The cost of school consolidations: impacts of reduced accessibility

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Abstract

The reduction of mobility-induced GHG emissions is a top priority for many communities around the world. From a different standpoint, communities are consistently under pressure to increase operational cost-efficiency savings, including the consideration of spatially consolidating public resource provision. This is the case for public schools, where governments are opting to close under-capacity schools and expand existing schools to accommodate lost capacity. This study quantifies the travel burdens of school consolidation/closure policy through the case of Hamilton, a mid-sized city in Ontario, Canada. Between the years 2011 and 2015, 7% of the elementary schools closed in the city. Specifically, we quantify how these closures changed the accessibility landscape for the elementary school aged population by using spatial availability, a novel singly-constrained accessibility measure. Spatial availability allows for an interpretable comparison between 'before' and 'after' policy implementation because of its unique proportional allocation property. The analysis is conducted at the parcel-level with all school seats being eligible and travel behaviour based on observed home-to-school patterns for motorzied and non-motorized modes. System-wide impacts resulting from the closures, such as potential GHG emission increases and walk minutes decreases, are detailed. Overall, spatial availability decreased in the city. Though the school conslidation policy resulted in short-term operational cost-savings, families, students, and the environment now pays the price. This paper showcases how spatial availability can be used by decision- makers to quantify spatial and travel implications associated with policy changes.

Keywords: accessibility; spatial availability; carbon emissions; journey-to-school; walkability; active transportation; school consolidation policy; service provision thresholds

1 Introduction

Communities are by nature in flux: economic and demographic shifts, rural and urban configurations, and political pressures stoke changes in community characteristics. These forces spur the re-organization and consolidation of public facilities in communities around the world where changes to service provision may improve the quality of service for some but not for all (Christiaanse 2020; Rosik, Puławska-Obiedowska, and Goliszek 2021). Oftentimes, top-down consolidation decisions that are driven by operational cost-savings do not take into consideration the full extent of benefit loss.

From this perspective, journey-to-school trips are tremendously important: this trip purpose is the largest contributor of carbon emissions from personal travel after journey-to-work trips (Rong et al. 2022; Pantelaki, Claudia Caspani, and Maggi 2024). In many communities globally, school locations are closing (Sageman 2022) and trips made to school are increasingly motorized (Rong et al. 2022). Nonetheless, school closure policies have been pursued by governments to optimize per-student operational cost-efficiency (Rong et al. 2022) but spatial and travel implications have often been overlooked by decision makers (Bierbaum, Karner, and Barajas 2021; Lee and Lubienski 2017). For instance, 65% of comprehensive schools (e.g. grades 1 through 9) in rural Finland since 1990 closed (Autti and Hyry-Beihammer 2014), 10% of elementary schools (kindergarten through grade 8) in Chicago, USA in 2013 (Lee and Lubienski 2017), and 7% of primary and lower secondary schools (kindergarten through grade 9) were closed in Denmark between 2010-2011 (Beuchert et al. 2018).

In this study, we focus on the spatial travel implications of school closure and consolidation policies. The quantification of lost potential active transportation trips and associated carbon emissions due to school closures and the unequal impacts attributed to the increased reliance on a motorized commute is scarce in the literature. In this way, our contribution is both methodological and empirical. We use a novel singly-constrained accessibility measure to quantify changes before- and after the first wave of school closure/consolidations implemented in Hamilton, a mid-size city (~570,000 pop) with rural, suburban and urban characteristics in Ontario, Canada (Government of Canada 2022).

In 2013, the City of Hamilton's largest English school board the Hamilton-Wentworth District School Board (HWDSB), which is the largest English school board in the city, released their Long Term Facilities Master Plan (HWDSB 2013). To ensure "equitable, affordable and sustainable learning facilities", the Master Plan indicated that 80% of it's elementary schools (i.e., schools attended by students aged 5 to 13) would be subject to accommodation strategies, including a "Accommodation Review" whose outcome is possibly closure/consolidation (HWDSB 2013; Craggs 2013; Seasons 2014b). These decisions were in part motivated by operational savings based on projected reductions in student population and under-utilized school capacity (Craggs 2012). However, the case of Hamilton and the HWDSB is unlike others in the province: the HWDSB underwent an unprecedented number of Accommodation Reviews relative to other school boards (Seasons 2014a). Though the Accommodation Review guidelines outline a community-focused process to deliberate a school's future viability to students, the community and the economy (Seasons 2014b; Ministry of Education 2006), concerned residences felt a fulsome breakdown of costs to repair schools were not made consistently available (Kleinhuis 2013). Further, others pointed to flawed incentive structures motivating the HWDSB: "By closing three schools the HWDSB would have a strong case with the Ministry of Education to receive full funding for a new school" (Kleinhuis 2013). Along with insufficient funding to maintain schools in a state of good repair (Auditor General of Ontario 2015), the operational savings as a case for school closures is a long-standing critique of the school "funding formula" established by the conservative provincial government in 1998 (Mackenzie 2018). With the backdrop of budget cuts, the funding formula pits financing of school maintenance and student needs against the financial compensation of staff and powers of local school boards as they no longer have the ability to levee property taxes (Mackenzie 2018).

