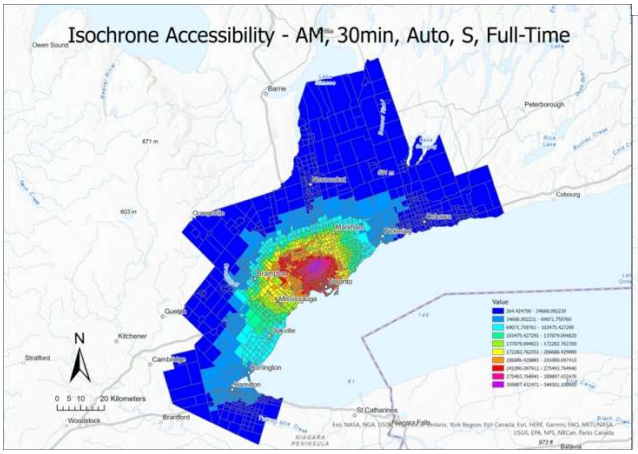


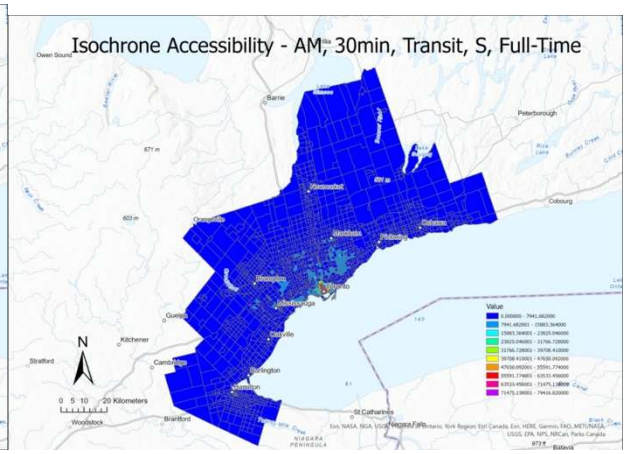









Isochrone Accessibility - AM, 30min, Auto, S, Full-Time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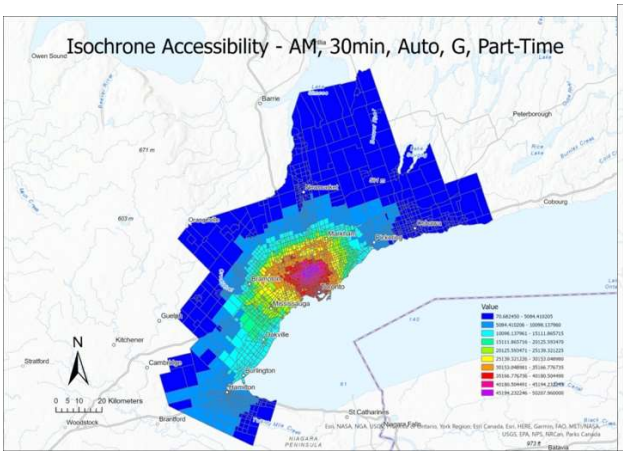
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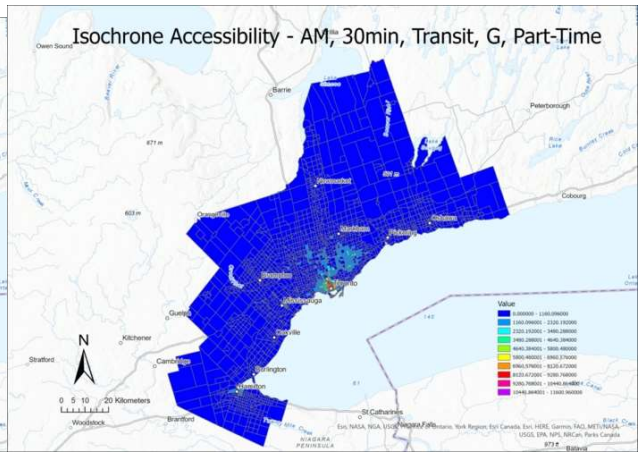
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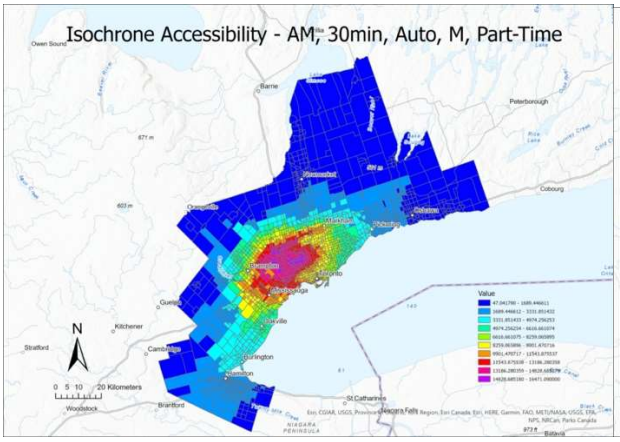
