Scenario Development and Microsimulation of Travel Demand during COVID-19

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ABSTRACT

This paper presents the findings of pandemic scenario simulation within an activity-based travel demand forecasting model – shorter-term decisions simulator (SDS), which is currently implemented in Halifax, Canada. The study develops five pandemic scenarios within SDS, namely business-as-usual, lockdown, reopening phase-1, reopening phase-2, and reopening phase-3 focusing on the COVID-19 outbreak. These scenarios are developed utilizing multiple data sources such as Google’s COVID-19 Community Mobility Report. Utilizing the scenarios, SDS predicts changes in individuals’ activity-travel decisions during the COVID-19 pandemic. For example, the microsimulation results suggest a 47% reduction in activity participation during lockdown, which starts decreasing with the reopening phases. It is predicted that 81% people will participate in only two out-of-home activities a day during lockdown, however, people engage in more activities as the urban system begins reopening. Spatial distribution of activities illustrates lower mandatory activity participation in downtown areas during lockdown that gradually reduces until reopening phase-2, however, increases in reopening phase-3. The proportion of discretionary activities is predicted to increase significantly in adjacent suburban areas and South and North Ends of Halifax from lockdown to reopening phase-3. In the case of mode choice, results suggest that choice of auto mode during the lockdown scenario reduces by 46% compared to the business-as-usual scenario. It is predicted to increase by 13% during reopening phase-3. Proportion of non-shared travel for different activity-based tours is also predicted to increase from lockdown to reopening scenarios. Moreover, SDS predicts lower vehicle usage during pandemic compared to the baseline scenario, specifically subcompact vehicle allocation to different activity-based tours. The findings of this paper will help policymakers to develop essential policy interventions to be prepared for any further epidemic situation in future.

Keywords: Pandemic; COVID-19; shorter-term decisions simulator (SDS); scenario simulation; microsimulation; travel demand forecasting.
1. INTRODUCTION

Activity-based travel demand forecasting models have been widely used in practice for the last three decades in order to predict household and person-level activities and associated travel decisions. Such modelling can microsimulate agents’ (households’/individuals’) decisions by considering their underlying behavioural processes, thus providing a better prediction of future travel patterns. Various transportation stakeholders including engineers, planners, and policy makers have been increasingly developing and practicing activity-based microsimulation models to support their decision-making process (1). In the absence of real time activity participation, schedules, and location data, an activity-based travel demand forecasting model could be one of the most reliable resources for predicting mobility patterns for informed decision-making. Although activity-based analysis of travel demand models share some similarities with conventional four-stage travel demand models, they incorporate significant advances such as the interdependencies among activity and travel decisions, and the explicit representation of realistic constraints of time and space (2). The activity-based models are built on behavioural theories that anticipate the underlying decision processes of daily activity schedules in the presence of realistic constraints, including decisions such as types of activities, where to participate in activities, when to participate in activities, and how to get to these activities (3). The behavioural realism of such models come in two forms, practical and theoretical level (4). While the conceptual structure of the activity-based model is comprehensive and interesting, its complexity and relative novelty have limited its practical application. A major advantage of activity-based modelling lies in its ability to provide a better understanding and prediction of traveler response to changes in activity patterns, infrastructure, and policies (5). Various policy scenarios can be examined within an activity-based microsimulation model to understand the disaggregate-level future changes in activity and travel behaviour that have occurred due to policy implications (6). For example, the San Francisco Bay Area has recently used their activity-based models to analyze the regional transportation plan implemented by MPOs (7). Furthermore, future travel patterns can be foreseen in times of emergency or panic situation (e.g. outbreak of communicable diseases, floods, cyclones, volcanic eruptions, land slides, and terrorist attacks) by managing different parameters and constraints of an activity-based travel demand model. Recently, a contagious disease – Coronavirus disease - 2019 (COVID-19) has caused a global outbreak and forced governments to shutdown and then gradually reopen businesses, services, recreational activities, and other facilities in order to protect people in cities around the world. These situations may create major changes in daily person-level activity and travel behaviour of a region as well as have large economic impacts (8). An activity-based microsimulation model could be a useful tool to accommodate such scenarios and predict activity-travel patterns in order to anticipate changes in future travel behaviour. Utilizing such modelling efforts, planners, engineers, and policymakers could develop necessary policy strategies and interventions to mitigate drastic changes that have occurred within transportation environment/infrastructures due to pandemic situations. This study presents the implementation of an activity-based microsimulation model – shorter-term decisions simulator (SDS) to evaluate COVID-19 pandemic scenarios including lockdown and reopening stages. SDS is an integral part of the iTLE (integrated Transportation, Land Use and Energy) urban model that is currently implemented in Halifax, Canada. iTLE is an agent-based integrated urban systems model that is developed by addressing process mechanisms and multi-domain interactions among a number of long-term, medium-term, and short-term decisions. The SDS microsimulation tool is developed utilizing various advanced heuristics and econometric micro-behavioural models, including Markov Chain Monte Carlo method, conditional logit modelling method, and mixed logit modelling method, among others. This study develops scenarios for the COVID-19 pandemic situation. A business-as-usual scenario, a lockdown scenario, and three reopening scenarios are conceptualized and developed endogenously within the SDS microsimulation framework. These scenarios are run within the SDS
microsimulation tool and provide future activity and travel information based on restrictions implemented within the modelling framework.