In the first wave of school accommodation reviews between 2013 and 2016, 12 elementary schools closed. From between 2011 (before the school closures) to 2016, these closures represented a 7% and 4% decline in elementary school locations and capacity, respectively, across the city though overall student population in the city did not significantly change between 2011 and 2016 (58,265 (2011) and 58,865 (2016)).

While accommodation reviews were undertaken to reduce operational costs, how might the closure of schools impact local communities? In this paper, we hypothesize that the school consolidation policy reduced accessibility to schools for many students. By extension, this loss in access resulted in a displacement of trips to school made by active modes that increased transportation-related emissions. To test these hypotheses, the paper examines the following: how does the (1) spatial availability, (2) loss in walk minutes and (3) associated carbon emissions change for home-to-school trips after a city closes and consolidates schools? Further, this work examines (4) what communities, based on low-income prevalence, experienced the greatest losses as a result of this policy. Spatial availability, a singly-constrained competitive accessibility measure (Soukhov et al. 2023; Soukhov et al. 2024), is used to quantify the before- and after- accessibility and associated impacts for the city of Hamilton and the elementary school-aged student population as a result of the school closure and consolidation policy. The methods introduced in this paper can be used by decision-makers to evaluate the spatial and transport-related impacts of public service provision policy. Furthermore, to increase the diffusion of this analysis, all work is completed in a R environment and all associated code and data will be open and reproducible within the lead author's GitHub repository

2 Data and Methods

Our focus is to evaluate the impact that the school consolidations between 2011 and 2016 had on the multimodal school spatial availability and travel-related GHG emission landscape of the city of Hamilton. To facilitate comparison, two scenarios are generated. The first and second reflect estimated as-is conditions in 2011 and 2016 assuming the respective school configurations, average student population and low-income prevalence of households, residential parcel locations, and estimated modal travel times in both years. The difference between these scenarios are quantified in terms of accessibility, emission and equity implications and discussed in context with the school consolidation policy. Data is retrieved at different spatial granularity from the following six data sources.

2.1 Schools

First, schools and associated school catchments are retrieved from the City's school boards. In Hamilton, the majority of student-aged population attends a school in one of the two English public school boards. One board is referred to as *public* (i.e., Hamilton Wentworth District School Board (HWDSB)) in our work and the other is referred to as *public-catholic* (Hamilton Wentworth Catholic District School Board (HWCDSB)). These catchments indicate what residential property is assigned to what school, by default. Families can decide to attend schools out of catchment, in fact 21%-23% of motorized school trips are out of catchment according to the regional travel survey, the Transportation Tomorrow Survey (TTS) in 2011 and 2016 (Data Management Group 2018). The elementary school locations and catchments are provided by the HWDSB and HWCDSB for the 2010-2011 and 2015-2016 academic years and visualised in Figure 1.

Formally, elementary schools are defined as schools that provide instruction to any combination of grades between kindergarten to grade 8 (i.e. typically children aged 5 to 14). As such, elementary includes middle schools that only instruct grades 6 to 8 (*Mid*), primary schools that only instruct kindergarten to grade 5 or 6 (*JrElem*), and all grade elementary schools (*Elem*) which instruct all grades from kindergarten to grade 8. The maximum number of students that may be enrolled in a school is calculated by the provincial Ministry of Education; this value is referred to as the on-the-ground capacity ($OTGC$) and is assigned to each school. The current/historic OTGC province-wide is not publicly available (Ontario 2017). However, for schools that underwent the full Accommodation Review process, the OTGC for a given year can be obtained from publicly available School Information Profiles. A regression model was derived to estimate the OTGC for schools with no capacity information based on 1) the school's building footprint (F) in units of (m^2), 2) the school's shortest Euclidean distance from the centroid of Hamilton's central business district area ($DistCBD$) defined in units of (m), and 3) coefficients associated with a binary variable indicating the type of school grade instruction (*Mid*, *JrElem*, *Elem*). The building footprint from an archived spatial data set (Spatial 2015) and the 2016 footprints were retrieved from OSM (OpenStreetMap 2021). Because the age of construction for different schools is not available, we use each school's distance from the centroid of the Downtown Business Improvement Area (Hamilton 2014) as a proxy for school age as the oldest buildings are generally located closer to the city centre (Merrall 2021).

Equation (1) and (2) describes the estimated OTGC for public schools and catholic schools respectively. School status and OTGC summed by catchment is also visualised in Figure 1. See the Table in the Appendix for the associated regression results.

$$OTGC_{Public} = F^{0.346} - e^{0.00003*DistCBD} + e^{3.123*JrElem_b} + e^{3.752*Elem_b} + e^{3.068*Mid_b} \quad (1)$$

$$OTGC_{Catholic} = F^{0.471} - e^{0.00003*DistCBD} + e^{2.333*Elem_b} \quad (2)$$

