APPLICATION OF INTEGRATED LAND-USE AND TRANSPORTATION MODEL TO
KEELE-FINCH MOBILITY HUB IN TORONTO

By

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Hamidreza Forouzandeh Shahraki,
Master of Engineering in Civil Engineering,
Ryerson University, 2018.

Abstract

There is a debate between land owners, who think their property should be approved for higher height permissions of zoning by-laws due to being located close to a transit station, and policy makers who want to consider potential future developments in a way to suit the whole area. This study tries to establish a methodology and provide a decision making tool by introduction of a land-use and transportation interaction (LUTI) model considering all the involved aspects such as a number of settled households, their income level, number of employments and categorization, travel preferences and inventory of housing. The goal is to observe what housing demand changes will occur, where and what types are most wanted, at the smallest currently possible level of census dissemination area (DA) for conditional scenarios of before and after completion of major transit projects of light-rail transit (LRT) and subway in the study area.

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Dedication

This work is dedicated to my dear parents for their persuasions and praise, and to my compassionate wife and loving son who tolerated me and provided me with unlimited support and joy.

Creation of this work would have not been possible without their help and sacrifices. Thank you so much dear god for every moment being beside them and being in this life.

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1. Introduction

How development patterns change by construction of major transit facilities, and even if they are correlated phenomena or not were a controversy subject among researchers. Some researchers mentioned that the influences did not exist, or they are not quantifiable, while others mentioned that a dynamic relationship existed, is slow but measurable.

As per City of Toronto's Planning office, the legal cases of land owners asking their property to be considered for change of zoning by-laws height and intensification due to construction of major transit stations are increasing. The only reference currently used is the guidelines of transit-oriented development (TOD) which considers a boundary of walkable access around stations. On the other hand, policy makers or urban planners need to consider a comprehensive outlook of the whole region while dealing with such cases.

This study tries to investigate and measure the influences of major transportation projects on land-use by implementation of the LUTI model. This model compares the analyzed floor space and locations they are mostly demanded for two scenarios defined before (current situation) and after completion of LRT and subway and to designate intensification potential regions. Not to mention that, floor space, here is defined as types of housing or dwelling.

Proper land-use planning can avoid unwanted cities sprawling, and it necessitates densification as cities grow in population. Plus, densification around major transit stations can ensure profit maximization of the constructed transit system, having healthier society and more appealing mixed-use urban environment via increased multi-modal trips. Currently walking and cycling, as two sustainable means of transportation, have a slight multi-modal transportation share in the City of Toronto (4.6% and 1.2% accordingly (Statistics Canada, 2015)). Intensification, is generally dependent on many different factors because transportation and urban planning decisions are multi-disciplinary and effects are to be seen in long run and collaterally. This report can help provide scenario-based analysis to deal with such concerns applying a scientific approach.

This "transportation impact assessment on land-use" study can define how any future development permit applications can be reviewed conveniently. It was tried to collect as much information as possible from the available open source web-content about the Keele-Finch study area, accomplish the analysis by combining the most up-to-date tools in methodology such as ArcGIS, Tranus software packages and to check the

validity of results. Likewise, different provincial guidelines were reviewed in consideration of extents of study area, initiated by the Ontario's "Places to Grow" (Ministry of Municipal Affairs, 2017) report.

This is to be done, yet, by considering cities as socio-economical places. Hence, the analysis starts by creating a comprehensive database of origin-destination, population, employment, and floor space and land-use data, then after iterative calculations by modeling software, it is possible to predict the demand changes. It was tried to focus on results from the land-use model due to limitations in time available in this study, though, the possibilities of improvement always exist as some limitations in availability of input data imposed some assumptions to be made. And, consideration of any such assumptions involves some quantity of error.

To summarize, it should be restated that the procedure translates all possible interactions to a same monetary terminology language to provide a realistic model based on costs of land-use and movement.

2. Problem Statement

Currently, no integrated system or model is available to be considered in new development permit approvals or to help in land-use decision-making process, other than qualitative guidelines.

3. Report Scope

The goal is to predict the land-use modification patterns and potential zoning by-law changes as a result of construction of major transit stations. Therefore, a micro-simulation model was calibrated in Tranus LUTI software to overcome the challenge. Thereby, not only it predicts potential demand in TOD limits, but also, it adds to it by considering a wider influenced area.

The scope of this study is limited within the study area of Keele-Finch Mobility Hub as will be defined. Generally, an overlook of the process would be as per flowchart displayed in Figure 3.1.

Figure 3.1 - LUTI Overlook via Tranus (Modelistica, 2018).

4. Selecting Study Area and Its Boundaries

After reviewing the manuals, plans were analyzed in ArcGIS to create the boundaries and related characteristics of access, land-use, connectivity of network and sidewalks, height restrictions, zoning by-laws and etc. were evaluated. Not to mention that, other documents such as official and secondary plans also were reviewed for creation of this report, though, in this section only the most important relevant ones designating the transit station's service area are named.

4.1. Review of Provincial and Regional Manuals

In order to provide a broad angle on how to set the study is boundaries and considers some characteristics of the public transit system such as waiting times and capacities, some of the most important information and guidelines available were reviewed.

4.1.1. Growth Plan 2017 (Ministry of Municipal Affairs, 2017)

In the guideline, different policies prioritize investments on intensification in any new developments. Moreover, it states that growth in an urban context to be transit-supportive and inside major transit-station service areas by approaches such as re-development, infill, etc. It was planned that by the year 2031, 60% of all residential developments should occur in built-up areas and not green fields.

Furthermore, it supports the compact built form or mixed-use within proximity to transit while the importance of providing multi-modal access for users, including better pedestrian sidewalks and bicycle facilities and pick-up, drop-off location was highlighted. It is further stating that in order to suit this purpose and to encourage more active transit users, parking lots near the stations are to be limited.

It sets minimum density targets near stations of 200, 160 and 150 people and jobs per hectare for the ones close to subway, LRT or bus rapid transit (BRT) and Go-transit rail system. And, transit-supportive context is defined to increase the quality of experience of using transit. It can be said that, it tried to provide policies to incorporate the complete street term into TOD. Service area of major transit station was said to be within 500 meters or 10 minutes walk distance, but it was not mentioned where this should be calculated from. For instance, will it to be from the closest intersection, main entrance of station or, etc.

4.1.2. Transit Supportive Guidelines (Ministry of Transportation, 2012)

This guideline specifies the intersection of nearest corridors as the point of considering circular densification boundaries. It recognizes 5-10 minutes walking distance or 400-800 meters from this, so called, Focal Point. Another point is that, it somehow it mentions that TOD needs to consider local community demands in designation of densification and apply appropriate changes when needed.

It, also, emphasizes on the density and mixed use at appropriate nodes to improve functionality of transit infrastructures and its ridership. Intensification mentioned to be stepped lower towards peripheral boundaries. Generally, for growth areas it is said to include at least 50 people/jobs per hectare and higher numbers as reaching closer towards station. Specifically for LRT stations, it recommends 72 units per hectare of 160 residents and jobs, while for subway station, numbers are 90 and 200 accordingly. Access, balance of needs and appearance, further, mentioned in complete street context. Plus, to support, it mentions the requirement of sidewalks on both sides for at least 400 meter radius from transit stops in all streets and 800 meters from express stops or rapid transit stations. Not to mention that, radius is not a good wording here as people cannot fly yet.