2. LITERATURE REVIEW

2.1 A synopsis of pandemic and travel behaviour

COVID-19 is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (9). The disease was first identified in 2019 in Wuhan, the capital of Hubei China, and has since spread globally, resulting in a pandemic situation (10). The World Health Organization (WHO) officially declared the SARS-CoV-2 outbreak a Public Health Emergency of International Concern on January 30, 2020 and as a global pandemic on March 11, 2020. By October 31, 2020, more than 47-million cases of COVID-19 had been reported in more than two hundred countries and territories, resulting in over 1,213,600 deaths, however, approximately 34,115,700 people have recovered (11). The COVID-19 virus is unique because of its high transmissibility, substantial fatality rate for high-risk groups, and ability to cause huge societal and economic disruptions globally. It has substantially affected human travel behaviour because countries were advised by WHO to implement strict lockdown, social distancing, and quarantine measures to avoid the spread of the virus and to protect public health (12). Such measures in a pandemic situation are combined with travel restrictions as well, which reduce overall mobility activities. This may impose severe impacts on the economy. During a pandemic control period, human activities decline greatly that results in a significant decrease in industrial operations, vehicle kilometers traveled, and construction, which further contribute to a reduction in emissions (13). People begin using online shopping platforms to purchase their daily necessary products, causing a reduction in shopping trips (14). Jonas De Vos (15) recently found that implementing measures such as social distancing and closure of facilities have decreased the overall travel demand; specifically, public transportation has been the most affected. The study further identified that working from home, e-learning, and a reduced number of public activities and events are the primary reasons of lower travel demand during a pandemic. People realize that it is safer to stay at home rather than be out in public. These circumstances yield less traffic, less congestion in peak hours, and lower public transportation ridership. People become more accustomed to using private vehicles during pandemic situations because it helps to limit contact with others (16). Pandemics also influence travel behaviour of student groups as university authorities and public health officials implement restrictions on their mobility to and from institutions. Ma T. et al. (17) investigated Chinese International Students who stayed in Australia during the outbreak of the COVID-19 pandemic and explored reasons these students were high-risk, such as their low-risk perceptions and lack of seeking travel health advice. Most importantly, airports, harbors, ports, and road transportation are entry points to countries that play a critical role in the international transmission of diseases via persons, goods, and vehicles. Therefore, most governments implemented restrictions on travel that caused a decline in tourism activities. Although the outbreaks of SARS (2002) and MERS (2012) did not have a long-term impact on the tourism sector, COVID-19 has already put this sector into great danger (18).

The relationship between pandemics and transportation is vital to understand everyday mobility pattern changes during COVID-19 crisis (19). The transportation system connects people’s activities and places, thereby creating a potential source for the spread infectious diseases. There have been 10 major influenza pandemics over the past 300 years and the outbreak of these pandemic was centered on shipyards, rail terminals, large workplaces, and tram stations (20). To mitigate such spread of diseases, people rarely go out to perform out-of-home activities due to the restrictions imposed on mobility, which significantly impacts the travel patterns of the region (21). An activity-based travel demand model could be useful in such situations to understand individuals’ mobility pattern. In general, activity-based travel demand models have the capability to predict changes in individuals’ travel-activity choices such as activity participation, activity frequency, activity destination, mode choice and vehicle allocation with
respect to various policy scenarios. The application of an activity-based travel demand model is not new. Such modelling approaches have been implemented in multiple cities around the world to estimate future activity and travel pattern under emerging policy scenarios. Some notable examples are – analyzing travel demand due to congestion pricing in New York and San Francisco, USA (7); light duty vehicle demand under emission scenarios in Greater Toronto Area (GTA), Canada (22); and development of regional plans based on activity generation and transportation infrastructure-based scenarios in Netherlands (23), among others.