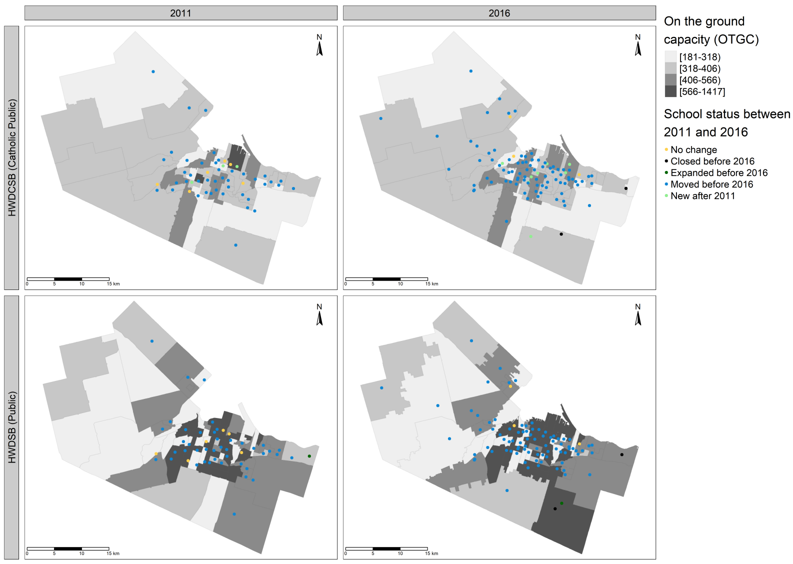

Figure 1: The school catchments, estimated on the ground capacities of schools summed per catchment, and school status for both public and public catholic school boards for year 2011 and 2016. OTGC is presented by quartiles.

2.2 Students, residential locations and low-income prevelance

Second, student population and proportion of household low-income after tax (LIM-AT) prevalence is retrieved from the 2011 and 2016 Canadian Census (Canada 2011, 2016). The census releases population data by age group category in 5-year increments. The LIM-AT prevalence for households with children under 18 (there is no LIM-AT prevalence tabulated for households with exclusively elementary aged children) is retrained. LIM-AT is refers to the proportion of private households that are below the median after-tax income (Government of Canada 2017). These census variables are taken at the Dissemination Area (DA) level, which is the finest geographic unit for which census data is made publicly available. Census data is retrieved using the {cancensus} R package (Bergmann, Shkolnik, and Jacobs 2021). DAs are designed by Statistics Canada with the aim of population uniformity hence DAs greatly vary in area but represent between approximately 400 and 700 (1st and 3rd quartile) in total population. The population aged 5 to 14 and the proportion of LIM-AT are visualised in the first and last row in Figure 2.

The third data source consists of centroids of residential parcels in 2011 and 2016 that are used to represent residential locations (Teranet 2009). There are 134,340 and 139,467 residential locations in 2011 and 2016 respectively, representing 203,806 and 211,596 households (according to the Canadian Census (Canada 2011, 2016)). As the number of children per residential location are publicly unavailable, the average number of 5 to 14 year olds for each DA is divided by the number of residential households in that DA. Then the potential number of children at each residential location is calculated by multiplying this DA rate. Due to the proprietary nature of the parcel data, the middle row in Figure 2 visualises an aggregation of the information: the average rate of 5-14 year olds per residential household at the DA level.

2.3 Estimated travel times and emissions

It is assumed that children can go to any elementary school, but certain schools are more likely to be attended depending on their proximity to their residential location. Based on this assumption, the fourth data source is empirical data regarding the mode-used and origin-destination locations of home-to-school trips from the 2011 and 2016 TTS (Data Management Group 2018). The TTS is a travel survey conducted in the Greater Golden Horseshoe Area in Ontario every 5 years. With a target 5% sampling rate, the survey is expanded to be representative at the traffic analysis zone (TAZ) level of geography. TAZ are spatial units created for the purpose of the TTS; a few DAs typically nest within each TAZ. The trip-level travel data extract for this paper represent 13,715 and 12,878 motorized trips (mode used includes private care passenger, school bus, taxi, and transit) and 2,736 and 1,430 non-motorized trips (mode used includes walk and cycling) for 5 to 13 year olds from home to school in 2011 and 2016 respectively. The travel times for motorized and non-motorized travel are estimated using the {r5r} (Pereira et al. 2021) package, which interfaces with the java-based R5 routing engine developed separately by Conveyal (Conveyal [2015] 2022). Motorized and non-motorized travel times are estimated for all TAZ centroids to all TAZ centroids and these estimated travel times are tied to the associated OD trips. The travel times and the intensity of modal home-to-school flows are visualised in Figure 3 along with the boundaries of the TAZ and DAs. As can be seen in Figure 3, not all TAZs capture an elementary school trip by both modes. For this reason, the

