Four-Step Modelling Active Transportation For Small Cities: Challenges And Opportunities

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1 Introduction

The role of active transportation (AT) in the transportation system has been growing, but there is still lots to learn about planning for the travel behaviours that are associated with it. One major challenge is that there is a lack of standardized approaches for forecasting for AT infrastructure demand. The ITE Transportation Planning Handbook, 4th edition, has a chapter about planning for pedestrians and bicyclists, but is missing any modelling component. ITE notes that while bicyclist and pedestrian travel demand models have not reached the level of sophistication of road network demand modeling, some techniques can provide reasonable estimates of the demand for such travel, but does not go into details about how to model any of them. There is a general lack of technical guidance in how to model new AT infrastructure and integrating it into existing facilities, determining how many users there would be, and as well as any changes in users travel behaviour within a network due to changes in this infrastructure. These technical aspects are yet to be fully integrated into the guidance of standard practice.

1.1 Goal and Objectives

The goal of this research was to create a travel demand model for the use of a new pedestrian and cycle bridge between two neighbourhoods in Fredericton, NB separated by a four-lane highway (Route 8) to determine the impact of this link on mode choice (motorized and non-motorized) for people in the neighbourhoods. Currently, this route is a popular at-grade crossing for pedestrians travelling between residential neighbourhoods and the two universities and community college.

The specific objectives were as follows:

- Assessment of the 4-step travel demand model for AT
- Model the network before and after the link is added
- Calculate new travel times with the new link added for non-motorized users
- Estimate the number of users that would use the new link
- Determine the change in modal split after implementing the new link in the network

1.2 Expected Outcomes and Value of the Work

The expected outcome of this project was an assessment of the 4-step travel demand model for modelling a new AT link. The travel behaviour in terms of person trips per day was examined before and after the AT link was modelled to quantify any impacts on mode choice of introducing the link into the network. The estimate of number of non-motorized trips using the link was another outcome of this project. It was expected that applying the 4-step travel demand model in this context would help contribute to understanding modeling AT in the small city environment with this method. Small cities may be limited in their capacity to provide the necessary data inputs for complex travel demand modelling used for individual travel behaviour, such as Activity-Based or Agent-Based models and the four-step is a well-known and accepted technique for infrastructure demand modelling, though primarily for vehicle use.

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2 Background

This section describes previous models that incorporated AT infrastructure and the change in travel demand, as well as different potential models that can be used for this project.

2.1 Active Transportation

Active Transportation (AT) describes all forms of human-powered non-motorized travel. This mode of transportation is readily accessible to all users, and as more people begin to incorporate AT into their daily lives, this reduces road congestion, saves money of gas and parking, contributes to reducing greenhouse gas emission, and increases social exchanges (Government of Canada, 2014). Evidence shows that residents choose AT where there is infrastructure available for it and where destinations are close together (BC Healthy Communities Society, n.d.). This involves transportation planning and design for networks that efficiently connect trip origin and designations with safe infrastructure.

2.2 Modeling Non-Motorized Travel Demand

Many transportation planners typically rely on traditional travel demand forecasting models to focus on highway and roadway improvements to optimize motorized traffic. These models are typically not equipped to evaluate AT modes, as models usually just focus on motorized modes. The objective of travel demand forecasting is to predict changes in travel behavior and transportation conditions as a result of proposed transportation projects. For non-motorized forecasting in particular, the objective is generally to predict the change in the number or characteristics of bicycle, pedestrian, or vehicle-trips as a result of facility improvements or policy changes which are designed to make non-motorized travel the more attractive option. In addition to affecting overall levels of non-motorized travel, changes in non-motorized travel conditions may affect travel behavior in a variety of ways: trip making, mode choice, route choice, and land use (Federal Highway Administration, 1999). Travel behaviour can be modeled in two ways: aggerate or individual. Aggregate-level methods tend to be relatively easy to apply, with readily available data sources and computational methods. Individual-level methods are more complicated to develop but can be much more effective at predicting behavior changes because it can explain individual choices rather than making generalizations based on overall population characteristics (Federal Highway Administration, 1999). Future improvements and integration of non-motorized travel into models will help to bring AT up to a 'level playing field' with motorized modes in transportation planning.