It highlights the active transportation to be prioritized over motorized means of transportation. And, it also suggests the monitoring of the passenger or boarding counts to adjust frequency or capacity of transit systems as per the governing agencies' maximum acceptable capacities.

In addition, it states that services that connect trips, arrival of one should be within 10 minutes or not as much from departure of the other one in order to allow passengers to have smooth transfers. Adding to that, it mentions that waiting times are to be minimized to 5 minutes or less between connecting services for higher than regular demanded routes reaching key destinations, through scheduling.

Service or boarding standards and their frequencies are mentioned as well. These numbers were applied in the transportation model of Transus as per this guideline by 57 passengers per vehicle (PPV) for Toronto Transit Commission (TTC) buses and 72 PPV for York Region Transit (YRT) buses. Zum system of buses, also, follows the YRT data and considered to be a rural bus system. It was further mentioned that they were designed for 100% target occupancy at peak, but lower quantities were considered as will be discussed.

4.1.3. Metrolinx Mobility-hub Guidelines (Metrolinx, 2011)

This manual provides a wider service area in compare to previous ones in a more elaborate way. It introduces a different terminology as follows to define a mobility hub or higher-order transit station's land-use influenced areas (, please see Figure 4.1). Therefore, 250 m or 2.5 minutes walk is considered as primary zone, which is the area settling the highest density; 250-500 m is to be secondary zone having high density; 500 m-800 m or tertiary zone, in which the structures' height to be stepped towards outer limits, and 800 m-6 Km, which is the catchment area with a minimum amount of change.

Figure 4.1 - Land-use Change Areas Surrounding a Mobility Hub (or Higher Order Transit Station). (Metrolinx, 2011).

It is suggested in this manual that transit supportive densities to be more than 250 residents and jobs, and, to be 200-400 for subway and LRT service areas.

4.2. Study Area Background

The city of Toronto has seen the most population growth in the last decades, while budgeting for infrastructure was limited and could not keep the pace. Moreover, having different municipalities in the region and zoning by-laws made it difficult to react fast enough, which lead to having problems of traffic during the rush hours and fewer multi-modal trips.

Keele and Finch area in the city of Toronto is a special location as it accommodates a large industrial zone (DUKE heights or Dufferin-Keele North employment area), aviation platform (Downsview Airport), York University, Pioneers Village historical area (Black Creek), and is a cross-section of two major transit systems of LRT and subway. Hence, there are a lot to be taken into account.

Employment in manufacturing rose by 8.9% from 2010 to 2015 in this area. Industrial areas near the intersection of Keele and Finch are mostly oil-related factories, warehouses and dangerous reservoir tank establishments creating noise and odor pollutants. Please see Figure 4.2 for an example. The picture was taken at the intersection of Pond Road and Petrolia Road, viewing south.

Based on the previous studies and Ontario's Ministry of the Environment and Climate Change Guideline D-6 of industrial classes, these require separation distances ranging from 20 m to 300 m and influence of 70 m to 1000 m from class I to III. Not to mention that, some class II and III establishments are located in 800 m radius of the main intersection (GHD Limited, 2016).

Figure 4.2 – Example of Reservoir Tanks inside Industrial Zone and their Location on Map (OpenStreetMap, 2018).

The area's population mostly lives in rental buildings and has low incomes. 63% of overall households are living in condominiums and apartments, and over 82% of them constructed before 1990. 16% of households are single detached homes.

The Keele-Finch station is so-called a mobility hub and is an ongoing transit project that will provide transit improvements in the northwest area of the city of Toronto. Mobility hub is the term used as a station located at intersection of two or more rapid or higher-order transit lines. In this area, they are the Finch West LRT and Spadina subway extension line.

The LRT lane was approved as part of The Light-Rail Plan by the TTC in March 2007 and endorsed by Province of Ontario in June 2007 as a part of the strategic transit plan of Move Ontario 2020 for the Greater Toronto and Hamilton Area. As a matter of fact, this mobility hub will improve the mobility and transportation options, while it creates potential in new development investment.

TOD is a concept that considers all what is mentioned plus complete street concept. It is commonly defined to include the terms of density, mixed-use and access by walking to transit station. Neighborhoods with a mix of affordable housing can provide many advantages, such as reducing income segregation and help lower-income residents move up the occupational and social ladders.

Lower income households usually settle in smaller units and have higher transit share. Furthermore, when more workers live in close access to transit, it helps providing longer distances traveled to workplace. Traffic calming policies and less availability of parking as means of TDM can encourage more multimodal travel in this area as well. Currently, parking areas near the hub (as can be seen in Figure 4.3) can accommodate approximately 1040 vehicle spaces.

Different studies on this area revealed that most of the transportation is vehicle oriented and roughly 40% is done by public transit, walking, cycling, etc. Area's proximity to commercial and industrial sites as well as institutional areas, has been under review to make the neighborhoods grow stronger (Toronto Strong Neighborhood Strategy 2020) and these areas are so-called Neighborhood Improvement Areas (NIA).

The study area of this hub can be extended to 2 km to include areas of most origin and destinations. Most of the extended area trips occur during mid-day hours. While in the morning times, most trips were originated from York region or GTA west, transferring workers and students to this region. The transit use is increasing by 2.5% on a yearly basis, while the use of cars remained constant (City of Toronto, 2017).

Areas around Sentinel Road in this area, also, has a great potential for development as it is the busiest active transportation area having cycling lanes connecting residential homes to York University and other destinations by walking or cycling. Likewise, capacities of mentioned modes in Pond Road are reaching ultimate limits and require some improvements.

Figure 4.3 - Parking Lots near the Keele and Finch Intersection (Google Maps, 2018).

As per continuity of the cycling network, it must be said that, it is not an integrated system, though, there is a designated lane approaching from Finch west and also one in Dufferin north of Steels. Not to mention that, lack of cycling facilities and lack of street calming policies caused fewer cycling ridership numbers. Walking scores at the mobility area surroundings is at 62 and transit score is at 74 (City of Toronto, 2017). On the site visit that was done on November 20th 2017, it was seen that some of the streets and local areas require better access for cyclists and pedestrians, but in major arterials and collectors, it is generally acceptable.

Walking share passes 10% at signalized intersections, and some of those have more than 6,500 pedestrians per day. While, in many areas lack of street landscaping causes uncomfortable experience and in other areas with inadequate infrastructure such as walkways or crossing facilities, pedestrian share is limited. Another point is that due to construction, traffic congestions are higher than normal in peak hours. Which caused shockwave traffic jams in the arterials reaching the area of study as well. However, on the other side, it persuaded more pedestrian share.

Higher volume of industrial activities and sites, caused high movement of heavy vehicle transit (4.5% of total vehicles), which is also challenging due to induction of unsafe feeling for pedestrians and cyclists. Almost 1/3 of the traffic in the Keele or Jane on the north side of Finch originated from outside the city. And, investment on roads not only was not beneficial for the neighborhoods, but also has just been attracting more and more vehicles.