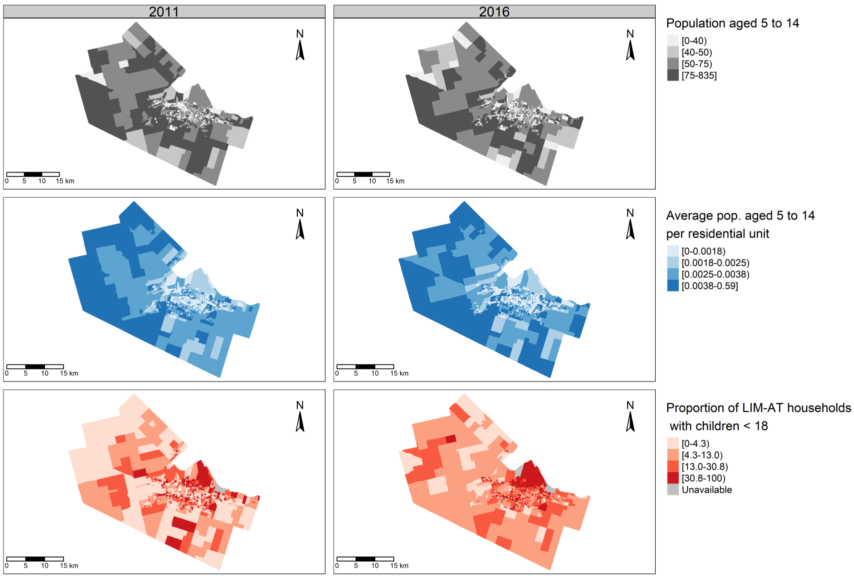

Figure 2: The magnitude (top row) and rate per residential unit (middle row) of elementary aged student population per DA in 2011 and 2016. The proportion of low-income households with children under 18 years old is also shown (bottom row). All scales are represented in quartiles.

proportion of modal-split is aggregated at the community level. Hamilton (Ancaster 85%-95%, Dundas 89%-100%, Flamborough 91%-97%, Glanbrook 92%-95%, Hamilton Central 80%-87%, and Stoney Creek 82%-88%).

The fifth data source consists of estimated travel time matrices from all residential parcel locations to all elementary schools for both motorized (car) and non-motorized (walking) travel. The travel times are estimated using the {r5r} package (Pereira et al. 2021). For both modes, the inputs assume a maximum travel time threshold of 60 minutes and the free-flow OpenStreetMap road network of Hamilton (retrieved using Geofabrik (Geofabrik 2022) and manually edited to only include the Hamilton boundary). Further, walk travel times that are only less than 27 min minutes were retained. This travel time is approximately equivalent to 1.6 km which is the minimum distance that is required from a school within-catchment to qualify for a school bus (HWDSB 2019). Estimated trip-weighted motorized travel times are on average 16.5 minutes in 2011 and 16.8 minutes in 2016 (summary statistics for both years are approximately min: 0.5, Q1: 11.0, Q2: 16.0, Q3: 21.0, max: 60.0). Estimated trip-weighted non-motorized travel times are on average 18.0 minutes in 2011 and 18.1 minutes in 2016 (summary statistics for both years are approximately min: 0.5, Q1: 13.0, Q2: 19.0, Q3: 24.0, max: 27.0).

These travel time matrices along with the origin-destination flows are used to create modal trip length distribution (TLD) functions. A TLD is a useful technique to

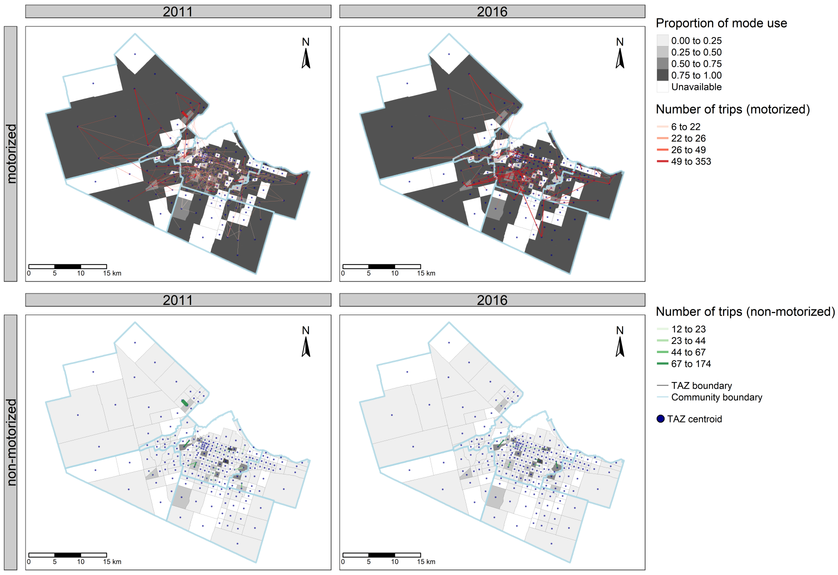

Figure 3: The origin-destination flows from home-based motorized and non-motorized school trips for students between 5-13 years old as retrieved from TTS 2011 and 2016 mapped atop proportion of TAZ non/motorized modal share, DA boundaries, and community boundaries.

calibrate impedance functions as they are a representation of the likelihood that a proportion of trips are taken at a specific travel cost (Horbachov and Svichynskyi 2018; Batista, Leclercq, and Geroliminis 2019). The empirical TLD is fit to a density distribution using maximum likelihood and moment matching techniques and the Nelder-Mead and Brent methods for direct optimization available within the {fitdistrplus} R package (Delignette-Muller and Dutang 2015). Based on goodness-of-fit criteria and diagnostics , the gamma and exponential distributions are selected for the motorized and non-motorized modal distributions respectively. The gamma distribution is defined by the shape (α) parameter of 1.939 (2011) and 2.046 (2016) and the rate (β) of 0.233 (2011) and 0.236 (2016). The exponential distribution is defined by the rate (β) parameter of 0.092 (2011) and 0.1 (2016). The TLDs for the motorized and non-motorized trips are shown in Figure 4. For reference, the gamma distribution and the exponential distribution function are displayed in the following Equation (3)) and (4)) where x is c_{ij}:

$$f(x) = \beta e^{-\beta x} \tag{3}$$

$$f(x, \alpha, \beta) = \frac{x^{\alpha-1} e^{-\frac{x}{\beta}}}{\beta^{\alpha}\Gamma(\alpha)} \quad \text{for } 0 \leq x \leq \infty$$
$$\Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1} e^{-x}\, dx \tag{4}$$