Currently, small cities may rely more on planning methods that are based on analysis of gaps in the network, given the challenges associated with modelling AT demand. In the City of Fredericton, for example, the latest AT plan was completed in 2017 (Parsons, 2017) and focused on identifying and bridging gaps in the trail and bike network and did not include a demand modeling component.

2.3 Model Selection

Research shows that there are a few ways to approach solving the problem of incorporating AT infrastructure into a network: Agent-based modeling, activity-based modelling, and the 4-step travel demand model.

2.3.1 Agent-Based Modelling

Agent-based modeling (ABM) is capable of simulating a large number of individuals with different attributes, characteristics, and behaviours. The agent chooses the mode of transport with the highest utility based on rational choice theory, and they look for an appropriate mode of transport in the traffic system to meet annual travel demand (Ahanchian, Gregg, Tattini, & Karlsson, 2019). The agents then decide on the preferred mode of transport according to personal attributes and properties of modes through mode choice algorithm. Ahanchian, Gregg, Tattini, & Karlsson (2019) explain that some limitations include a lack of data as the agents then decide on mode of transport independently and they do not communicate and do not learn from others while there is an interaction with the network. Also, the methodology requires extensive survey data to define the characteristics of consumers, which are input to the model as agents' attributes and could be challenging to acquire (Ahanchian, Gregg, Tattini, & Karlsson, 2019).

Agent-based modeling is best applied to situations in which the interactions between the agents are complex, non-linear, discontinuous, or discrete, the agents have complex behavior such as learning, each individual agent is potentially different, and the agents move and their positions are not fixed (Ardeshiri & Jeihani Koohbanani, 2017). In the transportation field, ABM is appropriate for modeling systems in which human decisions and actions are a critical component, such as demand modeling (Ardeshiri & Jeihani Koohbanani, 2017).

2.3.2 Activity-Based Modelling

Bhat, Srinivasan, Guo, & Sivakumar (2003) state that "the activity-based approach to travel-demand analysis views travel as a derived demand, derived from the need to pursue activities distributed in space". The approach adopts a framework that recognizes the complex interactions in activity and travel behavior (Bhat, Srinivasan, Guo, & Sivakumar, 2003). Axhausen & Garling (1992) have noted that the aim of activity-based approaches is to "account for decisions concerning activities which affect demand". All of these decisions are interrelated for each activity of whether, where, when, for how long, and with who to participate (Axhausen & Garling, 1992).

ITE and Meyer (2016) explained that "the need to better reflect the range of individual travel decisions and intrahousehold interactions has motivated the development of activity-based modeling". Activity-based models estimate travel demand based on a basic premise; that the demand to accomplish personal activities during the day produces a demand for travel that is often connected, like trip-chaining for example (ITE, 2016). Three key components of an activity-based model include: an activity-based foundation with household activities as the starting platform, a tour-based structure that retains associations between individual household activities, and the use of micro-simulation tools (ITE, 2016). To ensure accuracy and calibration for these activity-based models, local geographic data is needed to produce more accurate results (Baerg, Chow, Martinez, & Ward-Waller, 2014).

2.3.3 The 4-Step Travel Demand Model

The 4-step travel demand framework has primarily been applied to automobiles and transit but is increasingly being modified to include bicycles and pedestrians. Non-motorized modes can be incorporated in the models in various ways. For example, a bicycle or pedestrian network can be defined, or can be included as modes in the mode choice model (Federal Highway Administration, 1999). Traditional travel demand modeling consists of four sequential steps: trip generation, trip distribution, mode choice, and trip assignment (Meyer & ITE, 2016).