By-law no. 72 has prohibited tank trucks or oil-trucks from continuing the use of intersections at Keele and Finch for three tank farm facilities within the study area. The only exemptions were given to inflammable liquids. Even so, still some amounts of truck transit were considered to and from the industrial area in analysis as will be seen. Worst cases of traffic, between streets reaching the intersection of Keele-Finch, are seen on Finch West and Keele South during rush hours. The other portion of traffic is passing through the area toward destinations in downtown Toronto. Building heights in this area follow zoning by-laws and are affected by the proximity to Downsview airport and its aircraft flight pathway, which is so-called Schedule D of North York Zoning by-Law 7625, and mentioned in City's secondary plans as well. Further studies have identified this height limit is based on above sea level altitudes; therefore, in some cases having topographic data it might be possible to go higher than these limits.

4.3. Creation of Service Area and Analysis Area

Service area is the area that will be influenced by the presence of any new transit facility. The service area should reflect travel behavior, regional documents and policies and any relevant past studies. It can range from a couple of hundred meters to an extended area of up to several kilometers.

Nevertheless, the focus for accessible service area should be on the core surrounding area. Realistically, we need to consider that transit stations require a substantial time to show their effectiveness and the fact that people usually do not walk more than 5-10 minutes to use such facility.

Rather than the following circles from the closest intersection, the current situation of sidewalks needed to be investigated and the distance that can realistically be walked should be calculated using GIS software. Shape files were gathered from different sources from open data of municipalities, University of Toronto map and library website; Website of Statistics Canada and used for various purposes. Some of the challenges working with these files were that no licence for the Network Analysis was available in the Planning Office of the City to be borrowed and took a lot of time to provide one from the University.

Other than that, there were variations in coordinate systems of different files from the City's web-site compared with the ones collected from the York region's web-site. Some of them were in WGS1984 and some others in NAD1983-Zone17N and sometimes conversion of coordinate systems was required.

This first step of identifying the service area is implemented by ArcGIS and the use of Network Analysis. Approach works this way that, shape files of streets called Centerline were gathered and compared to the Sidewalk shape file and after some modifications on elimination of unnecessary data such as lines carrying characteristics of “No side walk,” the network was created by introducing the distance limits of 500 m and 800 m for the hub and 500 m for the rest of the stations.

Extended analysis area is considered to a higher extent in order to incorporate GO-transit, subway and LRT, Peel region’s Zum buses and YRT buses added to TTC buses. Nodes and links that were created during this stage can be imported to the LUTI software network.

As a result of disused points, the service areas of stations of Finch Avenue West can be seen in Figure 4.4 and the full map of all stations in the extended area analyzed by Network Analysis software, can be seen in Appendix.

Moreover, the land-use map is as shown in Figure 4.5. The amount of available land will be considered as consumable (induced non-transportable) in coming sections to be used by floor space demands of households.

Figure 4.4 - Service Area of Mobility Hub and LRT Sentinel Station.

Figure 4.5 – Land-use Map

5. Methodology

5.1. Review of Contemporary Researches

The main goal is to find a relation between land-use and transportation in micro or neighborhood scale. The land-use planning is a tool to avoid urban sprawling, which is to avoid cities from spreading out to the rural surroundings by introduction of development boundaries and avoid metropolitan areas merging into previously independent municipalities. By defining so and increase in population, there is no other choice than increase density of inner city spaces or built-up areas within a city. Densification, can either be done by defining smaller dwelling units or by multi-story buildings. Based on a study (Peterson, 2004), the lower urban density will cause the more dependency on private vehicles for transportation with all other associated disadvantages of production of high volumes of green gas emissions and energy consumptions.

Not to mention that, distance from transit stations defines the modal share (Wegener & et al., 1999). And, quality of living on a neighborhood level is defined by speed context, so traffic-calming measures increase more active transportation. Car ownership, on the other hand, reduces the opportunity for other land-uses than the land required for its movement (roads) and cease (parking).

No LUTI model in Great Toronto Area (GTA) is yet implemented. So, no previous experience in modeling or calibration currently exists. There have been some guidelines among municipalities such as City of Hamilton (City of Hamilton, 2005) mentioning the integration is required, but not an actual study. Most of the found studies in the area were focused on traffic impact assessment of new developments such as proposed residential development in 346-350 Eglinton Ave. West (MMM Group, 2015).

Another reviewed related study (N. Barry Lyon Consultants Limited, 2017) researched the potential of real-estate price changes only based upon statistical data of Multiple-Listing Service (MLS) on sold households and time that they were on the market for Eglinton Crosstown LRT. This report, also, did not provide an integrated approach or methodology.

In a guideline recently published in USA (Litman, 2017), it was mentioned that lack of consideration of such impacts exists, and a checklist of items was provided to perform evaluations in a qualitative way, but still not a simulation model.

In addition, so many manuals and reports were reviewed, and many approaches were examined to see what needs to be done and what the results might be. One of these approaches was the use of dynamic agent-

based models (ABM) or cellular automata (CA) in the simulation of urban growth. This approach helps in conditions where human-environment interact. Therefore, the problem becomes so complex.

An agent is a programmed piece of information that can react and learn. In an urban land-use model, an agent can be identified as for example an individual (employee, traveler), a social group (household, industry or government), a physical entity (infrastructure, region) etc. These agents can learn to behave like humans by defining some cognitive functions and also to reproduce themselves (Martinez & et al., 2012).

In this approach, by the help of programming languages such as Python and NetLogo software, pixels like agents were introduced and their growth is related to attractors and different conditions. Which, in the timeline of this project, it was impossible to accomplish such a task. Netlogo, is a free and open source modeling environment used for simulating complicated social phenomena. Different cities show a variety of spatial development patterns according to the major growth waves they experience. City of Toronto, shows the development pattern as can be seen in Figure 5.1 from 1971-2011.

There are too many parameters involved when we want to talk about the integration of land-use and transportation that makes it so complicated in a sense that dictates a team of different disciplines to contribute in finishing and calibrating such programs, for instance: dynamic behavior, exogenous variables, controls, parameters, urban land and updating the system at each time step.

Figure 5.1 - Spatial Development of City of Toronto (Statistics Canada, 2016).

Another method is done by having Landsat spatial picture with high-quality pixel clarity. Urban development patch or sites, connects current developments using existing road network. There are different types of growth that can be identified as a result of transportation projects namely, infill, expansion, branched, etc., which requires availability of very detailed information from the network, households, income, employment in level smaller than census tract (CT) or even (DA), time and Landsat pictures. Pointing out that, a DA is the smallest area which Statistics Canada collects data on and usually includes 400-700 people.

The ABM plus spatial data is usually done through investigating multiple Landsat pictures in different times, before and after a certain kind of development to identify a pattern or rule-based system while having created an urban growth map to predict effects of any new projects. This is also based in a theory so-called forest fragmentation of pixels. This conjointly requires spatial analysis using GIS software. And, this approach was neither possible to be used due to mentioned limitations.

However, as a result of this review, the potential for growth in this study considered to be either infill or clustered. An infill is the encouragement to develop a vacant land in already built-up areas. And, clustered branching is a new neighborhood or large multistory building.