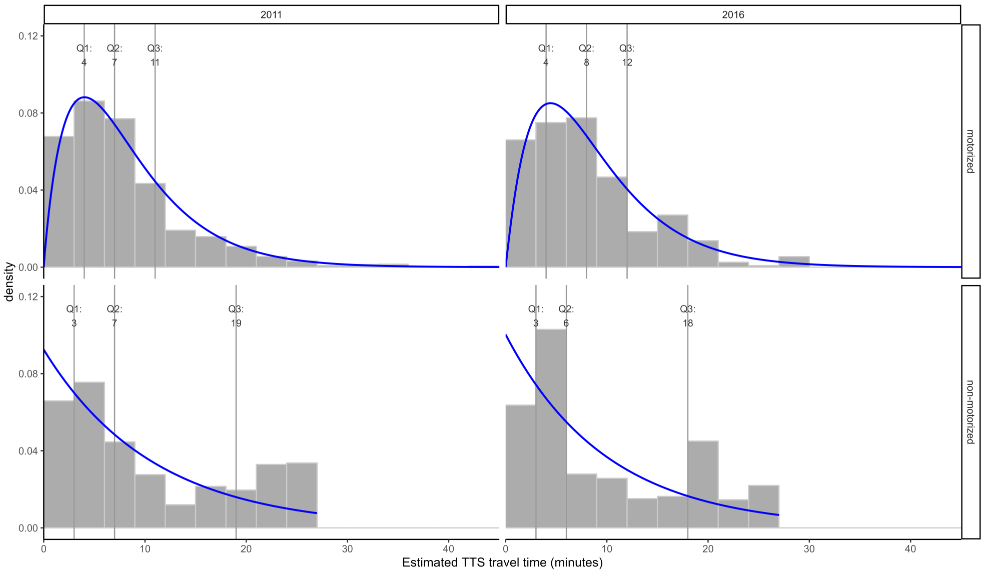

Figure 4: Empirical (grey bars) and theoretical (blue curves) motorized and non-motorized impedance functions. Motorized theoretical impedance function is based on the gamma distribution function and non-motorized on the expoential distribution function

The sixth and final data source relates to motorized GHG well-to-wheel estimations. It assumed that all non-motorized trips produce no emissions and those that are motorized take the average emission factor of 0.1 kg CO2e per minute travel. This emission factor is assumed based on an average speed of 40 km/h, the 2,380 g CO_2e produced when 1 L of gasoline is combusted, and an internal combustion engine passenger vehicle fuel efficiency of 7 g/100km as discussed in Soukhov and Mohamed (2022).

2.4 Putting it all together: multimodal spatial availability

Accessibility is defined as “access to opportunities” or the “potential for spatial interaction”. It is classically presented as the gravity-based measure popularized by Hansen (1959) and takes the following general multi-modal formulation (Equation (5)):

$$S_i^m = \sum_{j=1}^{J} O_j \cdot f^m(c_{ij}^m) \tag{5}$$

where:

- m is a set of modes.
- c_{ij}^m is a measure of the cost of moving between i and j for each m.
- $f^m(\cdot)$ is an impedance function of c_{ij}^m for each m; it can take the form of any monotonically decreasing function chosen based on positive or normative criteria (Paez, Scott, and Morency 2012).
- i is a set of origin locations $(i = 1, \cdots, N)$.
- j is a set of destination locations $(j = 1, \cdots, J)$.
- O_j is the number of opportunities at location j.
- S is Hansen-type accessibility as weighted sum of opportunities.

As indicators of urban structure, Hansen-type measures are informative, but the meaning of 10,000 accessible school-seats is harder to pin down: how many opportunities must any single student have access to? Furthermore, in scenario comparisons, the interpretation of the percentage change in accessible school seats is unclear. The interpretability of Hansen-type accessibility has been discussed in numerous studies, including recently by Hu and Downs (2019), Kelobonye et al. (2020), and in greater depth by Merlin and Hu (2017) along with Soukhov et al. (2023) and Soukhov et al. (2024). The interpretation of accessibility is suggested to depend on how many people demand the opportunity, especially for exclusive opportunity-types like schools-seats (i.e., one school-seat is for one student).

In this paper, we benefit from new developments in accessibility research, particularly the multimodal spatial availability measure (Soukhov et al. 2023; Soukhov et al. 2024). Spatial availability is a singly-constrained accessibility measure that accounts for competition by students using different modes for exclusive opportunities, such as school seats. The measure's single constraint ensures that the marginals at the destination are met and thus the number of estimated school seats (opportunities) are preserved and allocated proportionally to the mode-using student population. This proportional allocation of opportunities yields an interpretable and meaningful measure of opportunity access, particularly when comparing across modes, at the spatial resolution of a residential parcel, and multiple time periods. See Soukhov et al. (2024) for further discussion, multimodal spatial availability V_i^m is defined as given by Equation (6).

$$V_i^m = \sum_{j=1}^{J} O_j \ F_{ij}^{tm} \tag{6}$$

where:

- F_{ij}^{tm} is a balancing factor that depends on the population and cost of movement in the system as part of the gravity modelling framework and is captured in Equation (7) for mode m.
- O_j is the number of opportunities at j.
- V_i^m is the number of spatially available opportunities from the perspective of i for mode m.