2.2 Research questions

Although the practical application of activity-based travel demand forecasting models is increasing, none of the existing studies have focused on forecasting activity-travel pattern involving pandemic situations (e.g. lockdown and gradual reopening of a region) (24). It is critical to understand individuals’ activity and travel behaviour during a regional shutdown since it contributes to a plan for reopening activity centers while addressing public health concerns and activity needs of people. Also, as an urban system starts to reopen after a complete lockdown, recognizing changes in activity-travel patterns is essential at different reopening stages in order to develop policy interventions. In particular, the following research questions require further attention: 1) how COVID-19 pandemic influence person-level activity and travel patterns, and 2) what are the impacts of alternative reopening scenarios on activity participation, schedules, and mobility? This study attempts to address these research questions by presenting the application of an activity-based shorter-term decisions simulator (SDS) in various pandemic situations.

2.3 Contribution of the study

This study contributes to the existing literature in two ways – 1) by developing different pandemic scenarios within the SDS microsimulation modelling framework, and 2) by forecasting various activity and travel dimensions under pandemic scenarios. The study adds a new dimension in literature by focusing on the application of activity-based travel demand modelling to predict changes in activity-travel behaviour during a pandemic, specifically the COVID-19 disease outbreak. To the authors’ knowledge, this research is a first of its kind that studies the application of an activity-based travel demand forecasting model using pandemic situations.

The SDS microsimulation tool has the capacity to develop various scenarios and policy measurements within its modelling framework. This study develops five pandemic scenarios within the conceptual modelling framework of SDS: a) Scenario 1 – business-as-usual case that refers to normal activity-travel pattern without a pandemic situation; b) Scenario 2 – lockdown, which represents the complete shutdown of a region with only essential activities and travel allowed; c) Scenario 3 – reopening phase-1. This refers to the first stage of reopening businesses of a region, where certain non-essential activity and travel is allowed; d) Scenario 4 – reopening phase-2, which refers to opening more businesses and permitting more out-of-home activities and travel than phase-1; e) Scenario 5 – reopening phase-3 that refers to no restrictions on out-of-home activity participation, and limited restrictions on travel alternatives. These scenarios are developed by utilizing multiple data sources, including Google’s COVID-19 Community Mobility Report (25). The output of the model will simulate a fine-grained representation of activity concentrations and mobility patterns at a 24-hour timescale. For each scenario, multiple short-term decisions are simulated such as activity participation, activity frequency, travel distance, mode choice, shared travel choice, and vehicle allocation, among others. Results are then compared to the business-as-usual scenario, which assists to recommend potential policy measures on the changes that occurred during the lockdown and reopening phases. The broad objective of this study is to understand the potential impacts of a pandemic in a region, so that governments and stakeholders will be well-prepared for potential future pandemic situations. Findings from this research will assist transportation
planners, engineers, and policymakers to design effective policy interventions in order to mitigate travel and economic impacts that occur due to a sudden pandemic.

3. METHODOLOGY

3.1. Overview of the Shorter-term Decisions Simulator (SDS)

The pandemic scenarios are developed in this study within the SDS microsimulation framework, which is implemented within the iTLE urban modelling platform. iTLE is an agent-based microsimulation model that addresses various behavioural process mechanisms and multi-domain interactions between agents’ decisions. The model consists of three core modules - longer-term decisions simulator (LDS), shorter-term decisions simulator (SDS), and traffic flow simulator (TFS). Various long-term decisions such as life-stage transitions, residential relocation, and mobility tool ownerships at the household- and individual-level are simulated within the LDS module. Details discussion on the LDS module implementation can be found in Fatmi and Habib (26, 27). SDS is an essential part of the iTLE urban model that simulates individuals’ daily activity and travel decisions. Figure 1 presents the operational framework of the SDS model. The heuristics algorithms and econometric models in SDS are developed using the 2016-17 Nova Scotia Travel Activity (NovaTRAC) survey.

![Figure 1 Operational framework of the Shorter-term Decisions Simulator (SDS)](image)

The microsimulation process in SDS starts by generating daily activity programs within the activity generation sub-module. It simulates different types and number of activities following a Markov Chain Monte Carlo method that represents the process orientation of generating activity types. The activity scheduling sub-module is developed utilizing both heuristics and econometric modelling methods as a three-stage decision process. The sub-module consists of several components, such as activity agenda formation, destination choice, shared travel choice and an activity conflict resolution manager. Furthermore, the mobility assignment sub-module operates as a two-stage dynamic process of mode choice and vehicle allocation. A detailed description of the SDS microsimulation tool can be found in Khan and Habib (28). SDS is a validated activity-based travel demand microsimulation tool. A comprehensive
validation for base year and forecasting years is performed during the development of multiple components of SDS. Details on model validation can be found in Khan and Habib (28), and Khan et al. (29).