Nevertheless, TELUM is another free simulation software that was reviewed and is pretty much similar in definition for the method used by Tranus and is an interactive software for modeling LUTI. The reason that Tranus was chosen over that was the graphical representation within the network system of roads and routes. Although, because TELUM being more user friendly, one may prefer that over Tranus. This is not all, and the use of software packages such as LandSim was another possibility that was excluded due to the registration fees.

5.2. Theoretical Background of Tranus

In reviewing the papers and references, at first it was seen that there was a doubt in some of them about the relationship between transportation and land-use. Mostly, they were saying that the transit projects are slow to show their influences and even at that time it might have been resulted from other factors and not only the transportation. Even so, this was a challenge of this report that was tried to overcome. LUTI model is the goal to investigate such doubts. Further more, here a short summary of involved LUTI theories will be provided.

Initiation of the idea for creating an LUTI software comes from the spatial analysis of Von Thunen (1826) and Spatial Microeconomics. In short, he applied economic geography into the theory of rent and developed marginal productivity theory to relate them. His results formed the Isolated State (monocentric model) theory, stating that any industry will be formed in circular patterns from a center point called market by the

optimal profit that it brings. That is the optimization of land-use and transportation costs. The latter, relates to the distance from the market. The term rent in his wording is equal to land value or its affordability.

Then, Wingo (1961) and Alonso (1964) developed this theoretical foundation more. Wingo was the first person considering transportation demand and spatial distance between home and work, whom implemented a residential land development model. Moreover, the trip to work was related to employment and production costs. And, he found a location equilibrium for distribution of households at different income levels, replacing transportation costs for location costs. His work generated a price and density gradient pattern which was declining as moving from the center to peripheral areas.

Alonso, later, developed a same model replacing transportation inputs and lot size. He considered income levels and preferences of the households. It is done by considering the facts that low-income families will more probably choose the higher density and cheaper residences near city centers. And, higher-income level households, they will choose bigger lot sizes, lower density and generally more expensive near peripheral boundary residences.

Moreover, works of Mills and Anas added the concepts of spatial economics, location, land-use and the generation of land prices or rents and shape the spatial microeconomic theories. Based on these theories, households would try to live as close as possible to their daily activities. Equally important, it says that firms would try to minimize their costs by be in neighboring distance to the services and their clients or customers. Therefore, being close to services causes the competition which results an increase over the land prices of areas closed to them, and pushing households and activities to far areas in cities and not central areas (Liu, 2009).

Gravity and Entropy theories initiated from the works of Hansen (1959) and Lowry (1964) which was followed by Wilson (1970) who introduced the maximum entropy principles. This lead to spatial models showing an integration of land-use and transportation, which is a base for Tranus. Lowry's model was based upon two assumptions: residential densities within a city form around employment centers and location/employment levels influenced by accessibility to local customers. Hence, he maintained an equilibrium of employment-household-service in an iterative approach and reached more acceptance than Wingo and Alonso's models in 1960s.

This became the gist of the Tranus modeling analysis, as will be seen in later sections. Wilson, followed applications of gravity models in urban spatial interaction studies, developing the socio-physical approach considering second law of thermodynamics or the Maximum Entropy. He stated that the movement of people and goods follows such law in mechanics of gases.

Input-output model was, then, based upon the work of Leontief (1936) to create a full system, considering the spatial system's economy plus formation of prices. These models were extended in Tranus in order to integrate the transportation system as well. Leontief mentioned that the main purpose was to describe economy as real as possible.

He added public sector and consumptions (demand), taxation and input (supply) to the previously in-use models. Based on his work, consumptions are to be divided into different categories such as private, public or government, investment, changes in stock, exports and then value added is divided by several categories such as wage, profit, subsidies and imports for production. He predicted that there is a quantifiable equilibrium in which demand and supply of goods and cost of production or supply are equal to demand price for goods (Davar, 2000). Hence, it considered convergence in two aspects of price and amount, which will, also, be calculated by Tranus.

Paul Waddell (1993) researched the assumptions, whether the choice of workplace in a residential location model is exogenous or not and then helps building the McFadden's theory (1978). Moreover, Random Utility theory anchored in discrete choice models derived from the work of McFadden (1975). In his work, he mentions how individuals decide to commute to destinations by application of a binary choice model between two means and adding the alternative options after. Therefore, individual will decide to choose one based on attributes of that commute alternative.

In this selection process, parameters such as cost and time travelled, wage and comfort, and accessibility concepts, etc. can be introduced and weighted in a computable mathematical monetary expression (McFadden, 1974). In Tranus, this is considered in all aspects of the system from trip generations, choices on path, location, land-use and others. Tranus software includes all these complex models as per Figure 5.2.

Figure 5.2 - The Theories Contributing in Tranus (Modelistica, 2018).

5.3. An Introduction to Tranus

Tranus is an activity-based simulation software which considers the location of activities (in Universal Transverse Mercator coordinate system or local system), land-use, and real-estate market; employment and transportation system. It can investigate cost/benefit analysis of implementation of projects, effects of policies for traffic calming and restriction on the other mentioned sectors and many more. Although it sounds very promising, but as the parameters involved in the problem increase so the confusion on the calculations and results. What Tranus tries to say in short is that, overall transportation system and accessibility interacts with real estate market, housing and population and affects the demand for housing.

This program was written in Venezuela by Tomas De la Barra in 1982 and is a free software under copyright of Modelistica, Caracas (Modelistica, 2018). Some previous applications in Swindon, UK (Steadman & et al., 2011) and Brazil (Pupier, 2013) was reviewed implementing similar simulations and models. The former was a full integration application as was reviewed containing many different years, growth rates, policy scenarios created by a team of contributors, faculty members of two universities and was a result of a 2 year project. And, the latter was more concentrated on the transportation model.

There are two aspects in land-use and transport interaction models as can be seen in Figure 5.3. One, is the transportation planning and the other is socio-economic. The idea evolved from the view that daily trips are done due to individual's activities, then land-use and transport models generate trips and predict land-use evolution. Due to limitation of this MRP timeframe, some assumptions and simplifications were made in order to reach the convergence in calculations, but this report proves that it is possible to calibrate an LUTI model, while making important concessions on the model's accuracy.

Figure 5.3 - Main Elements of LUTI (Modelistica, 2018).

The equilibrium point(s) of transportation system and land-use cannot be reached easily but can be converged to as per Figure 5.4. Equilibrium between the most lucrative activities and the high-income households which tend to concentrate in the city centres or to occupy larger areas, while the less profitable activities and the low-income households tend either to relocate from city centers or to choose smaller residences (maximization of the utility within a given budget). Discrete choice model has applied in all the aspects of the modeling in Tranus in either transportation step or land-use. Basically, it is a series of discrete choice models, which can apply Logit or Scaled Utility and new Powit Model by Galvez. The model chosen in this study, though, was Logit.

Figure 5.4 - Iterative Process of LUTI (Modelistica, 2018).

Activities necessitate travel by transportation system and in each system, equilibrium reaches when supply and demand balances. Demand can be the need of people or goods for movement, and supply can be roads, railway, etc. (physical) or bus, truck, private vehicle, etc. (operative). So, the operative supply uses the physical supply. Every entity, including passenger, freight, and different modes of transportation uses a common transportation network while the different vehicle types, and sizes compete on the space available along the road.