F_{ij}^{tm} can be understood as the joint probability of allocating opportunities, where F_i^{pm} is the population-based balancing factor that grants a larger share of opportunities to larger m population spatial units and F_{ij}^{cm} is the impedance-based balancing factor that grants a larger share of the opportunities to less m-travel costly centers. Together F_{ij}^{tm} ensures proportional allocation such that opportunities O (like school-seats) are preserved for the whole region (i.e., $O = \sum_j O_j = \sum_i V_i = \sum_m \sum_i V_i^m$) and is reflected in Equation (7):

$$F_{ij}^{tm} = \frac{F_i^{pm} \cdot F_{ij}^{cm}}{\sum_i F_i^{pm} \cdot F_{ij}^{cm}} \tag{7}$$

where:

- The factor for allocation by population for each m at each i is $F_i^{pm} = \frac{P_i^m}{\sum_m \sum_i P_i^m}$
- The factor for allocation by travel cost for each m at each i and j is $F_{ij}^{cm} = \frac{f^m(c_{ij}^m)}{\sum_m \sum_i f^m(c_{ij}^m)}$

It should be noted that, when summed over all spatial units in the region, the population-based allocation factors F_i^{pm} always equal 1 (i.e., $\sum_m \sum_i F_i^{pm} = 1$), likewise for impedance-based allocation factors F_i^{cm} (i.e., $\sum_m \sum_i F_{ij}^{cm} = 1$).

Hansen-type accessibility is not designed to preserve the number of opportunities in the region, it simply counts the intensity of opportunities that those in a zone can potentially interact with (weighted by the friction of distance). Also, as discussed in Soukhov et al. (2023), popular competitive accessibility measures such as the 2SFCA (Shen 1998; Luo and Wang 2003) end up preserving the number of opportunities in the analysis region but the definitions of variables are internally obscured; the only way it preserves the number of opportunities is if the effect of the impedance function is ignored when expanding the values of opportunities per capita to obtain the total number of opportunities. On the other hand, the proportional allocation procedure associated with calculating multimodal spatial availability V_i^m consistently returns a number of opportunities available to all mode-using populations that matches the total number of opportunities in the region when summed. As a result of this consistency, it is possible to define a measure of multimodal spatial availability per capita (P) as presented in Equation (8) for use as a benchmark to compare against the regional opportunities per capita ($\frac{\sum_j O_j}{\sum_i P_i}$).

$$v_i^m = \frac{V_i^m}{P_i^m} \tag{8}$$

For the reasons outlined, this paper uses the multimodal spatial availability V_i^m and spatial availability per student v_i^m measures to quantify accessibility changes for the following reasons. First, all residential locations are associated to their respective census DA, TTS TAZ, and community boundary (Figure 3) based on spatial location. Each residential location is assigned a number of 'potential' motorized and non-motorized student aged population from these different data sources to calculate a motorized and non-motorized population balancing factor F_i^{pm}. For each residential location the following is retained: the 2011 and 2016 census average elementary-aged student population per residential location (Figure 2 second row) and the average motorized and non-motorized split as informed by the TTS aggregated by community (Figure 3). Second, the school capacity O_j is estimated and associated with each school (Figure 1). All residential locations are assumed to be able to access all schools by either motorized or non-motorized mode. All origins (residential locations) can reach all schools by motorized mode, but few residential locations can reach schools within a 27 minute non-motorized trip.

Third, the motorized and non-motorized impedance-balancing factors F_{ij}^{cm} are calculated using the modal theoretical TLDs (Figure 4) based on the respective travel times for each origin (residential location) to school combination. Finally, outputs from all three stages are joined together. F_i^{pm} joined with F_{ij}^{cm} yields the total balancing factor F_{ij}^{tm} which serves to proportionally allocate the school capacity O_j to each residential location. The value is multimodal spatial availability V_i^m which can be interpreted as the number of school-seats that are available to the mode-using population at that residential location. V_i^m is then summed and represented at the DA and community level along with the calculated v_i^m for interpretation.

3 Results

The motorized and non-motorized spatial availability V_i for both 2011 and 2016 is represented in the top half of Figure 5. Though at different magnitudes, both populations using non- and motorized modes have higher spatial availability when more proximate to schools. Hence, all DAs have higher values within Hamilton Central and those more proximate to schools in less-urban communities. Trends appear similar for both 2011 and 2016: proximate populations using motorized modes benefit from a wider-range in high spatial availability than non-motorized modes. When V_i^m is divided by the number of mode-using students in that DA, v_i^m is derived (bottom half of Figure 5). A similar spatial distribution seen in V_i^m can be seen in v_i^m plots, but as a rate of student population. If our aim is to provide sufficient availability to schools for both motorized and non-motorized populations (i.e., greater than 1.0 v_i^m school-seat availability per student), this rate is only achieved in the core of the city for motorized modes, and notably only for non-motorized populations in DAs that are in less-densely populated rural areas that are school proximate and certain pockets of Hamilton Central. The majority of schools closed were within Hamilton Central, so