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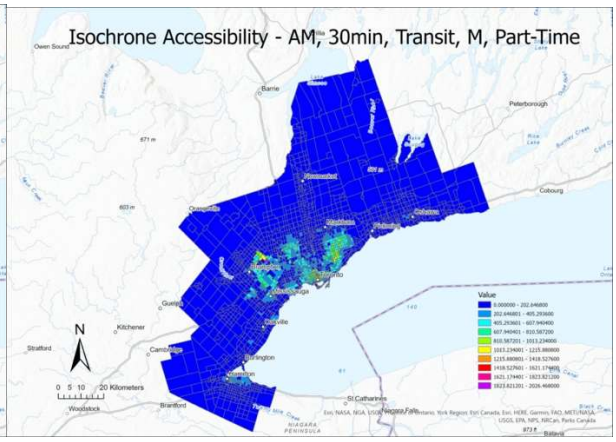
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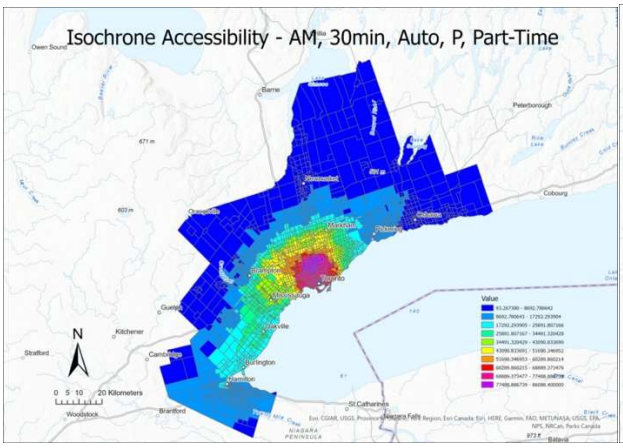
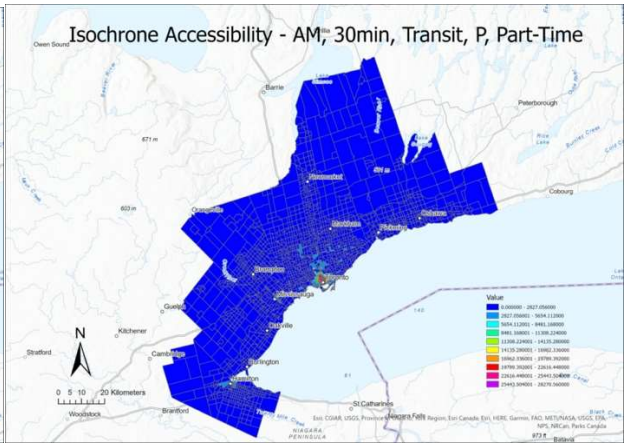
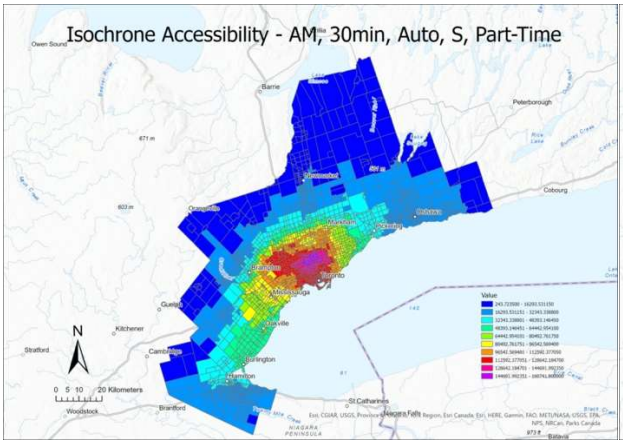
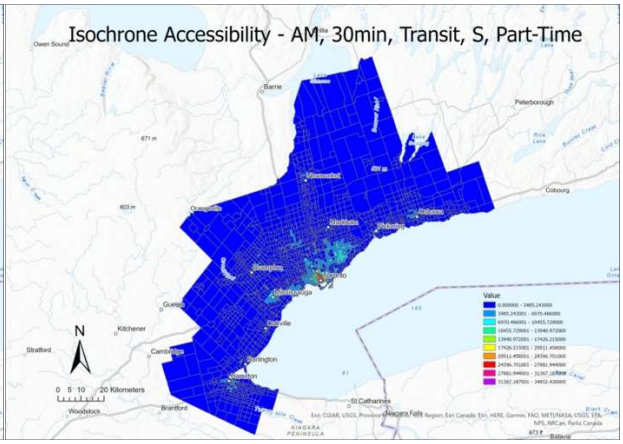
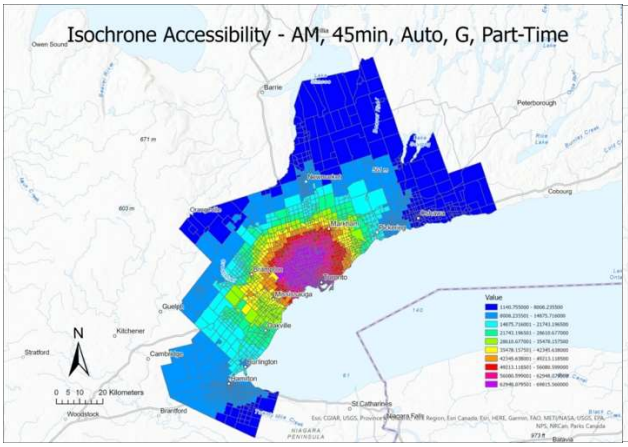