LUTI models, consider the traditional four-step as mentioned below for transportation planning model, in addition to land-use model.

- 1- Activities generate trips between zones, which cause trip production or attraction:

By econometric models of activities, the number of departing trips from origins and the same for destinations are calculated. There might be more than one model, for instance, when travellers are divided by the purpose of trips (study, work, service, etc.). Production is when a trip's end is the origin of the trip, and attraction is when the trip's end is the

destination of the trip. Procedures, generally, are based on factors that influence urban trip demands as will be mentioned (Willumsen & Ortúzar, 2001):

- Location and land-use magnitude,
- Socio-economical characters,
- Cost and quality of the available transportation system,

Cross classification and rates based on purpose of trips, are two of the most popular ones. Former is developed by Federal Highway Administration (FHA), which estimates the trips started or ended at home. So, the commonly used parameters to be considered are, household size and average income, and private vehicle ownership. Trips generated at home are productions that will be attracted to other zones for work, service, education, etc. Trip generation rates are based on the purpose of travel and can be used from related literature or survey data. And, attractors can be defined by the number of employees, floor space, and such.

- 2- Then, these trips are distributed in Origin-Destination (O-D) matrices.

Destination choice models and the spatial interaction models started by the work of Wilson (1970). The models that determine the matrices are the gravity model or entropy model by Murchland (1966), and growth factor. The former is done via the attractiveness of zones and quality of links that connects them and the cost efficiency principles. And the latter, is done via definition of growth rates at origin and destinations, which suits best for short-term extrapolation (Mathew & Krishna Rao, 2007).

- 3- For each O-D pair, one or a combination of several transport modes (modal share or split) will be chosen in accordance with their corresponding travel costs.

McFadden (1975) choice theory was elevated by discrete (probabilistic) choice model of Ben-Akiva and Lerman (1985), which considered choice as a stepped decision-making process of (Wittink, 2011):

- a. Definition of a choice problem,
- b. Alternative generation,
- c. Choice,
- d. Implementation.

Alternatively, in other words, choice is a process rather than a single selection. Hence, attributes of modes such as per time, cost, comfort and feasibility (utility functions) are to be considered. They divide utility theory into two types of constant and random utility (for uncertainty).

Anand (1993), considered the attributes for agents rather than decision-makers. Then, Train (2003), added to this idea by introduction of representative utility for unknown to researcher aspects. Binary choice models and Logit or prodding choice models.

4- And, finally, trips are assigned to the transport network:

Assignments can be done to road or rail system, and a network equilibrium is to be defined. Equilibrium model was introduced by Beckmann et al. (1976). This is done based on costs and delay of links and etc. Integration of land-use can help make it a dynamic equilibrium.

Other than what was mentioned, new approaches were emerging using the geographic information system (GIS) and ABM. In an aggregated model, geographic information is used for processing data, designation of traffic analysis zones (TAZ) and results in demonstrations. Furthermore, geospatial analysis can help consideration of spatial autocorrelation on O-D matrices. In addition, global positioning system (GPS) and Bluetooth sensors help providing real-time trip flow information, although, there are privacy concerns about using them. In addition, open source web-sites such as OpenStreetMap can facilitate the required geospatial transport analysis. ABM models also help transportation model to consider road pricing at congestion areas; traffic signals optimization, route choice, vehicle's communication and safety, having downsides mentioned in earlier sections (Loidl & et al., 2016).

Based on probabilistic logit calculation of travel demand, model can forecast travel demand. Calibration requires a large and accurate amount of statistical database and several months for an experienced modeller to perform. Mostly, such models are implemented for Macro and not Micro simulation models or small-scale studies as this study. However, the presented model illustrates the effectiveness of it even in that scale.

Most of the software packages in use for transportation take O-D matrices as input and do not produce them versus LUTI that does the forecast of trip generation for scenarios. As per reviews of many transit-oriented cases proved, intensification and change of zoning by laws do not happen over night, and it takes 5-10 years for one, sometimes, to initiate after a transportation project has been completed. It is when people start to realize the new path and developers will be attracted to invest. Nevertheless, luckily, in the software created virtual reality the influences were immediate and measurable.

Considering all correlated components of the system, an integrated simulation is modeled, which also requires staggering amount of effort, knowledge and well organised and accurate database. The sequence of calculations in Tranus is as displayed in Figure 5.5.

Figure 5.5 - Sequence of Calculations in Tranus (Modelistica, 2018).

It is a common approach in detailed urban cases to consider freight as exogenous, as it contributes to congestion but in higher scales, this is not true. As mentioned previously, graphical representation of the network and nodes that are being modeled is an advantage of this software over competitors, while it is possible to feed the input data from several sources, including ArcGIS and AutoCAD.

And, it can deliver the results by interaction with the Office software package. Not to mention that, Tranus is very detailed in consideration of public transit as it was first developed in Latin America as it is an important factor. Every route and path can be represented in detail. Furthermore, it includes modeling of the non-motorized means, and their combinations with motorized means, separate or integrated fare systems, frequency, capacity, values of time and waiting times and many other parameters as will be discussed in future sections.

6. Model Setup

After identifying the service area and based on that, information was collected based on DA level and not CT regions to suit the purpose of micro-simulation. Although, not all the required data were available at this level and lack of information imposed the need for some assumptions to be made while also brought more challenges. The lack of existing of common boundaries between information collected by Statistics Canada on households, land-use GIS layers and Employment information added more to the confusions as well.

DAs were divided into internal and external zones. Internal meaning that they can receive information about land and population, etc. and external meaning that they are used to model travels to and from other regions. Centroid of these regions were calculated using ArcGIS and a zone point representing the region was set at that coordination. Several external zones were allocated to distribute the data in hand between them and avoid concentration on one area.

The Figure 6.1 shows the zones (green color showing external zones) that were defined and a complete map can be seen in Appendix. As it can be seen, the area considers a bit larger extents of the Keele-Finch Plus study of the City for transportation modeling (considering external zones) and smaller area than that for land-use modeling (only via internal zones).

Figure 6.1 - Internal and External Zones Specified in ArcGIS.

These nodes were transferred to Tranus as well as nodes for network and links. A beneficial point is that, it was possible to add a background of the street network having *.DXF format in order to check the connectivity and eliminate some excessive links or nodes that Network Analysis creates at curbs. Besides, Tranus only recognises version 12 of DXF files, and it was required to open the files created by clipping the layers in ArcGIS into AutoCAD and exported to the named format. Otherwise, it would just show disconnected links. The initial raw model created in Tranus is shown in Figure 6.2.

Figure 6.2 - Initial Tranus Model of Keele-Finch Study Area.

Before creating nodes, it is required to assign a mode (in this context meaning entity that travels). Modes introduced were passenger and truck considering 12 and 10 possible path choices between each origin-destination it travels and path overlapping factors of 1.4 and 1.2, subsequently. These are the data needed in PASOS extension later to identify the shortest path or in path selection procedure in general.

After this step, categories of travel will be specified. In this study, categories were as follows:

- 1- HWhigh: Home-work trips by high-income households,
- 2- HWmed: Home-work trips by medium-income households,

- 3- HWLow: Home-work trips by low-income households,
- 4- Serv: Home-service trips,
- 5- Educ: Home-education trips,
- 6- External: Trips made to and from external zones, from and to internal or external zones,
- 7- Internal: Trips made between internal zones to themselves or to other internal zones.