3.2. Development of pandemic scenarios within SDS microsimulation framework

During the COVID-19 pandemic situation, all Canadian provinces have experienced major impacts on everyday activities and associated travel. The federal government of Canada has offered guidance and travel restrictions in collaboration with provincial and territorial governments in order to respond to the public health threats of the virus immediately. The Emergency Management Office (EMO) of the Government of Nova Scotia is working closely with provincial partners to mitigate the impacts of COVID-19 and ensure public wellness (30). The state of emergency is developed and the province takes multiple preventative actions, for instance, restrictions on activity participation (e.g. shopping, eating out, on-campus class, childcare services, etc.), maintaining social distancing in public spaces (e.g. parks, playgrounds, transit, etc.), and reducing the allowed maximum capacity in grocery stores and shopping malls, among others. Due to such restrictions, it becomes possible to control the spread of the contagious COVID-19 disease, albeit these restrictions create greater impacts on the region’s transportation systems and mobility patterns. This paper attempts to develop scenarios based on government directions and data obtained from multiple sources. The following is a brief discussion of the scenarios developed in this study.

3.2.1. Scenario 1 – Business-As-Usual (BAU)

The first scenario developed within the SDS microsimulation modelling framework is the business-as-usual scenario, which reflects everyday normal life without a pandemic. This scenario represents the basic SDS microsimulation model, which was developed based on 2016-17 Nova Scotia Travel Activity Survey (NovaTRAC) data and models described in the previous section.

3.2.2. Scenario 2 – Lockdown

After the confirmation of the first presumptive COVID-19 cases, the provincial government of Nova Scotia announced a state of emergency on March 22, 2020 (31). Major restrictions were imposed during this lockdown scenario to stop the spread of the COVID-19 disease. In accordance with the emergency declaration, land, sea, and air points of entry were closely monitored. Travel was restricted to a certain limit. People were ordered to stay home, and activities such as work, school, shopping, dine out, personal business (including work and household related errands, healthcare, civic/religious activities), dine out and recreation (including visiting friends/relatives and entertainment) activities were suspended temporarily. All parks, provincial trails, and tourists’ attractions were closed until further notice. Police were authorized to enforce orders under the Health Protection Act, as well as the Emergency Management Act, and gatherings over 5 people were prohibited. However, after a couple of weeks, the government allowed some small businesses to open but asked to maintain the 2-meter social distance and restrict occupancy to a certain amount of people depending on the establishment. People started working remotely, while schools, universities, childcares were either closed or moved to online (32). This situation continued until April 30, 2020. The lockdown scenario developed in this study accommodates such restrictions within the modelling framework. This study utilizes Google’s COVID-19 Community Mobility Report (25) to develop the scenarios. According to the report, the percentage of people participating in work, shopping and recreational activities have dropped by 52%, 22% and 48%, respectively, since the beginning of the lockdown in Nova Scotia. These percentages are utilized to limit individuals within the microsimulation modelling framework to participate in the aforementioned activities during lockdown. In addition, activities such as school, escort (drop-off and pick-up passengers), personal business (including work and household related errands, healthcare, civic/religious activities), dine out and recreation (including visiting friends/relatives and entertainment) activities are restricted to no participation during this scenario development. Furthermore, choice of travel modes is controlled within the model. Choice of auto and active transportation (walk and bike) modes are given priority over transit, since transit was limited during the lockdown scenario in Nova Scotia
(33). Finally, shared travel choices are restricted because lockdown in Nova Scotia allowed only one person from each household to travel to any facility (34).

3.2.3 Scenario 3 – Reopening phase-1

The reopening phase-1 scenario is developed within the SDS model by lifting restrictions on some of the activity and travel dimensions. The government of Nova Scotia began reopening business establishments and some recreational facilities starting May 1, 2020. It included the reopening of public parks, trails and sports fishing and people were allowed to visit community gardens and small businesses, e.g., nurseries and garden centres (35). On May 15, the provincial government lifted a few restrictions as well. People could attend boating, yachting, or sailing clubs for recreational purposes. Religious activities and travelling within the region were permitted by maintaining a 2-meter social distance after May 15. This study uses this timestamp to develop the reopening phase-1 scenario. According to the Google’s COVID-19 Community Mobility Report, during reopening phase-1, people participating in work, shopping and recreational activities were reduced by 39%, 7% and 23%, respectively (25). Similar to the lockdown scenario, SDS utilizes these percentages to limit individuals’ participation in work, shopping, and recreational activities. Additionally, escort activities are permitted while developing the reopening phase-1 scenario, since individuals are allowed to travel with household members during the timestamp in Nova Scotia. Other travel restrictions, such as mode choices are limited within the reopening phase-1 scenario.