Both the ITE Transportation Planning Handbook and NCHRP 716 have standardized approaches for the 4-step travel demand model. Yet neither of them includes the modelling of AT infrastructure into networks including both motorized and non-motorized travel. The Transportation Planning Handbook has a chapter on planning for pedestrians and bicyclists, but there is no section on the modelling aspect of these modes. The travel demand and network modeling chapter note that walking and bicycling are important in many cases not only as a primary mode of travel, but also as a mode for accessing other higher-capacity modes (Meyer & ITE, 2016).

3 Methodology

The 4-step travel demand model was chosen to model the incorporation of a new AT link in the Fredericton network. This model was chosen because this type of modelling is a more widely used and understood method in smaller cities. Also, it was more likely that all the data needed would be available. The 4-step travel demand model was sourced from standard practice through the ITE Transportation Planning

Handbook, 4th edition (Meyer & ITE, Transportation Planning Handbook, 2016), and with technical guidance from the NCHRP 716 (TRB, 2012).

3.1 Scope

The geographic scope of the research was limited to include only nine Dissemination Areas (DAs) within the City of Fredericton which functioned as Traffic Analysis Zones (TAZs) and are the smallest unit of aggregation available publicly from Statistics Canada, though as detailed in Figure 1 below, can still cover a large geographic area in a small city. Limiting the geographic size to a smaller network allowed for more feasible modelling within a four-month timeline, as well as for the model to be more sensitive to changes in the user routes since only a single AT link was introduced. Only two modes of transportation were considered: motorized and non-motorized, which was primarily a function of available default modes detailed in PTV VISUM modelling software. Private transportation were the cars, and public transportation represented walking. Also, there were only three main trip types considered: home based work (HBW), home based non-work (HBNW), and non-home based (NHB).

Figure 1: Study Area

3.2 Data sources

The data sources for the person trips were retrieved from the 2016 census dataset, therefore aggregated data was used for this research, to represent the travel behaviour of more than one individual. One challenge that came with this included that the model would not be able to account for variability within a zone. The employment data came from the Canadian Business Patterns, which included datasets from 2016 as well. Network speeds were determined through ArcGIS open-source data of the New Brunswick roads, and traffic volumes were determined by the NBDTI AADT Traffic maps.

Smaller cities such as Fredericton, may not have the same behavioural data availability as larger cities. Larger cities may have travel surveys to use from a larger population, while smaller cities may only be reliant on national data sets. These data sets may not be at the necessary resolution, but it is all smaller cities have to work with.

3.3 Model Development

After reviewing the literature and looking at the approaches noted above, preparations began for modelling the 4-step travel demand model. This model worked in four different stages: trip generation, trip distribution, mode spilt, and finally trip assignment. The majority of the modelling was completed with PTV VISUM, along with ArcGIS for some visual representations and geographical areas. VISUM is a traffic planning software designed for transport planners, and has the ability to model all road users and their interactions. The 4 step-travel demand model process was completed twice. Once before the new link is added into the network, and the second time after the new AT Connection link is added, in order to determine the impacts the new infrastructure had made. Below in Figure 2 displays a flow chart of the 4-step demand model process that VISUM runs though (PTV Group, 2020).