In each category, value of time (VOT) and waiting time (WT) need to be specified as in Table 6.1 and modes assigned. Another thing that should be specified is an administrator, which is the authority dealing with the link, maintaining it, collects the fare on usage and etc. In this study, City assigned to roads, TTC to bus ways and Metrolinx to Go-train link.

York and Peels regions were not considered as administrators because it was not the goal of this study to do cost/benefit analysis or to differentiate revenues among regions. By having this parameter introduced, it is also possible to calculate energy and fuel consumptions and pollution caused by travel means as well.

Table 6.1 - Travel Categories Characteristics.

Category	Generated by (consumption of)	By (sector)	Value of Time	Value of waiting time	Minimum trip generation rate	Maximum trip generation rate	Demand Elasticity
HWHigh	High Income Households	All sectors	\$20	\$40	1.2	2.2	0.003
HWMed	Medium Income Households	All sectors	\$10.3	\$20.7	1	2	0.003
HWLow	Low Income Households	All sectors	\$4.3	\$8.6	0.9	1.8	0.003
Serv	Health and Service	All households	\$18	\$36	0.4	1	0.005
Educ *	Education or institution	All households	\$10	\$20	1	2	0.003
External trips	External zone or Households	Households or External Zones	\$12	\$24	1	1	0.003
Internal	Internal Zones	Internal Zones	\$22	\$44	1.14	2.14	0.005

**For education, it is basically the number trips made to education by students of a household on average not the trips to education for work.*

Means of transportation or operators considered were single occupancy vehicles (SOV), high-occupancy vehicles (HOV), Bus, Walk, Bike, Rural Bus, Rural rail. In proceeding scenario, Subway Rail and LRT were added into the model as well.

Trip generation and distribution works as to say consumption of land will not require any flows, but the rest of the economic flows will. Modeling the transportation system and route are done through introduction of operators, frequency, total capacity and cost of the trip. Latter is based upon the vehicle costs for private vehicles and paid fare via transit systems. Transus provides a great detailed system to take into account all these parameters and considers fares for bus system as per number of passenger boarding. If the route's capacity reaches a certain percentage of total, the travel times will increase to compensate. It is also possible to model speed deductions when the vehicle per capacity parameter of road links reaches 1.

Unfortunately, the source of data to make a comparison of O-D matrices is available only for a broader area of North York (Transportation Tomorrow Survey, TTS) (University of Toronto, 2011) and for more current years, it is not yet available. However, based on the TTS-2011 households in North York area had on average 5.3 trips per day, 1.3 working force of 2.7 leaving in a household.

They made on average 6 km (by vehicle) to 15.5 km trips per day in peak period. 24% of trips were to school, thus 1.3 trips were made to education. Therefore, in the related menu, it was considered between 1 to 2 trips per day. This lack of availability of data caused scenarios to be based on data from 2011 in analysis. Trip generation rate is a factor defining consumption of one induced transportable unit producing certain amount of trips. Moreover, VOTs and WTs are to be 1/3 and 2/3 of an average hourly payment of each household category as per recommendations of the software.

Value of time, generally, considering utility for a mode is as per Equation 6.1 (Small, 2012):

Equation 6.1 - VOT.

$$V = \alpha C + \beta Tw \text{ or } \frac{\partial V}{\partial t} = \left(\frac{\beta}{\alpha}\right) w$$

, where C is cost, T is travel time, and w is wage rate, α and β are constants.

Transition costs between the different means and systems of transportation considered based on the parameters in Table 6.2. INF means the transfer is impossible, for instance, connection of SOV and HOV directly to buses are prohibited. Modeled systems of links and nodes versus road classification map are illustrated on Figure 6.3.

Table 6.2 - Transfer Rates.

	11111 SOV	11112 HOV	11113 Bus	11114 Walk	11115 Bike	11116 RuralBus	11117 RuralRail	11118 SubwayRail	11119 LightRail	11121 Truck
11111 SOV	0	INF	INF	INF	INF	INF	INF	INF	INF	
11112 HOV	INF	0	INF	INF	INF	INF	INF	INF	INF	
11113 Bus	INF	INF	0	0	INF	4	8.5	0	0	
11114 Walk	INF	INF	3.5	0	INF	4	8.5	3.5	3.5	
11115 Bike	INF	INF	INF	INF	0	INF	INF	INF	INF	
11116 Rural	INF	INF	3.5	0	INF	0	8.5	3.5	3.5	
11117 Rural	INF	INF	3.5	0	INF	4	0	3.5	INF	
11118 Subw	INF	INF	0	0	INF	4	8.5	0	0	
11119 Light	INF	INF	0	0	INF	4	INF	0	0	
11121 Truc										0

As it can be seen, different colors showing the various classifications. Part of the city of Vaughan was considered in the model due to the construction of Vaughan Metropolitan station and also to have Rutherford Go-station and their connections on the transportation network.

Figure 6.3 - Road Classification Map (left) (City of Toronto, 2013) , versus Modeled Links in Transus (Right).

Many parameters are to be considered when defining link types for transportation model. As such we can name:

- 1- Average speed of each operator,
- 2- Capacity based on road classification,

-
- 3- Penalty which is defined to reflect the preference of users.
 - 4- Distance cost which is the operational cost for an operator. This is important for SOV and HOV operators as it was defined that costs will be paid by passengers versus buses which passenger just charged the fare amount and not for operation costs directly.
 - 5- Equivalent vehicle or Passenger Car Unit (PCU) in literature for level terrain which is defined to consider consumption of space available on roads by different vehicles and per Table 6.3. Not to mention that, based on the recommendations of Highway Capacity Manual, PCU may differ from one road to another, but in here the assignments are done to vehicle characteristics and not to the roads, unfortunately.

Table 6.3 - PCU Values (Smith & Blewitt, 2010).

Vehicle Type	PCU Value
Pedal Cycle	0.2
Motor Cycle	0.4
Passenger Car	1.0
Light Goods Vehicle	1.0
Medium Goods Vehicle	1.5
Buses and Coaches	2.0
Heavy Goods Vehicle	2.3
Articulated Buses	3.2

An example of modeled parameters for road is as per Table 6.4 for a collector. HOV cars considered to have PCU of 1.1 as to differentiate sedan vehicle class (of SOV type) from sport-utility vehicle (SUV) or caravan classes (more typical in HOV). Trip assignment is done through link and nodes in the network, while transportation is provided by operators or modes of transportation. Similar to the situation that happens, in reality, transfer cost applies while changing from certain modes to others.

In the study area, buses from York Region and Zum system of buses from Peel Region (considered under Rural Bus operator) introduced as well as TTC buses (considered under Bus operator). Plus, in simulations, preference was defined towards the two private vehicle modes named to consider real-world situation. Energy consumption data for operative costs were considered, and data was input from Canada Automobile Association (CAA) documents (Canadian Automobile Association (CAA), 2012), ranged from \$0.089/km to \$0.115/km and cost of gas considered \$0.123/Liter. For trucks, these were \$0.18 to \$0.22.

Table 6.4 - Collector Link Characteristics.