3.2.4 Scenario 4 – Reopening phase-2

The Government of Nova Scotia relaxed restrictions on various activity and travel dimension on June 15, 2020. A timestamp of June 15 is considered for the reopening phase-2 scenario in the SDS microsimulation tool. From June 15, provincial campgrounds were opened at a reduced capacity. Individuals were also permitted to gather in close social groups (10 persons), and restaurants were allowed dine in services. In addition, travelling within Atlantic provinces (New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador) was also allowed starting July 3. The Google’s COVID-19 Community Mobility Report states that people participating in shopping activities increased by 3%, whereas people participating in work and recreational activities decreased by 29% and 3%, respectively. To reflect the actual pandemic scenario adequately within the SDS microsimulation model, the percentages of people are controlled to participate in work, shopping, and recreation activities according to the Google’s report. In addition, shared travel is allowed while developing the reopening phase-2 scenario within the SDS microsimulation tool, however, restrictions on mode choices are kept the same.

3.2.5 Scenario 5 – Reopening phase-3

The reopening phase-3 begins from September 1, 2020 when schools have opened again in Halifax, Nova Scotia (36). While developing this scenario, it is assumed that everything will be almost back to normal. Therefore, the reopening phase-3 scenario is developed within the SDS modelling framework by allowing individuals to participate in all types of activities, however, restrictions on mode choices are implemented.

4. Microsimulation Result Analysis of Pandemic Scenarios

This section explains the changes in activity-travel patterns during the COVID-19 pandemic. The microsimulation results suggest that COVID-19 significantly influences activity and travel pattern of Halifax residents. For analysing such impacts, this study considers the activity-travel pattern of business-as-usual (BAU) scenario as the baseline, which is presented in Table 1.

Table 1: Activity type, frequency, mode choice, shared travel choice and vehicle allocation in Business-As-Usual (BAU or baseline) scenario
<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Category</th>
<th>Baseline Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity type</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work</td>
<td>20.82%</td>
</tr>
<tr>
<td></td>
<td>School</td>
<td>7.95%</td>
</tr>
<tr>
<td></td>
<td>Shopping</td>
<td>21.87%</td>
</tr>
<tr>
<td></td>
<td>Escort</td>
<td>12.95%</td>
</tr>
<tr>
<td></td>
<td>Personal business</td>
<td>11.02%</td>
</tr>
<tr>
<td></td>
<td>Dine out</td>
<td>6.39%</td>
</tr>
<tr>
<td></td>
<td>Recreation</td>
<td>19.02%</td>
</tr>
<tr>
<td>Activity frequency</td>
<td>2</td>
<td>51.74%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>24.90%</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>12.34%</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5.82%</td>
</tr>
<tr>
<td></td>
<td>6 and more</td>
<td>5.20%</td>
</tr>
<tr>
<td>Mode choice</td>
<td>Auto</td>
<td>79.78%</td>
</tr>
<tr>
<td></td>
<td>Transit</td>
<td>9.41%</td>
</tr>
<tr>
<td></td>
<td>Active transportation (Bike, Walk)</td>
<td>10.81%</td>
</tr>
<tr>
<td>Shared travel choice</td>
<td>Travel alone</td>
<td>95.35%</td>
</tr>
<tr>
<td></td>
<td>Travel with household/non-household members</td>
<td>4.65%</td>
</tr>
<tr>
<td>Vehicle allocation</td>
<td>Subcompact</td>
<td>6.36%</td>
</tr>
<tr>
<td></td>
<td>Compact</td>
<td>34.77%</td>
</tr>
<tr>
<td></td>
<td>Midsize</td>
<td>14.10%</td>
</tr>
<tr>
<td></td>
<td>SUV</td>
<td>35.05%</td>
</tr>
<tr>
<td></td>
<td>Van</td>
<td>9.72%</td>
</tr>
</tbody>
</table>

### 4.1 Activity participation

During the pandemic, individuals’ mobility is restricted to a certain scale. Results suggest that during the lockdown period, the total activity participation is reduced by 47% from the business-as-usual (BAU) scenario (Figure 2a). This indicates that a higher number of people are staying home during the lockdown period. Participation in out-of-home activities gradually increases as the urban system proceeds from lockdown to reopening phases. Figure 2b exhibits the changes in activity participation by category. The percentage of work activities decreases by 10% during the lockdown scenario. With time, participation in work activities increases throughout the reopening phases, although the participation is lower than the BAU scenario in reopening phase-1 and -2. This may be because majority work facilities do not reopen to work-at-site until the occurrence of reopening phase-3. Results also suggest a 23% reduction in recreational activities during lockdown. However, this percentage is found to increase in the reopening phase-1, possibly due to relaxing restrictions on recreational activities during the reopening scenario. However, this percentage starts decreasing as individuals are allowed to participate in other activities during reopening phases-2 and -3. Similarly, participation in shopping activities decreases by 8% during the lockdown period compared to the baseline scenario. Participation in shopping activities in reopening phases exhibit a similar trend to recreational activities. Finally, the percentage of both personal business
and dine out activity participation is found to gradually increase in reopening phase-2 and -3 scenarios from BAU condition.

