SIMULATING THE FUTURE IMPACTS OF URBAN TRANSIT SYSTEM IMPROVEMENTS: APPLICATION TO LONDON, ONTARIO AND HALIFAX, NOVA SCOTIA[1]

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1. Introduction

Continuous growth of Canadian cities during the second half of the 20th century has significantly changed the landscape of personal travel. A host of factors has contributed to the observed changes in travel behavior including horizontal expansion of cities, massive investmentsin highway infrastructure, and reliance of the automobile as the primary source for personal mobility(Maoh et al., 2010). The modernization in urban lifestyle that was triggered by these factors hasalso led to a remarkable increase in commuting distance (Maoh and Tang, 2012). Further, the growth of cities has been associated with urban sprawl and the consumption of natural resources to accommodate new suburban land development. Sprawl has also been responsible for degrading urban air quality due to vehicular emissions.

The planning process to accommodate rapid urban development in Canadian cities has been lacking when compared to Europe. More specifically, many Canadian cities evolved to become auto-oriented as opposed to relying on more sustainable modes of travel such as transit, walking and cycling. For instance, the share of transit ridership in London, UK was 43% in 2011. By comparison, Toronto, Canada had a share of23% for its transit ridership in that year (Husein et al., 2019). Table 1 presents the modal split shares for journey-to-work trips in Canadian cities and 112 European cities.Compared to Europe, the Canadian shares are highly dependent on less sustainable modes of travel. More specifically, the share of sustainable modes in Europe is more than twice when compared to the share of these modes in Canada.

Table 1: Modal Split Shares for Canadian and European Cities

Region	Auto	Transit	Bicycle	Walk	Other
Canada[1]	80%	12%	1%	6%	1%
Europe[2]	59%	18%	10%	10%	3%

1: 2011 Canadian Census; 2: Santos et al. (2013)

Sustainable urban futures in Canadian citieswill require long-term urban and transportation planning strategies that focus on promoting the use of transit, walking and biking as viable alternatives to driving. Integrated Urban Models (IUMs) can be used to evaluate the efficacy of such strategies (Maoh and Kanaroglou, 2009).Theseplanning support systems can be used to tease out the impact of a given policy (e.g. adding a commuter rail line) by changing the features reflecting such policy in the model, while holding the rest of the urban characteristics constant.

The work presented in this paper utilizes the SMARTPLANS (**S**imulation **M**odel for **A**ssessing the **R**amification of **T**ransportation **P**olicies and **LAN**d use **S**cenarios)IUM to analyze the impacts of introducing transit priority corridors (i.e. dedicated bus lanes) in the following Canadian census metropolitan areas (CMA): Halifax, Nova Scotia and London, Ontario. More specifically, the dynamic relationship between the improvement of the cities' transit systems and the reallocation of the total population in favor of areas in close proximity of transit corridors is evaluated. Moreover, the

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effectiveness of this infrastructure as a sustainable solution is analyzed in terms of various measures of sustainable indicators.