Operator	Speed	Charges	Penaliz.	Distance Cost	Equiv. Vehicles
11111 SOV	45		1.2	0.53	1
11112 HOV	42		1.2	0.53	1.1
11113 Bus	35		1	2.17	2.9
11114 Walk	5		1
11115 Bike	11		1		0.3
11116 RuralBus	35		1	2.17	2.9
11117 RuralRail			1
11118 SubwayRail			1
11119 LightRail			1
11121 Truck	40		1	0.8	1.5

The capacity and frequency of each bus route were considered based on YRT (York Region Transit (YRT), 2018) and TTC website's information (Toronto Transit Commission (TTC), 2018) about them and also the manuals reviewed. Modes of transportation are defined by the characteristics mentioned in Table 6.5. Not to mention that, bus system does not have a fixed waiting time as it is considered in frequency of service, but the subway system has as the time for buying the ticket and boarding. Rural rail considered for Go-Train with a fixed price of boarding almost \$8.50 (it was also possible to calculate the fare based on the boarding and distance). An example of information about the route that was applied can be seen in Figure 6.4.

Figure 6.4 - Bus Route 60 TTC's Frequency. (Toronto Transit Commission (TTC), 2018)

Mainly, capacity was defined from at nearly 400 vehicle/hour for local streets increasing to 1500 vehicle/hour for major arterials in both ways and almost 5000 vehicle/hour for highway in one way. Capacity and speed were, also, based on the City's road classification system (City of Toronto, 2013). Adding to that, a part of the highway 400 was considered in modeling just to explore the capacity of software in modeling the flow in one way systems.

Another challenge of using maps from distinct sources was that, for instance, in the street networks level of service (LOS) categories (or road classification names) were different in the York region maps from the City of Toronto's files. Therefore, it was tried to keep the network continues into the York region as per guidelines of Transus to create a valid connected transit system.

Table 6.5 - Operators Characteristics Assigned.

Operator	Type	Occupancy	Modal Constant*	Boarding Tariff
SOV	Normal	1	1	0
HOV	Normal	2.3	1.7	0
BUS	Transit with Route	57	1.2	\$3.50
Walk	Non-motorised	1	2.0	0
Bike	Non-motorised	1	2.2	0
RuralBus	Transit with Route	7.2	1.2	\$4.00
RuralRail	Transit with Route	1944	1.3	\$8.50
SubwayRail	Transit with Route	1100	1.3	\$3.50
LRT	Transit with Route	171	1.3	\$3.50
Truck	Normal	1	1	0

*Higher the modal constant, less attractive the mode.

It was found out after the calculation, though, that these amounts are not going to be reached, and most of the traffic at rush hours is from the other zones passing through the area in reality. In the model, most traffic was concentrated near the central zones.

Target occupancies considered to be 70%, so bus frequency increases if the occupancy reaches it to avoid having overloaded buses, while this increases the waiting times. It was, also, possible to prohibit access for pedestrian and bike on the highway system. The same can be done to designate "only rail transit access" for Go-train pathway and as such. "Pedestrian access only" was provided as per reality for access to stations as well.

Accesses to zones were provided with links having unrestricted capacity (INF) which is not actually an existing street, as they are feeders of the system. And likewise, this is the case for stations. One point to be mentioned is that, transportation model is set for AM peak hour data, though, the intention was not to investigate the characteristics of the transportation model, as it helps land-use model to operate and derive conclusions.

Boarding capacity of the LRT was considered to be 171 passengers while its average speed considered to be at 22-23 km/hr (City of Toronto, 2010). Passenger boards with waiting times for this type the same as subway. Accessibility as a cost function or transport disutility synchs with equilibriums and loops back to activities (flows), location and real estate prices. Any changes in the land-use or addition of floor space or building will make an immediate impact on transit system and vice versa in the Transus model.

Activities can be categorized into exogenous or induced, plus they can be either non-transportable (such as land) or transportable (goods or services). Thereupon, the latter can be produced and consumed in different locations. Exogenous activities can be categorized to demands or productions. Production in this context includes for production not generated or required by internal sectors or final demand in input-output models.

Their locations is free of logit implicit. It will be given into the model as input to be added to endogenous induced production. For this study, Industrial and Government employment (others in National Household Survey (NHS)) considered to be exogenous as they serve beyond the borders of the study area. Growth in this section can be applied globally and assigned by distribution values specified, if needed for proceeding scenarios. Exogenous demand, is the demand generated beyond internal zone demands. Consequently, if external zones demanded production of activities (for instance, jobs that are outside boundaries to be positioned by households from within boundaries) it will be called export. The growth for these can be applied by incremental models, if needed.

Induced production and demands can be explained accordingly as production generated by an internal or external demand and assigned to the internal zones by the sectoral distribution model, and consumption requirements of final demand sectors or intermediate activities. Former grows as the section demanding it grows, for instance, floor space by having more households living within the zone.

Demand function generally follows Equation 6.2 and effect of elasticity can be seen in Figure 6.5.

Equation 6.2 - Demand Function (Modelistica, 2018)

$$a_i^{mn} = \min^{mn} + (\max^{mn} - \min^{mn}) \cdot \exp(-\delta^{mn} U_i^n)$$

Where, a is the supply of n demanded by a unit of m in zone I ,

$\max$ and $\min$, are the maximum and minimum amount of n required by a unit production of m ,

δ , is the elasticity of m with respect to cost of input n ,

U , is the consumption disutility of n in i ,

Figure 6.5 - Effect of Elasticity (Modelistica, 2018)

Location and quantities of the factors must be identified. Prices will be adjusted to reaching equilibrium if needed as mentioned. Land-use sub-model generates output of location of activities from an iterative process. O-D matrices is also produced by it for the use of the transportation sub-model.

Transport calculation, at first step starts, by PASOS or path search model which reads nodes, routes, cost and etc. and generates several paths or travel options by considering physical and operative supplies for each O-D pair. Hence, number of trips will be calculated in each link and mode. Then based on capacity of links, when reaching it, speed reduces and travel time increases. The congestion can realistically be spread towards the upstream links and all users, causing delays (shockwave effect). Then, all the four step will be done iteratively again to reach equilibrium.

Activity generation and location can be done through an input-output model with production-consumption relations. An important factor is that Transus inputs are unit less. As a result, it is possible to consider money units, square meter, square foot, hectare, etc. as required. In this study, floor space is in square meter and land is in hectare and their prices are in \$1000.00 dollars. Introducing relationships with external zones can be done by assigning trips as in O-D matrices format, commercial trips as for jobs occupied by people from outside study area (import for employments) and residents going to work outside the study area (exports). Another way which found to be better in convergence is assigning all external trips in O-D matrices.

It must be said that, another source of O-D matrices data is the Transportation Tomorrow (University of Toronto, 2011) but a challenge was that those data, as reviewed, only considers territorial trips and not local trips, therefore, those would be more appropriate in macro simulation of regional areas. Hence, for this

report, data from Keele-Finch Plus study of City of Toronto (City of Toronto, 2017) were input in O-D matrices as per Table 6.6.

Table 6.6 – External Trips Assigned.