Figure 2 Changes in a) overall activity participation, and b) activity participation by category
Figure 3 demonstrates the spatial distribution of mandatory (work and school), maintenance (shopping, personal business, escort) and discretionary (dine out and recreation) activities. The maps concentrate on urban areas in Halifax and Dartmouth and surrounding suburban areas. Results demonstrate that the participation in mandatory activities decreases in the Halifax and Dartmouth downtown areas from lockdown to reopening phase-2 scenario. Although the urban core provides more opportunities to participate in mandatory activities (e.g. work and school), the controlling of individuals to participate in such out-of-home activities within the SDS modelling framework may contribute to the prediction result. An increase in maintenance and discretionary activity participation from lockdown to reopening phase-2 is observed in the adjacent suburban areas (Clayton Park and Bedford), possibly due to the presence of higher shopping/retail shops and recreational parks in those areas. Moreover, participation in discretionary activities increases in both South and North Ends of Halifax during reopening phase-2. This result is plausible, because the majority of restrictions to participate in discretionary activities are lifted during reopening phase-2 and South and North Ends of Halifax have several points of discretionary activity attraction (e.g., restaurants, Halifax Commons, Museum, Park, Waterfront).
phase-3 reopening scenario illustrates a similar scenario to the business-as-usual with a growth in mandatory activities throughout the adjacent suburban areas.

4.2 Activity frequency

Figure 4 reveals changes in the number of activities that people participate. During the lockdown period, most individuals are found to participate in two activities, which is an increase of approximately 30% from the BAU condition. In reopening phase-1, most of the people (84%) limit their movements for two or three activities. As restrictions to participate in various activities are relaxed, individuals’ participation in activities is found to increase.

![Figure 4 Prediction of activity frequency](image)

4.3 Mode choice

Figure 5 exhibits the changes in tour-level mode choice decisions during the pandemic scenarios. The choice of auto mode for different activity-based tours is found to decrease by 46% in the lockdown scenario compared to the BAU condition (Figure 5a). This is plausible since the lockdown scenario represents individuals’ stay-at-home condition. As expected, this percentage starts to decrease as business facilities begin to reopen (i.e. reopening phases-1 to -3). Interestingly, auto mode choice is found to increase by 13% in reopening phase-3 compared to the BAU scenario. This may be attributed by the auto ownership choice in the long-term decision module of iTLE, which suggests households’ inclination towards buying more vehicles during a pandemic (37).

Figure 5b illustrates that during the BAU condition, 9% people choose transit for their daily activity-tours. However, it is found that individuals have a lower propensity to choose transit as their mode during pandemic situations to ensure their safety. Initially, transit choice is found to decrease by only 1% during the lockdown scenario. Interestingly, as the region starts to reopen, transit mode choice decreases. Results suggest that transit mode is chosen for only 3% of activity-based tours in the reopening phase-3, which is a 6% drop from the BAU scenario. This may be because these scenarios are limited to transit mode choices due to the fact that transit could be a critical factor in the spread of a contagious disease (38). In the case of active transportation choice, results indicate that active transportation is used for 19% of the total activity-based tours during a lockdown, which is an 8% increase from BAU. This percentage drops to 9% during the reopening phase-1, which is predicted to be constant over time.
Figure 5 Changes in a) auto mode choice, and b) transit and active transportation mode choice.

4.4 Travel distance

Figure 6 demonstrates the predicted changes in density of travel distance for all age groups during the pandemic. Regardless of age, most people exhibit a higher density for a 3-10 km travel distance in the business-as-usual scenario. This result changes by a significant margin during the lockdown period and reopening phase-1. Density of travel distances reduces considerably until reopening phase-1 for people who are aged below 40 years. Such changes probably occur due to the restrictions on majority activity points during lockdown and reopening phase-1. Interestingly, people who aged over 40 years demonstrate higher density for an 8-12 km travel distance in the aforementioned two scenarios. Such individuals are highly likely the household heads and higher travel distance even during lockdown and reopening phase-1 may suggest their responsibility to conduct households’ maintenance activities (e.g. grocery shopping, household errands, etc.). The change minimizes as restrictions are relaxed. For example, the business-as-usual, reopening phase-2 and phase-3 exhibit a similar density for different travel distances regardless of individuals’ age.
Figure 6 Distribution of travel distance by age during pandemic scenarios

Figure 7 illustrates that in every scenario, people prefer auto for longer travel distances, except during the lockdown condition. This is plausible since people reduce their travel during lockdown. Individuals tend to use active transportation (walking and biking) during the lockdown period. Average travel distance by active transportation is found higher than auto mode by 2 km in lockdown scenario. The average travel distance demonstrates a gradual increase for auto and active transportation alternatives from reopening phase-1 to phase-3.