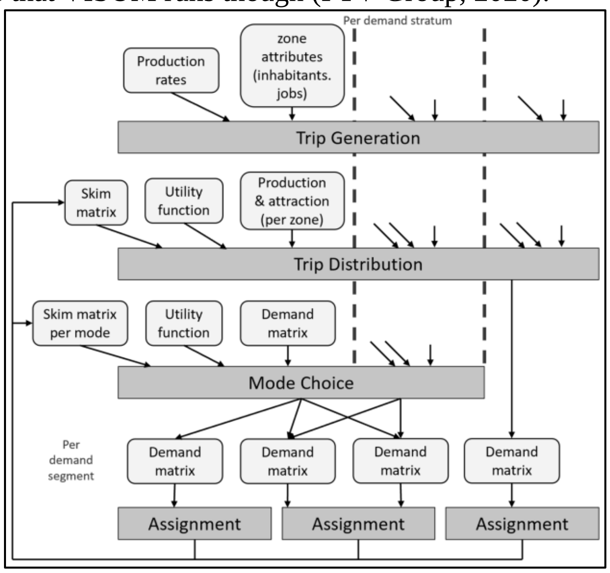

Figure 2: VISUM 4-Step Model Sequence

To first get the model set up, the study area was exported from GIS and both the network and zones were then imported into VISUM. The centroid connectors were then added as a way to assign traffic to the road network. Afterwards, the network in the study area was simplified by removing nodes and links that will have no traffic, with a focus on the major corridors. Some other links added into the network included walking paths that were not originally imported from GIS. The 4-step demand model was then created with the three main trip types: HBW, HBNW, and NHB. The transport systems were also defined, and this included only cars and walking.

<u>Trip Generation</u>: The generation of trips, either from a point of origin or attracted to a destination, is one of the most important components of travel demand modeling (Meyer & ITE, 2016). Trip generation is used to estimate the number of trips of each type that begin or end in each location, based on the amount of activity in a geographical area (TRB, 2012). The data and variables were gathered from the 2016 Census at the DA level (for trip productions), as well as 2016 employment data from Canadian Business Patterns, with household cross-classification tables being used (for trip attractions). Trip generation relationships to land-use characteristics are established cross-classification (or category) analysis. Household trip generation is usually a function of median income per family, household size as well as automobile ownership and availability (Meyer & ITE, 2016). Trip attractions and productions were produced for all 3 trip person types: HBW, HBNW, and NHB. External stations were not created for this model as it was not expected that AT link users would be from outside the study area, but could be established to account for all other users in the City of Fredericton and any external travel that enters the model network. All calculated initial productions and attractions were inputted into VISUM for their proper zones. Productions were based on household size and average values from NCHRP 716, while the attractions were based off

basic, retail, and service employment data. The employment data was then multiplied by trip attraction rates from Table 4.4 of NCHRP 716 to get the attractions for all person trips.

Trip Distribution: Trip distribution is the second step in the 4-step modeling process. It is intended to address the question of how many of the trips generated in the trip generation step travel between disseminations areas (TRB, 2012). The outputs of the trip distribution step were production-attraction zonal trip tables by the three trip types: HBW, HBNW, and NHB. The gravity distribution model was used in this step of the travel demand model. A deterrence function was also calculated to best fit this model and it was the combined function. A histogram was then created to observe the deterrence functions, by creating bins of 0.5 km and sorting the zones of driving distances from the skim matrix. The trendline for the mode choice of car best fit the combined function. VISUM completed the calibration for all three trip types, in order for the values to reflect reality. For the travel times affecting the deterrence function, they were calculated once the new link was added for the AT Connection. The walking time was calculated by dividing the link length by an assumed walking velocity of 5 km/hr.

In VISUM, a skim matrix was first calculated for the different modes. For the motorized mode, the free flow travel time was calculated, and to fill in the diagonals of the matrix the nearest neighbour technique was used: a direct distance matrix was calculated, and from this it calculated the average of the three closest zones then divided that value by two. Then for the diagonal of the free flow travel time matrix, it took that averaged distance divided by the speed, and was finally converted into minutes. For the non-motorized mode, the walking journey time was used as the skim matrix, with the nearest neighbour technique again used for the diagonals.

In the trip distribution step, a Combination function was used for both HBW and HBNW, and the Kirchhoff function was used for NHB, based on the histograms and trendlines discussed above. The formulas used can be seen below in Equation 1 and Equation 2.

Equation 1: Combined Equation

$$f_{combined}(U) = a \cdot U^b \cdot e^{(c \cdot U)}$$

Equation 2: Kirchhoff Equation

$$f_{kirchhoff}(U) = U^c$$

The following function parameters were used in the model (Table 1), as sourced from NCHRP 716. These values were based off a small MPO with a population between 50000 and 200000. The utility function was defined as the free flow travel time for cars, plus the journey time for the walking mode.