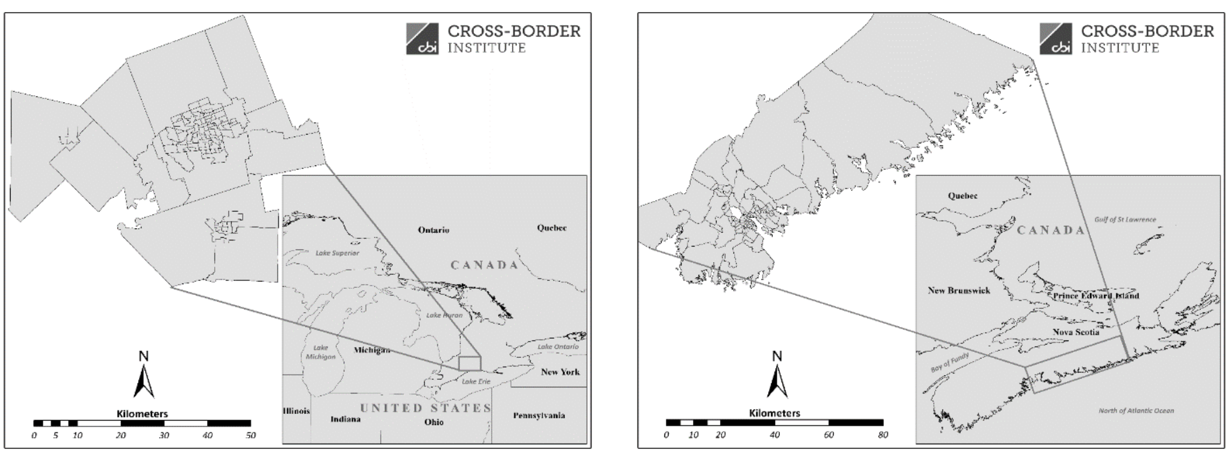
2. Background

Urban sprawl is typically characterized by the decentralization of both population and employment from the traditional urban center to sub-urban regions. Opponents of sprawlbelieve that this type of development deters cities from progressing towards sustainability. Such belief is supported by the arguments that sprawl contributes to the consumption of large portions of prime agricultural land, extensive depletion of petroleum reserves for transportation, and degradation of air quality(e.g. Ewing and Rong, 2008; Travisi et al., 2010).

Many planners and decision makers agree with the negative views about sprawl and as such, have been working on plans that could help Canadian cities achieve more sustainable urban growth. For instance, decision makers in London, Ontario are planning to introduce a rapid transit service that would offer a more appealing and sustainable mode of travel. As described in the region's *Transportation Master Plan*(AECOM, 2013), the proposed rapid transit corridors will be accompanied by smart-growth strategies that focus the intensification of land uses along these corridors. The overall objective is to provide a viable solution to create a shift from auto to transit to reduce traffic congestion and greenhouse gas emissions.

Similar efforts have been proposed by decision makers in Halifax, Nova Scotiatoexploreviable mobility options to meet the current and future needs of local residents, as outlined in their *Integrated Mobility Plan*(McPhail et al., 2017). This plan includes the development of a transit priority corridor to strengthen the transit connection between Bedford and the Halifax Peninsula. The goal of such infrastructure development is to improve transit modal share and trigger transit-oriented development around the potential terminals along the proposed corridor.With these issues in mind, this paper strives to provideevidence-based insights regarding the potential mobility transformation in London and Halifax, and to understand the travel patterns oftheir respective residents.

The London CMA is in Southwestern Ontarioas shown in Figure 1a andhas a land area of 2,662 square kilometers. According to the 2016 Canadian Census, itstotal populationwas 494,069, which represents a change of 4.1% from 2011. On the other hand, the Halifax CMA is located along the Atlantic coast of Nova Scotia (Figure 1b) and has a land area of about 5,496 square kilometers. The total population of the CMA was 403,390 in 2016, which represents a growth of 3.3% from 2011.



(a) (b)

Figure 1: London (a) and Halifax (b)Study Areas

3. Methods of Analysis

3.1 Modeling Framework

The modeling framework of SMARTPLANS(Maoh et al., 2019)is composed of the following integrated modules: (1) region-wide aggregate control module,(2) land use module, (3) transportation module, (4) health benefits module, (5) spatial disaggregation module,and (6) sustainability indicators module.

To begin with, the region-wide aggregate control module is comprised of two models:Roger's multi-regional demographic model andinput-output (I-O) macro-economic model. These models predict region-wide population and employment totals over time. In this exercise, results from this module were not utilized in the simulations; instead, aggregate official forecasts reported by the City of London and the Halifax Regional Municipality were used to control the future predictions.

The land use module uses base year (i.e. time t) zonal data to predict the future changes in land use for period $t + 1, t + 2, \ldots$, etc. For this analysis, the base yearis set to 2006 and future predictions in land uses are done in five-year increments until 2041. The land use module is divided into three sub-modules: real-estate sub-module, accessibility sub-module, andland use activities sub-module. The real-estate sub-module forecasts average zonal prices of different land uses. It also predicts the amount of development that will be available in a given zone for a specific land use type in future years. The accessibility sub-module predicts the level of zonal accessibility to various land uses based on the inter-zonal travel timesthat are estimated by the transportation module. Accessibility measures are typically used as predictorsof the amount of land use development or activities that will emerge in the zones. Lastly, the land use activities sub-module deals withpredicting the total number of people (i.e. population), businesses (i.e. firms), and/or jobs (i.e. employment) that will exist in the zones. More specifically, SMARTPLANS allows the user to specify the number of population segments and/or economic sectors to include in the simulations.