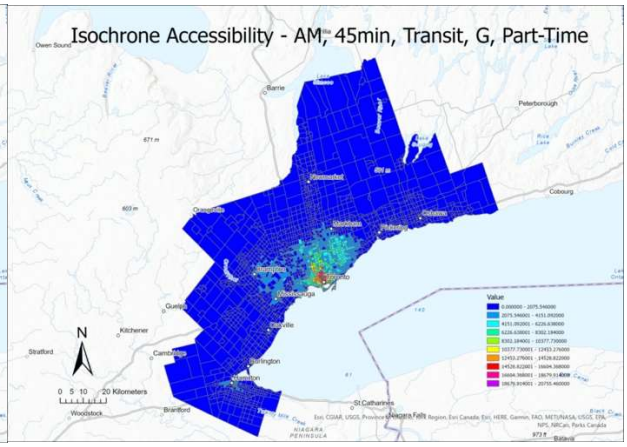


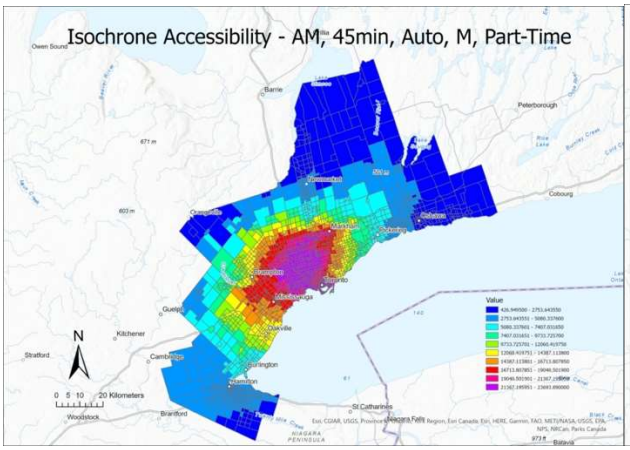




AM 45min Part-time Accessibility Maps



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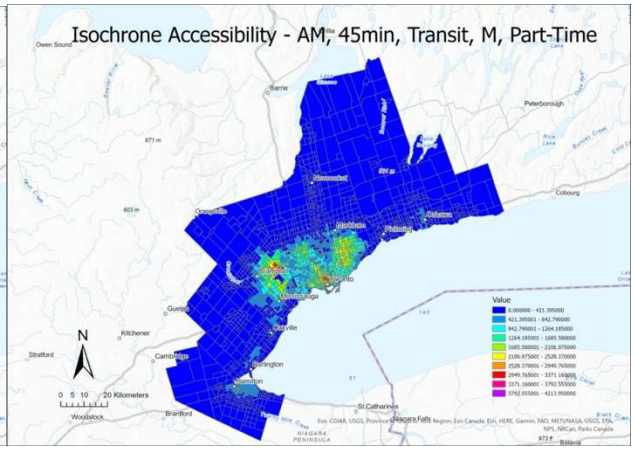
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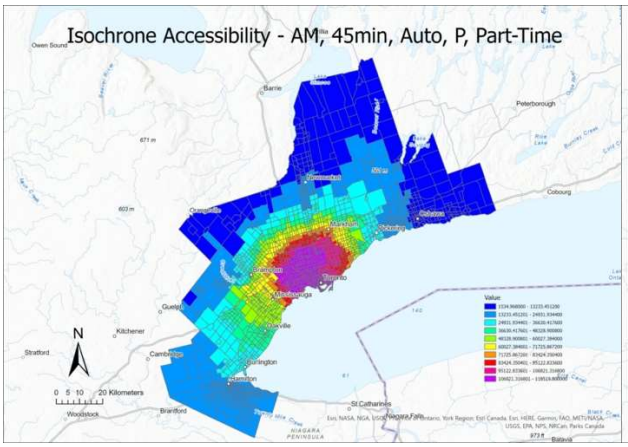
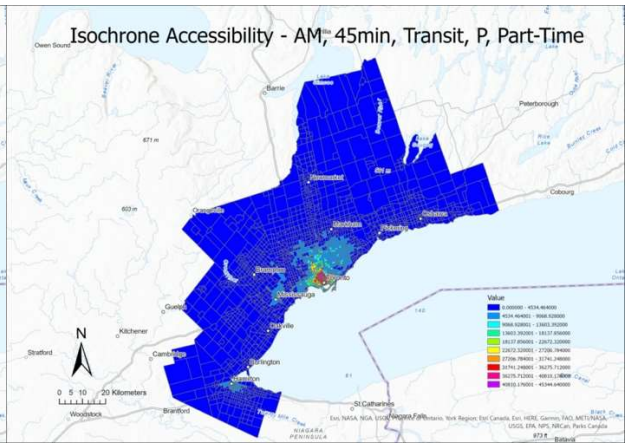