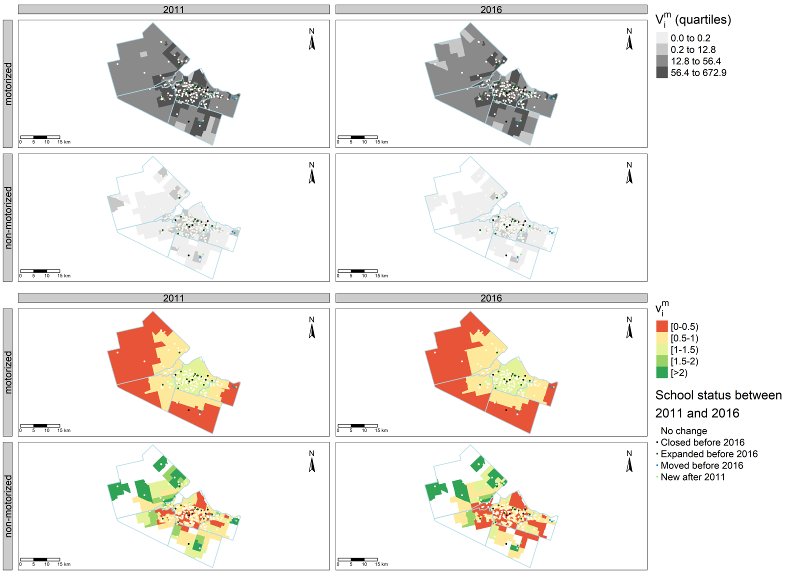

Figure 5: Multimodal spatial availability (greys) and spatial availability per mode-using student (diverging reds and greens) aggregated at the level of DA for 2011 and 2016.

non-motorized populations in DAs within Hamilton Central were the most negatively impacted by losses in availability while certain motorized populations captured these losses as availability gains.

To emphasize how spatial availability changed between 2016 and 2011, the change in V_i^m and v_i^m is visualised for both modes in Figure 6. Overall, a decrease in both V_i^m and v_i^m can be seen across both modes around closed schools (black points). An increase near new or expanded schools (green points) is not as notable as overall fewer school seats were added relative to increases in the school-aged population, leading to increased competition for these resources. For non-motorized mode-using populations, V_i^m decreases across the city. However, some motorized-mode using populations in DAs do experience an increase in V_i^m: these DAs are often relatively proximate to schools but more immediately outside walking-range. Under a competitive and constraint-based calculation, these DAs benefit from the losses in spatial availability that are predominately experienced by the non-motorized populations within Hamilton Central.

Spatial availability can also be summarized by community. The majority of schools were closed in Hamilton Center, this community represents 57% of the 5-14 year old population in 2016. Though the population between 2011 and 2016 decreased, the rate of school-seat spatial availability decreased disproportionately more (population by -4% and spatial availability by ‘r -8%). This out of proportion decrease is greatest in Hamilton Central than any other community. This may have equity concerns as

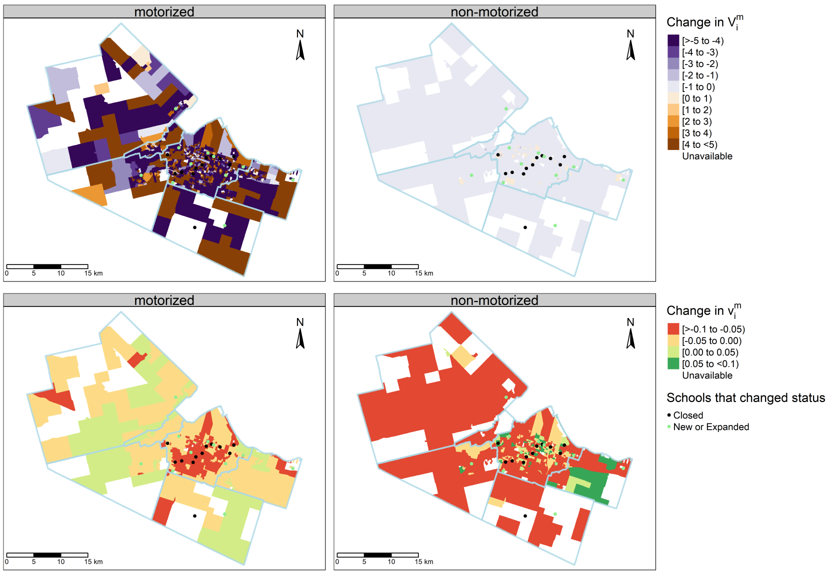

Figure 6: Change in multimodal spatial availability and spatial availability per mode-using student between 2016 and 2011 at the level of DA of the 2016 Canadian Census.

Hamilton Central has the highest LIM-AT prevalence, with 27% of households LIM-AT in 2016, 3.7 times greater than the community with the lowest level of LIM-AT prevalence in the city. Between 2016 and 2011, Hamilton Center had the lowest levels of emissions per student and saw the highest per student increase in 2016. Hamilton Center had the highest non-motorized trip potential, and it was reduced in part by the school closure policies.

Conversely, communities with the lowest LIM-AT benefit the most, notably in gains to motorized spatial availability. Glanbrook, Flamborough and Ancaster have the lowest prevalence of LIM-AT of any Hamilton Community and together account for 25% of the 5-14 year old population in 2016. These communities experienced a growth in student population (or only a small decrease) and proportionally benefited from an increase in motorized spatial availability.