The transportation module is based on the conventional four-stage travel demand model, where it uses the information estimated by the land use module (i.e. population and employment) to predict the total number of trips originating O_i and ending D_j at each zone in the study area (i.e. trip generation model). Next, the trip distribution model is engaged to estimate an origin-destination (OD) matrix with elements T_{ij}, each representing the total number of trips that originated from zone i and ended in zone j. The sum of the rows and columns of the OD matrix must equal to the O_i and D_j values, respectively. More specifically, the doubly-constrained gravity model (see de Dios Ortuzar and Willumsen, 2011) is used to estimate the OD matrix in SMARTPLANS. Although it is not usually part of the four-stage model, SMARTPLANS lets the user to utilize a vehicle ownership model to calculate the zonal average number of vehicles per household. This, along side with the estimated OD matrix, are then fed into a modal split model, which is based on a multinomial (MNL) model(Ben-Akiva et al., 1985), in order to split the estimated OD matrix into its respective modes. The result is an OD_m matrix with elements $T_{ij/m}$, each representing the total number of trips made by mode m between origin i and destination j. Lastly, the traffic assignment model, which is based on stochastic user equilibrium approach (Sheffi, 1984), uses the generated OD_{auto} matrix to estimate the number of passenger vehicles that will travel on the urban road network in a given hour of the day.

Next, the health benefits module of SMARTPLANS is engaged in the simulations. The model is based on the framework developed by Health Canada called Air Quality Benefit Assessment Tool (AQBAT) (Judek et al., 2012). SMARTPLANS uses this model to calculate the potential impacts of air pollution on the health of the exposed population.The tool starts by calculating the change in the level of pollution concentration between a reference and an alternative scenario. The change in concentration is then used to calculate the number of people that will be at risk of a specific health outcome. A total of 18 health endpointspertaining to the following four major health groups: mortality, hospital morbidity,restricted activity and symptom days, andbronchitisare evaluated based on the simulated concentrations for the following pollutants: fine particulate matter ($PM_{2.5}$), ozone (O_3), sulfur dioxide (SO_2), and nitrogen oxides (NO_x). Various land use regression (LUR) models are employed to estimate the concentration of these pollutant at a grid cell level of 600×600meters. A spatial disaggregate module is used to convert zonal and link-based measures into grid cell measure to use as input for the LUR models. The monetary value per each of the 18 health outcomes is also calculated to derive an overall health cost factor “air pollution health cost” to use as input into the sustainability indicators module.

Lastly, the sustainability indicators module in SMARTPLANS evaluates several indicators that pertain to the following five pillars of sustainability: air quality (4 indicators), economic cost (5 indicators), environmental outcomes (4 indicators), health outcomes (7 indicators), and transportation and mobility (4 indicators). Details on these indicators are provided in Oiamo et al. (2019). In addition, the calculations of the sustainability indicators follow the approach highlighted in Maoh and Kanaroglou (2009). SMARTPLANS is programmed to calculate a quantitative value$v_x$for each indicator x based on the simulated trips and associated traffic on the network. The model also calculates a hypothetical minimum value $v_{xmin}$and maximum value$v_{xmax}$for each indicator x. These values are used to calculate a normalize value nv_x for each x as shown below:

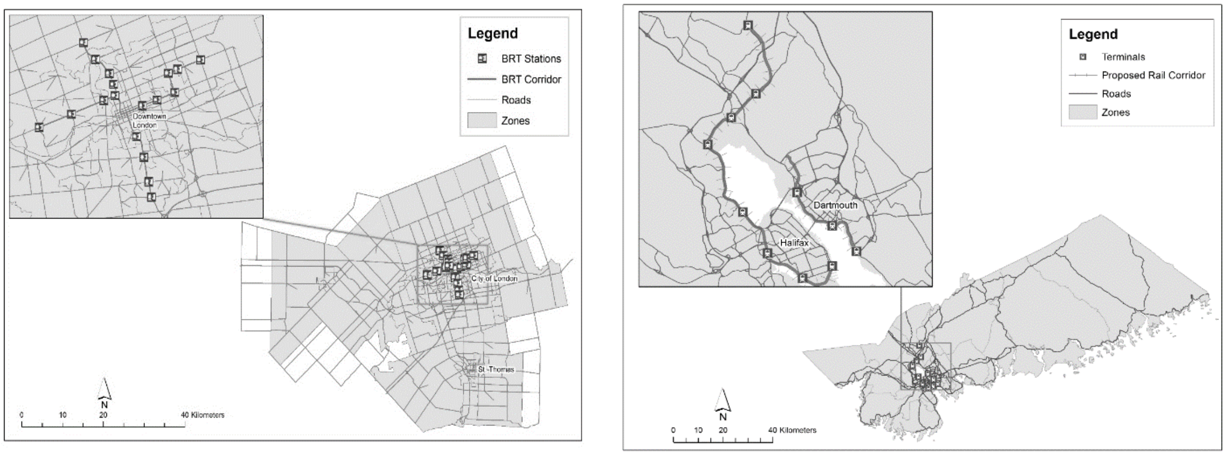
$$nv_x = \frac{v_x - v_{xmin}}{v_{xmax} - v_{xmin}}\text{; where } nv_x \text{ values range from 0 to 1} \qquad (1)$$