Table 1: Trip Distribution Function Parameters

Trip Type	**Function Type**	**a**	**b**	**c**
HBNW	Combined	1.000	1.017	-0.079
HBW	Combined	1.000	0.265	-0.040
NHB	Kirchhoff	0	0	-0.195

Mode Choice: Mode choice models are used to predict the number of trips that will use each of the available modes for origin-destination pair (Meyer & ITE, 2016). The mode choice model split the trip tables developed in the trip distribution step into trips for each mode analyzed in the model. These tables were segmented by trip purpose (TRB, 2012). For this project it was only split into motorized or non-motorized. A binary logit model was used for the two mode split options, and utility functions needed to be determined to calculate the probability of a traveler choosing a particular mode. A separate skim matrix was needed for each modal alternative. From the NCHRP, it notes that non-motorized modes, which are not yet included in some models, especially in smaller urban areas, include walking and bicycling (TRB, 2012).

For this step of the 4-step travel demand model, Excel was used to calculate the probability of each mode using the logit model. Originally, when using VISUM to complete the mode choice step of the travel demand model there were only a few walking trips being assigned from the total of 20994 person trips per day. There were no function type parameters that could be reliably sourced for each of the trip types and their respective utility functions, to accurately model this network, therefore model coefficients were used from NCHRP 716, based off different models from the MPO documentation database. The 2016 Journey to Work census data for Canada was also used to help adjust and calibrate the coefficients to better fit the modal split for the city of Fredericton, which was approximately 90% for cars and 10% for walking. Below in Table 2 are the calculated utilities from the NCHRP models, as well as the probabilities of both modes calculated from the logit model. Some assumptions to calculate the utility included a cost of 55 cents/km for cars and 5 cents/km for walking. These two costs were based of automobile allowance rates (Government of Canada, 2022) and travel cost calculator results (The City of Calgary, 2022). The in-vehicle travel time was taken as the average of the free flow travel time matrix, and the walk time was the average of walk time matrix. These probabilities were then multiplied by the appropriate trip type origin-destination matrix to create six new matrices all split into the two mode choices. Two more formula matrices were then calculated to determine the total trips by car and walking modes respectively.

Table 2: Calculated Utilities and Probabilities for both modes

	HBW	**HBNW**	**NHB**
Utility – Car	-0.3348	-1.09603	-1.40624
Utility – Walk	-2.49919	-3.28003	-3.60934
Probability – Car	0.897006	0.898804	0.900528
Probability – Walk	0.102994	0.101196	0.099472

<u>Trip Assignment</u>: Trip assignment results in an estimated demand on each of the network links. The network assignment step assigned trips through the network to minimize the time or cost of travel (Meyer & ITE, 2016). In this last step of the travel demand model the productions and attractions were converted into origins and destinations for each trip type. All-or-nothing assignment was used in this model, and assumed that there are no congestion effects, that all users consider the same attributes for route choice and they all perceive and weigh them in the same way. The absence of congestion effects means that link costs are fixed and can be a reasonable assumption in uncongested networks and where there are few alternative routes (Ortuzar & Willumsen, 2011). In NCHRP 716 the trip assignment step consists of separate highway and transit assignment processes. The highway assignment process routes vehicle trips from the origin-destination trip tables onto paths along the highway network, resulting in traffic volumes on network links by time of day. Speed and travel time estimates, which reflect the levels of congestion indicated by link volumes, were also output. The transit assignment process routes trips from the transit trip tables onto individual transit routes and links, resulting in transit line volumes (TRB, 2012).