Across the city, those who commute by non-motorized mode see the most dramatic drop in spatial availability across the city. In all communities, spatial availability decreases at greater levels than population. Notably, in Dundas (2nd highest LIM-AT), the only school in the community closed leaving the population in the community with no other option but to use motorized modes. Glanbrook (lowest LIM-AT), which experienced a sharp increase in student population along with non-motorized using population, suffered a lose in non-motorized spatial availability despite seeing the highest increase in motorized spatial availability. Overall, the gain in motorized spatial availability resulted in a further erosion of non-motorized spatial availability. This erosion results in a lose in active transport trips and an increase in emissions city-wide (19.67kg CO_2e per home-to-school potential student-trip in 2011 to 20.17 in 2016).

Study limitations:

- potential students per households, potential trips to all schools
- estimated travel times, direct car or walk trip (shortest path). Not necessarily car, could be transit or school bus. Walking shortest-paths are also optimistic for children's travel: could be unsafe and not taken in reality and/or alternative more pleasant paths are taken.
- estimated emissions. GHG emissions per minute of driving varies extensively depending on operating conditions and vehicle characteristics (Soukhov and Mohamed 2022).

4 Conclusion

In this paper, we estimate the change in multimodal spatial availability as a result of school consolidations/closures between the years of 2011 and 2016 in an empirical case study of Hamilton, a mid-size city (~550,000 pop) in Ontario, Canada. The spatial availability and spatial availability per student are visualized on a DA level; spatial availability for the city declined overall. This decline is then discussed by measuring potential walk minutes and GHG emissions (produced by additional car minutes that result since walk minutes are removed). Overall, the closure of 7% of elementary schools in Hamilton resulted in: a 2,280 decline of school-seat capacity, a decline of 3,309 *potential* home-to-school walk-minutes (per one-way trips), an increase of 3,416 kg CO2e as a result of increased car-minutes as a result of lost *potential* home-to-school walk-minutes (per one-way trips).

By quantifying the spatial availability, environmental, and active-travel implications of school closure/consolidation policies in Hamilton, we offer a methodology for spatial policy analysis scenario. This methodology can be used by researchers and decision-makers to plan and evaluate equitable and sustainable urban planning policies from a spatial perspective. We urge policy makers to view 'spatial availability' of public resources from a per-capita perspective, plan capacity and location of service provision with the cost of travel (and associated implications such as GHG emissions, active transportation mode, safety of active travel modes, etc.) that sufficiently serves the target population. In this paper we suggest and assume a benchmark of 1.0 school-seats per student which accounts for sufficiency. Spatial availability can be used to obtain this benchmark since the total number of opportunities (i.e., school capacity) is preserved in the region of analysis unlike unconstrained forms of accessibility measurement e.g., Hansen-type measure (Hansen 1959). As such, the assigned spatial availability can be divided by population at each zone to yield an interpretable per capita measurement.

Like many other localities, Hamilton is not immune to top-down financial efficient policy decisions to determine community infrastructure is underutilized and it be closed. From the perspective of the provincial government of Ontario, the school closures which occurred in Hamilton resulted in operational savings-per-student but we demonstrate how this resulted in both families and students paying a price through spatial availability, lost potential walk minutes, and increased GHG emissions. In the case of Hamilton Central, where households have the highest prevalence of LIM-AT in the city, those households suffer the most disproportionate decrease in motorized spatial availability and increase in percentage increase in emissions per capacity. As public schools should serve all students; the determination of spatial availability and spatial equity of impact, is critical to better inform decision-makers when evaluating school consolidation policies.

Ultimately, this case study furnishes evidence that consolidation of schools was particularly ill-timed: with the advent of the COVID-19 pandemic, the education system lacked the resiliency to accommodate reduced classroom capacities and left parents who once lived within active transportation distance to schools relying on motorized transportation for their children. These top-down austerity measures left the Hamilton local school system more vulnerable to the impacts of COVID-19 by undervaluing the societal role of schools in neighbourhoods. By identifying the impact of school consolidation policies in Ontario we anticipate that researchers and decision-makers will have better information to center the wellbeing of all residents, including students, and the planet in urban planning policies.

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6 Appendix

Table 1: OTGC Regression results

	Dependent variable:	
	log(capacity)	
	(1)	(2)
log(footprint)	0.346^{***}	0.471^{***}
	(0.107)	(0.153)
Grades.JKto5_6	3.123^{***}	
	(0.834)	
Grades.JKto8	3.752^{***}	
	(0.861)	
Grades.6to8	3.068^{***}	
	(0.893)	
Grades.9to12	4.094^{***}	
	(0.978)	
Type.Elementary		2.333^{*}
		(1.212)
Type.Secondary		2.936^{**}
		(1.398)
urban.dist	-0.00003^{***}	-0.00003^{**}
	(0.00001)	(0.00001)
Observations	42	42
R^2	0.999	0.998
Adjusted R^2	0.999	0.997
Residual Std. Error	0.212 (df = 36)	0.331 (df = 38)
F Statistic	$6{,}189.428^{***}$ (df = 6; 36)	$3{,}794.875^{***}$ (df = 4; 38)
Note:		*p<0.1; **p<0.05; ***p<0.01