SMARTPLANS uses the specified weights w_x associated with each indicator x belonging to a given pillar$p$to calculate an overall index SI_p per pillar$p$ as seen in Equation 2. It is important to note that SI_pvalues closer to 1 suggest less progress towards sustainability. Oiamo et al. (2019) provides details about the work that was conducted to determine the values of the weights w_x for the 24 sustainability indicators.

$$SI_p = \sum_x w_x(nv_x)\text{; where } SI_p \text{value range from 0 to 1} \qquad (2)$$

3.2 Scenario Definition

Figures 2a and 2b present the proposed transit corridors for London and Halifax, respectively. The designof the scenarios entailed altering the transit travel time to reflect the presence of these corridors as part of the existing transit network. For instance, the average inter-zonal transit travel time in the base case was 24.41 minutes and 29.90 minutes for London and Halifax, respectively. Once the transit corridors were implemented within the network, the average dropped by 2.25% and 6% for London and Halifax, respectively. To further reflect the benefits associated with the proposed transit corridors, residential intensification was assumed to be in the vicinity of the terminals servicing the new transit corridors.



(a) (b)

Figure 2: Proposed Transit Corridors for London (a) and Halifax (b)

In line with the London *Transportation Master Plan*(AECOM, 2013), we assumed that 44% of the CMA's future residential growth wouldoccur in the regional core, while 33% wouldbe in the suburban areas, and the remaining 23% will occur in rural zones. The above figures show that over 75% of the future growth was allocated to central areas where the proposed transit corridors will be established. Figure 3a highlights the zones pertaining to the regional core, suburbs and rural areas in London.Similarly, the allocation of future residential growth in Halifax was done in accordance to its*Integrated Mobility Plan*(McPhail et al., 2017). Here, 40% of the future housing growth was assumed to occur within the regional core, 50% was allocatedto the suburban areas, while the remaining 10% was assignedto rural zones. Figure 3b identifies the zones comprising the regional core, suburbs, and rural areas in Halifax.

(a) (b)

Figure 3: Regional Core, Suburban and Rural Boundry Profiles of London (a) and Halifax (b)

4. Results and Discussion

In this exercise, the impacts of the proposed rapid transit corridors on London and Halifax were evaluated specifically for the AM-peak period (i.e. 8 – 9 AM). Tables 2 and 3 provide a summary of some of the basic transportation performance measures estimated by SMARTPLANS for the two CMAs. The reference scenario indicators represent the outcomes of the status quo growth that will take place in each CMA. Under the reference scenario, the total vehicle kilometers travelled (VKT) for both study areas tend to increase over time due to the projected growth in travel demand between 2021 and 2041. A slightly similar temporal pattern can be observed in terms of the total vehicle minutes travelled (VMT) and the total energy consumed. These outcomes are reasonablesince both measures are highly correlated with VKT. Similarly, the increase in congestion over time is consistent with the predicted growth in travel demand.

The introduction of the rapid transit corridors improved the performance of the transportation system in the two CMAs over the 2021 – 2041 planning horizon. More specifically, the total VKT in London and Halifax was projected to decrease, on average, by 19.5% and 23.5%, respectively. In addition, the reduction in total VMT and energy consumed in both study areas was comparable to the reduction of their respective total VKT. On average, the transit corridors alleviated congestion by 32.2%and 38.7% in London and Halifax, respectively.