Figure 7 Change in average travel distance for different modes

4.5 Shared travel choices
Figure 8 demonstrates a greater change in non-shared travel (i.e. travelling alone) during different phases of COVID-19 pandemic scenarios. From the baseline, the percentages of non-shared travel are found to decrease by 47%, 30% and 13% during lockdown, reopening phase-1, and reopening phase-2 scenarios, respectively, however, this percentage increases by 2% in reopening phase-3. On the contrary, the proportion of shared travel (i.e. travelling with household/non-household member) are observed to increase from business-as-usual condition by 11% and 4% during reopening phase-2 and -3. Figure 9 does not demonstrate any representation of shared travel during lockdown and reopening phase-1 as this study restricts shared travel option during that time frame. Note that, the reasons behind controlling the shared travel options are discussed vigorously in the section of pandemic scenarios development (section 3.2).

**Figure 8 Changes in shared travel choices during pandemic scenarios**

### 4.6 Vehicle allocation

Figure 9 portrays the changes in tour-level vehicle allocation during pandemic scenarios. From business-as-usual (BAU) situation (or baseline), major reduction is noticed during lockdown period for all types of vehicles. This is expected since individuals mostly stay at home during the lockdown scenario. With the reopening of the urban system, microsimulation results indicate an increase in allocating different types of vehicles to individuals’ different types of activity-based tours, except the allocation of subcompact vehicle. During lockdown as well as reopening scenarios, percentage of subcompact vehicle allocation to individuals’ various activity-based tours is found lower than the baseline. The microsimulation results suggest that allocation of subcompact vehicles is the lowest during lockdown period (58% decrease from baseline). As the urban system reopens for businesses and activities, people start to use different types of vehicles, although the percentage is lower than the BAU scenario. In particular, compact vehicles are found to be assigned to individuals more instead of subcompact vehicles and other larger vehicles. For example, compact vehicle usage for different activity-based tours exhibit only 7% and 2% reduction from baseline during reopening phase-1 and phase-2. In the case of reopening phase-3, SUVs are allocated to more activity-based tours than the other types of vehicles. Results suggest a 19% increase in SUV allocation to different types of activity-tours during reopening phase-3 compared to the BAU scenario. These changes are plausible since SDS’s vehicle allocation component is influenced by the vehicle ownership component of LDS, where it is suggested an increase in compact vehicle and SUV ownership and a reduction in subcompact vehicle ownership during such pandemic situations (37).
5. POLICY DIRECTIONS

Results of this study have critical policy implications. The study suggests that people prefer more active transportation during the lockdown situation, whereas preference of transit is found to decrease during the pandemic situation. Policymakers should focus on developing improved active transportation and transit infrastructure, such as bike-friendly lanes, wide sidewalks, safe and convenient walking and biking facilities, and high-quality and well-maintained public transportation system to accommodate the changes in people’s daily mobility pattern. Results also suggest that people will be more dependent on private vehicles in post pandemic era as it provides personal sense of safety and least exposure with environment. Considering the mode choice results, proactive transportation planning should be implemented to ensure dynamic developments related to public transit and active transportation facilities. It is imperative to help feel the general public safe while taking transit during and after the crisis. As economy reopens and public transport ridership increases, transit authorities need to continue actions that keep employees and passengers safe. Efforts should be made for maintaining COVID-19 safety protocols and hygiene inside mass transits. Clear instructions, such as, physical distancing, using mask or face coverings, cleaning hands, must be provided to the transit workers as well as passengers on how to maintain personal safety on board or in facilities and terminals (39). Furthermore, the microsimulation results indicate a reduction in out-of-home mandatory activities during lockdown and reopening phases, suggesting individuals’ inclination towards work from home and online school activities. As found by Beck et al. (40), working from home is a key determinant in commuting behaviour when partial or full lockdown is in place during outbreak situations. Comprehensive investigations are needed to evaluate the efficacy of telecommuting as well as virtual schools as effective travel demand management strategies during a pandemic. Also, effective policy strategies should be developed to support telecommuting and enhance the learning process in case of distance education. Moreover, during lockdown period, people maintained stay-at-home restrained order of government and was largely dependent on online shopping for their grocery needs. Such behaviour is expected to persist even after the stay-at-home order is lifted and discretionary activities are permitted. Online marketing or e-shopping has the potential to emerge in future as it includes various advantages, e.g., ensure social distances, time savings, and reduce pressure in-store shopping among others. Developing efficient and diverse online shopping platforms (such as interactive
smartphone apps) should be an imminent step to take in order to make people more comfortable towards e-shopping.