Isochrone Accessibility - AM, 45min, Auto, P, Part-Time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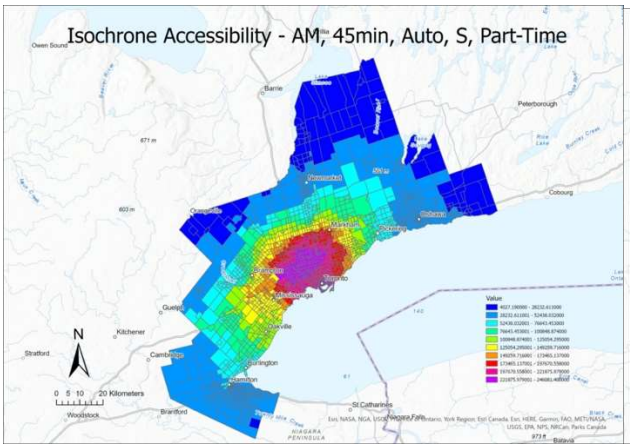
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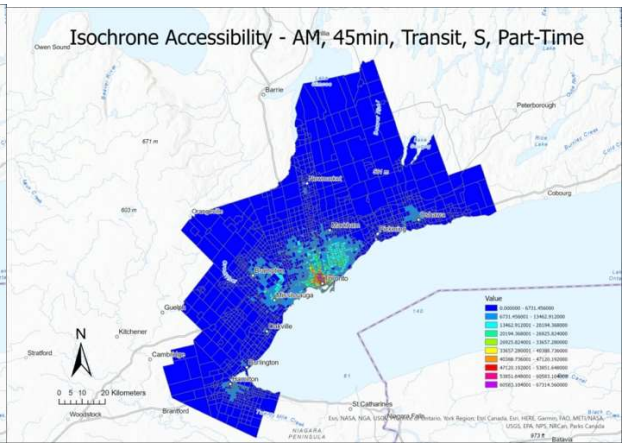
Isochrone Accessibility - AM, 45min, Transit, S, Part-Time

PM Accessibility Maps