Table 2: Estimated Transportation Performance Measures for London at 8AM Period

Performance Measures	2021	2026	2031	2036	2041
Reference VKT	1,121,630	1,166,600	1,191,043	1,208,855	1,245,208
% Change from Reference	-13.96%	-18.65%	-21.57%	-22.29%	-21.22%
Reference VMT	1,047,622	1,095,409	1,119,262	1,140,908	1,173,862
% Change from Reference	-17.15%	-21.53%	-23.44%	-23.75%	-21.61%
Reference Total Energy Consumed	89,889	93,495	95,455	96,884	99,798
% Change from Reference	-13.97%	-18.67%	-21.57%	-22.29%	-21.22%
Reference Congestion Index	0.309	0.318	0.323	0.327	0.337
% Change from Reference	-34.70%	-34.00%	-32.99%	-30.89%	-28.39%

Table 3: Estimated Transportation Performance Measures for Halifax at 8AM Period

Performance Measures	2021	2026	2031	2036	2041
Reference VKT	1,369,807	1,454,330	1,571,082	1,720,885	1,940,542
% Change from Reference	-27.64%	-25.05%	-23.34%	-20.77%	-20.67%
Reference VMT	1,432,692	1,509,888	1,651,565	1,850,320	2,209,109
% Change from Reference	-36.08%	-32.62%	-30.67%	-26.30%	-24.19%
Reference Total Energy Consumed	109,850	116,623	125,996	138,029	155,705
% Change from Reference	-27.69%	-25.10%	-23.38%	-20.80%	-20.69%
Reference Congestion Index	0.428	0.438	0.453	0.476	0.506
% Change from Reference	-43.49%	-40.76%	-38.82%	-36.23%	-34.23%

Reduction in region-wide road link emissions and transportation-related costs associated with the implementation of rapid transit corridors were also estimated.However, for brevity, detailed results are not presented in this paper. Generally, the effects on these measureswere consistent with the effects reported in Tables 2 and 3. That is, the presence of the rapid transit corridors in simulationsdecreased the levels of vehicular emissions.The decline in emissions ranged from 4.9% to 30.1% for London, and 13.7% to 34.8% for Halifax. Likewise, the costs associated with using the private automobile (i.e. commuting cost, congestion cost, infrastructure cost and traffic accidents cost) declined under the rapid transit scenario. The cost reduction in London and Halifax rangedfrom approximately 5.0% to 31.9% and 13.4% to 48.6%, respectively.

An overall sustainability index wascalculated for each of the five simulation periods from 2021 to 2041 to examine howLondon and Halifax would progress towards sustainability under the status quo scenario. According to Figure 4, each study area showsa consistent temporal trend, although Halifax exhibits a higher overall index of about 0.7.By comparison, London'sindex hovers around 0.50 over the period 2021 to 2041. A higher index suggests that Halifax's status quo situation generally presents less progress towards sustainability when compared to London.

As expected, simulation results suggest that adding transit priority corridors led to more favourable sustainable outcomes when compared to the reference scenarios of London and Halifax, likely due to decrease in automobile trips. Such result can be discerned from the 2041 comparison of the overall sustainability indices shown in Figures 4 and 5. The utilization of rapid transit decreased the overall sustainability index in London by 29% (i.e. from 0.515 to 0.366). Similarly, the index pertaining to the overall sustainability indicator decreased by approximately 17% (i.e. from 0.680 to 0.568). The individual contribution of each sustainability pillar to the overall index in each CMA is shown in Figure 5. To understand how each of the five pillars contribute towards improving or curtailing progress towards sustainability, each of the five weighted indices were normalized by the overall index, as shown in Table 4. As shown in Table 4, the air quality pillar appeared to be the largest contributor to deterring progress towards sustainability, followed by the environmental and transportation / mobility pillars.