Once the 4-step travel demand model was complete for both the before and after the link is added, the mode shift matrices were compared to see if there was an increase in non-motorized users. The trip assignment matrices were reviewed to determine the number of users that would cross the new AT link. Validation of this model can come from a past study completed by UNB students in October 2015, and found that for a 6- hour count (7-10 am, 4 -7 pm) on a Wednesday, there were a total of 50 people crossing over the highway at that location. This value was used to compare the order of magnitude of the volumes determined from the model.

4 Results and Analysis

The following section provides a breakdown of results from both scenarios of before and after the AT link was added into the network, as well as comparing the differences. This includes a general overview of VISUM outputs and the matrices created within the model. The model generated 20944 person trips per day that were distributed throughout three trip types and two different mode choices. For the mode choice of car there was a total of 18895 trips, and for the mode choice of walking there was a total of 2099 trips. There was no change in mode split before and after the new AT link was added.

The existing network was run through all steps of the 4-step travel demand process in VISUM. It can be seen below that Figure 3 on the left has 345 person trips per day (blue lines) walking along the paths that connect Forest Hill Road to the University of New Brunswick, as these travel times were shorter than compared to travelling on the same links as the cars. Then a new link was added into the network connecting College Hill and Skyline Acres over Route 8, allowing access to only non-motorized users. New skim matrices were calculated then the model was again run in VISUM. There was a total of 231 person trips per day that would use the link that can be seen in Figure 4. This number is larger than the past study completed by UNB students and found that for a 6- hour count there were a total of 50 people crossing over the highway at that location. A higher number was expected as the danger of crossing the highway was removed once the link was added, and more pedestrians would feel safer to cross to shorten their trip time.

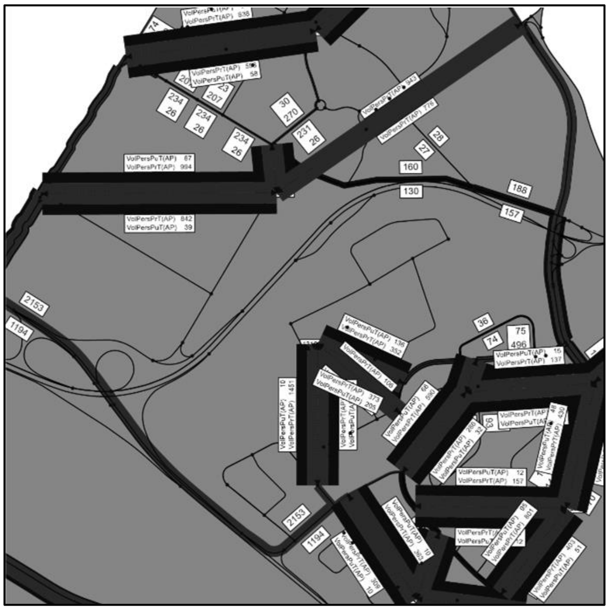

Figure 4: Network before AT link added

Figure 3: Network after AT link added

4.1 Differences between Before and After Connection Added

Comparing the person trips for before and after the AT Connection link was added, showed that there was no change in mode choice, only trips assigned to different routes and zones. This could be because the assigned walking route would still be longer than driving, and the lack or congested assignment for the road network means free flow times in the model which may not be the case in the real network. The travel behaviour did not change and the total trips for both car and walking stayed the same. Within each of the modes, there were changes between the different zones that the trips were assigned to. Some of the trips were assigned to different zones, and this would be due to the skim matrices, as once the new link was added, new lengths and distances were recalculated. Distances and travel times for the car mode did not change, but there were noticeable changes for the walking modes. From the zones directly on either side of where the new AT Connection link was be implemented, displayed the largest difference attributed to the addition of the new link, which was a shortened time of 11.5 minutes. These same zones also had the greatest change in walking distance, which was one kilometer shortened off of the user's trip.

5 Discussion

The goal of this research was to create a travel demand model for the use of a new pedestrian and cycle bridge and to quantify its impact on travel behaviour of the people in the city. This model calculated that 231 person trips per day would walk across the AT Connection link, based on average annual daily values. This compares favourably with the 6 hour counts, suggesting that the 4-step model and the associated inputs resulted in an output for use of this link that was in line with expectations.