6. CONCLUSIONS

This study describes the changes in activity and travel pattern during the pandemic COVID-19. An activity-based microsimulation model, shorter-term decisions simulator (SDS) is used to develop an operational framework considering the impacts of COVID-19 pandemic in Halifax region. To predict the changes in travel pattern during pandemic, five scenarios are developed within the SDS modelling framework, such as business-as-usual, lockdown, reopening phase-1, reopening phase-2, and reopening phase-3. Such pandemic scenarios are developed utilizing information from multiple external data sources such as Google’s COVID-19 Community Mobility Report. The outcomes of the SDS microsimulation model under the pandemic scenarios forecast the changes in multiple activity and travel dimensions, such as activity participation, mode choice, travel distance, shared travel choices and vehicle allocation, among others.

The microsimulation results of the pandemic scenarios developed in SDS model offers interesting insights. For example, a major decrease in activity participation occurs in lockdown situation (47%). However, out-of-home activity participation is predicted to increase gradually as the urban system proceeds from lockdown to reopening phases. Results demonstrate that a 23% reduction is observed in recreational activities during lockdown though it is increased by 3% in reopening phase-3. Work activities exhibit a decrease of nearly 10% for all scenarios except reopening phase-3. In general, people are found to perform two or three activities mostly but in lockdown period, majority (80%) perform just two activities. Spatial distribution of different activities indicates that mandatory activities decrease in Halifax and Dartmouth downtown area from business-as-usual condition in lockdown and reopening phase-1. Both South End and North End of Halifax experience higher share for discretionary activities in reopening phase-2. Suburban areas of Halifax downtown demonstrate a significant increase in maintenance activities in reopening phase-3. Furthermore, people are staying at home which provides a negative impact on their mode choices. For instance, auto mode choice for different activity-based tours is found to decrease by 46% in lockdown period from business-as-usual condition. People choose active transportation over transit during lockdown therefore 19% of trips of all activity-based tours have been conducted by walk and bike during this period. Transit mode choice shows a gradual decrease from business-as-usual to reopening phase-3. The analysis of kernel density portrays that that home to central business district (CBD) distance is skewed to the left of 22 km for auto during all scenarios. People who live in urban area choose more auto in lockdown and reopening phase-1 which is indicated by a secondary peak within a CBD distance of 2-10 km. Both urban and suburban dwellers are more likely to walk and bike along with the use of auto during lockdown since transit has the potential of spreading COVID-19. Moreover, COVID-19 scenarios are found to significantly impact individuals’ distance travelled. For example, SDS suggests that regardless of age, average travel distance by most people is approximately 3-10 km in a normal condition (i.e. business-as-usual scenario). However, in the lockdown and reopening phase-1, density of travel distance reduces considerably for the people aged below 40 years. In the case of shared travel choices, SDS predicts a 47% reduction in non-shared travel (i.e. travelling alone) during lockdown, which begins to increase gradually with the reopening phases. Moreover, SDS predicts a lower vehicle usage during the lockdown scenario, especially subcompact vehicle usage. Results suggest that allocation of subcompact vehicles to individuals’ different activity-based tours reduces by 58% compared to baseline scenario. With the reopening of the urban system, allocation of different types of vehicles to different activity-tours start increasing, in particular, compact vehicles and SUVs. Interestingly, percentage of subcompact vehicle allocation is predicted lower in all pandemic scenarios than the business-as-usual information.
This study has certain limitations. For instance, the pandemic scenarios are developed in this study within the SDS microsimulation modelling framework by utilizing multiple data sources due to the absence of a survey. It would be interesting if the scenarios could be developed by using the outcomes from a travel-activity survey that focuses on pandemic situations. An immediate future work of this study is to conduct a pandemic travel-activity survey, which would be useful to build more reliable pandemic scenarios. Furthermore, the development of SDS microsimulation model is primarily focused on predicting activity-travel patterns of a region based on multiple transportation heuristics and econometric behavioural models. It does not incorporate the rate of infection or risk persistency by a contagious disease in the operational modelling framework. Therefore, another immediate future work of this study is to develop a contagion model within the microsimulation framework of SDS, which would be useful to predict activity-travel patterns by accommodating infection rate and public health guidelines during any epidemic situation. Nevertheless, this study provides critical insights on the activity and mobility pattern of a region during different pandemic scenarios that have occurred due to an infectious disease, COVID-19. It will help the policymakers to develop policy interventions related to emergency situations, so they can be prepared for any future epidemic.

REFERENCES