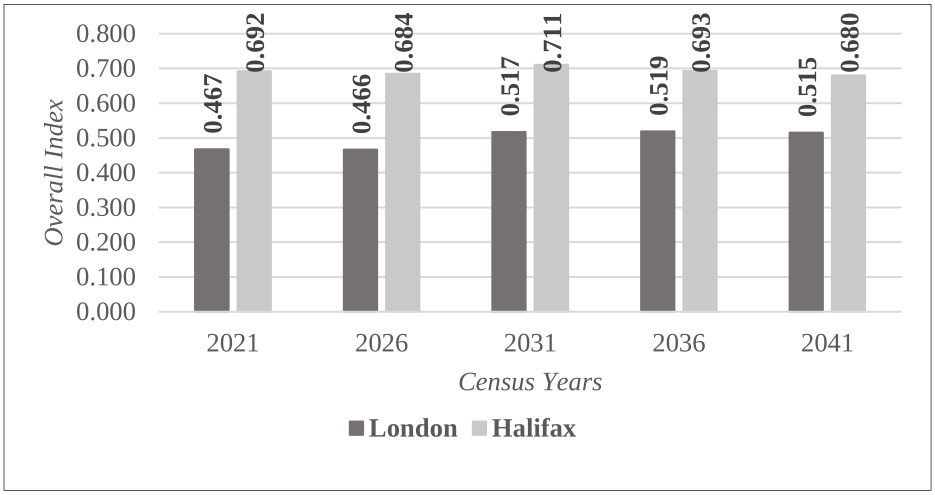


Figure 4: Overall Sustainability Indicator for the Reference Scenario at 8AM Period

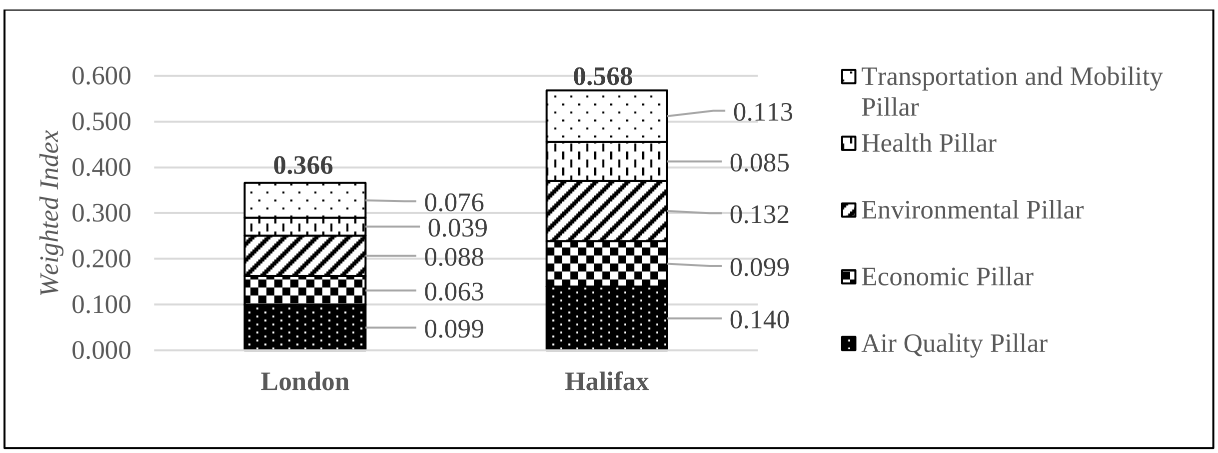


Figure 5: Sustainability Indicators for the Proposed Transit Priority Corridors for 2041 at 8AM Period

Table 4: Relative Contribution of Sustainability Pillars to Overall Sustainability Index, 2041

CMA	Air Quality Pillar	Economic Pillar	Environmen tal Pillar	Health Pillar	Transportation and Mobility Pillar	Overall
London	27%	17%	24%	11%	21%	100%
Halifax	25%	17%	23%	15%	20%	100%

5. Conclusion

SMARTPLANS is a tool that provides decision makers the capability of evaluating the efficacy of various potential land use and transportation development scenarios. An example of the latter is the construction of transit priority corridors in urban areas. This paper employs SMARTPLANS to analyze the potential benefits and expected effects of implementing transit priority corridors in London, Ontario and Halifax, Nova Scotia. The analysis starts with simulating a reference scenario in each study area to depict the natural progression of future development between 2021 and 2041, specifically for the 8 – 9 AM peak hour of a typical weekday. The effectiveness of the proposed transit corridors was assessed through various transportation performance and sustainability indicators. In general, simulations suggest that both London and Halifax metropolitan areas wouldbenefit greatly from implementing better transit systems. Interestingly, SMARTPLANS results suggest a greater projected impact of transit priority corridors in in Halifax, compared to London. However, addition of transit corridors resulted in a positive impact on sustainability in both cities.

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