VISUM defaults only allowed the stratification of users to be separated between cars and walking; public transportation was left out of this mode, though was not expected to be a factor due to overall modal share for Journey to Work being considerably lower than walking. The 4-step travel demand model successfully worked after simplifications to the network and using Excel to calculate the walking time for all links in the network because when it was imported from GIS, there was only the travel times for the cars. These travel times for the non-motorized users were used to calculated skim matrices before and after the new link was added.

Observing the differences in both the skim matrices, as well as the mode choice matrices, it displayed that there was some change in walking time and distance when the AT link was added into the network. Specifically, the zones on either side of where the new AT link was added saw the largest changes with shorted travel times and walking distances, and because of this there were more walking and driving trips assigned there.

This project showed that this approach in small cities for AT infrastructure can help with planning and forecasting through small changes in the model. There is often a focus on motorized modes, but with this approach all modes can be included and analyzed. In the future there may be population changes or different demographic growth rates, and with this approach, it can be incorporated into the model through the national data sets. Public health is another reason these models can have a large impact on smaller cities, as they often encourage the population to chose more active modes. AT infrastructure and changes to the network can be modeled to see if there will be any impact before investing money into building the new infrastructure.

5.1 Limitations

This model did not allow for seasonal adjustment factors for the AT users based on daily travel. More users would use the AT connection in the summer compared to the winter months, and this would change the number of users modelled on this network. Also, using the 4-step model and the aggregated data from the census or employment, did not allow for variability within zones. All of the results just displayed the nine disseminations areas, when there may have been some variability house to house, if certain households chose to use more active modes for example or have lots of cars to use.

Determining the transport modes proved to be a limitation within VISUM, as originally the research was going to split motorized versus non-motorized users, but ended up splitting into cars and walking modes. There was also no way to add in a biking mode into the student version of VISUM. If this were the case in VISUM, then the total number of trips passing over the AT connection would likely be higher. Recreation trips were not able to be captured in this model as well.

Using the 2016 census Journey to Work data for Fredericton, provided some calibration data for the models used in NCHRP 716, but was only limited to home-based work trips. Due to the limited data for small cities, the Journey to Work data from the Census for Fredericton was also used to aid the calibration of the remining two trip types. This resulted in approximately a mode choice split of 90% cars and 10% walking. Using this data could contribute to the numbers crossing the AT connection link. The number of walking and car trips stayed the same in this model, only the distribution of these trips changed. Which means that there was a change in the travel behaviour.

6 Conclusions and Next Steps

Through the 4-step travel demand process, it was estimated that a total of 231 person trips per day that would cross the AT Connection link. This research and model displayed that AT can be incorporated into different models to estimate users of new AT infrastructure. VISUM works well to model AT into existing networks, but there may be some limitations to the amount of detail that can be incorporated into the model.

Based on this project, data resolution and availability were some of the largest challenges for small cities when modelling AT. The dissemination areas can still be geographically too large to represent all the pedestrians travelling. As well, in many small cities travel data is focused on Journey to Work, but this data misses many other trip types and modals split by purpose. There can also be a lack of seasonal adjustment factors for AT users based on daily travel.

Next steps include incorporating missing linked trips, to better understand the way an entire day of travel is completed for a person, as opposed to the mode of transport used most often. Adding external stations, special generators, or taking into account congested assignment on road links would be other ways to add more trips into the model to get a more accurate number of non-motorized users crossing the AT connection. Special generators would be created when there are some locations when trip rates are insufficient to accurately estimate trip activity, such as hospitals or universities. Expanding the model to the entire City of Fredericton would create an even more accurate model to determine the number of users crossing the new link. Finally, agent-based modelling could be a different approach to take in the future, so the data and results will not be aggregated. This will allow for variability within all individuals simulated in the model.

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