Zone ID in Transus/AM trips	Inbound trips	Outbound trips
10049	1213	462
10050	752	710
10051	353	353
10052 & 10053	553	173
10055 & 10054	229	122
10056	618	368
10060	571	603
10059	92	86
10057	148	71
10058	65	60
10061 & 10062	259	291

Adding to these numbers, also, some extra traffic affixed to consider travel from external zones to each other through these regions to make the transit results more realistic. Movements of passenger and freight were modeled into the system and as per reality, freight was used for inbound/outbound transfers by truck. Furthermore, it was tried to take into account the internal movements inside the internal zones by adding more connections from the zone center to adjoining streets in O-D matrices as well. As discrete choice assignment dictates, if the system is not congested, the path will become the shortest path other wise based on the cost of travel, and user's preferences can decide to use longer faster or less-expensive routes.

Study area is located at Neighborhood Improvement Areas (NIA) (City of Toronto, 2018) number 27 and 24 (, please see Figure 6.6). NIA#27 area are limited between Steels and Finch while corridor profile segments between Pond St. and Grandravine Dr.

Although, this area is located at Ward 8 but information about the ward was not considered. The summary information of NIAs can be seen in Table 6.7 and Table 6.8. Another categorization was as per segments 7 and 8 in Metrolinx report for Finch LRT (, please see Figure 6.7, (City of Toronto, 2015)). The information about these segments can be seen in Table 6.9 and Table 6.10. However, the other source was the NHS surveys from Statistics Canada.

Table 6.7 - NIA Data on Population/ Employment based on 2011 NHS (City of Toronto, 2018).

NIA	Population	Labour Force	% Living in Not-affordable dwellings	% Living in Not-NOS met dwellings	% LIM-AT	% Medium Income	% High Income (+80K)
YYH	27,713	13,560	41	21	26	58	16
BG	22,057	9,575	34	26	28	58	14

Table 6.8 - NIA Data on Dwellings (City of Toronto, 2018).

Housing Type Percentages	Total No. Dwellings	Single - Detached	Semi - Detached	Row Houses	Apartment and Duplex
YYH	10,315	14	15	7	63
BG	7,245	10	9	15	65

Table 6.9 - Segments 7 and 8 Finch West Corridor Population/Employment. (City of Toronto, 2015).

Segment	Pop	Jobs	Employment Establishments	Density /Hectare	Increase Pop from 2006
7	19,342	556	39	1.8Jobs+63.31People	+5.5%
8	0	5101	590	27.13Jobs	-

Table 6.10 - Segments 7 and 8 Finch West Corridor Housing types (City of Toronto, 2015).

Housing Type Percentages	Single	Semi	Row	Detached duplex	Apt	other
7	16.5	11.4	6.7	1.5	52.9	0.7
8	-	-	-	-	-	-

Percentages are almost compatible, but as to be more accurate in micro-scale on dwellings and household, Statistics Canada's data were used as DA level.

Figure 6.6 - NIA #27 Left - NIA#24 Right (City of Toronto, 2018).

Figure 6.7 - Segment 7 Right - Segment 8 Left (City of Toronto, 2015).

DA level data on occupation and income was not attainable on NHS-2011 statistics, hence, appropriately a numerical fitting was done based on 2016 available data while having total households roughly as per occupied dwellings in 2011. Occupation, also, was considered based on Toronto Employment Survey data (City of Toronto, 2011) that will be discussed later. Annual income categories defined to be, less than 40K, 40K-80K, and +80K. An example of extracted data from the sample zone of 35202007 can be seen in the Appendix, so it displays how the numbers for this zone in the Table 6.11 are calculated. This table contains final assigned data for household incomes of zones. Considering these categories for base scenario, average

hourly wage of each household type would be as follows (12month a year, 20 days a month, eight hours a day = 1920 Hours):

Low (Aveg \$25K salary): \$13.00,

Med (Aveg \$60K salary): \$31.00,

High (Aveg \$115K salary): \$60.00.

Moreover, it was checked with CT data, which is an area bigger than DA. Final assignment of data about households with the high-income level can be seen in Table 6.12 as an example.

Table 6.11 - Household Data Assigned

DA Zone	Low Income	Med Income	High Income
35202098	0	0	0
35202013	292	168	263
35202016	161	142	47
35202017	742	490	192
35202028	25	35	40
35204106	325	133	147
35202024	58	92	131
35202001	398	175	122
35202002	80	64	91
35202003	144	153	97
35202004	40	66	110
35202005	48	70	48
35202006	30	40	51
35202007	45	60	80
35204014	312	479	371
35202097	73	58	26
35202000	51	51	92
35202027	29	33	57
35202026	45	54	79

Not to mention that, due to zone 35202098 be homogeneous and mostly employment or industrial, Duke Height's employment data (IBI Group, 2016) were compared with the ones from the City of Toronto's Dufferin-Keele North Employment Center, as per Table 6.13.

Table 6.12 - Number of Households with High Income.

Sector 11 HhHigh									
Base Year Increments									
Internal Data Imports Exports									
	Exog. Pr	Base Pro	Min. Pro	Max. Pro	Exog. D	Base Pri	Value Ac	Atractor	
■ 10000 35202098	0	0	0	0	0	0	0	0	
■ 10001 35202013	0	263	0	0	0	0	0	1	
■ 10004 35202016	0	47	0	0	0	0	1	1	
■ 10005 35202017	0	192	0	0	0	0	0	1	
■ 10007 35202028	0	40	0	0	0	0	0	1	
■ 10009 35204106	0	147	0	0	0	0	0	1	
■ 10010 35202024	0	131	0	0	0	0	0	1	
■ 10013 35202001	0	122	0	0	0	0	0	1	
■ 10014 35202002	0	91	0	0	0	0	0	1	
■ 10015 35202003	0	97	0	0	0	0	0	1	
■ 10016 35202004	0	110	0	0	0	0	0	1	
■ 10017 35202005	0	48	0	0	0	0	0	1	
■ 10018 35202006	0	51	0	0	0	0	0	1	
■ 10019 35202007	0	80	0	0	0	0	0	1	
■ 10022 35204014	0	371	0	0	0	0	0	1	
■ 10025 35202097	0	26	0	0	0	0	0	1	
■ 10032 35202000	0	92	0	0	0	0	0	1	
■ 10033 35202027	0	57	0	0	0	0	0	1	
■ 10034 35202026	0	79	0	0	0	0	0	1	

Jobs also, as per segment 7 other than institutional, can be reasonably spread along the intersecting major corridors of Keele and Finch via specified zones as other regions are residential. For land-use, all areas are employment land. Not to mention that, the data for segment 8 only considers a small portion of DA 35202098, and this information was excluded.

Table 6.13 – Number of Jobs in Each Category (City of Toronto, 2011) and (IBI Group, 2016).

Employment Category	No of Establishments	No. Jobs at 2011 based on Duke Heights	No. Jobs at 2011 based on Toronto Employment Survey 2011
Manufacturing	410	7821	9050
Retail	468	4703	4710
Service	507	2973	2870
Office	954	13161	13600
Intuitiional	91	1346	1600
Other	34	535	530

As it can be seen, the numbers are almost in the same range so data from City was entered. The data from City of Toronto's employment survey was used for employment district and the data for segment 7 also applied on the DAs having mixed commercial/residential zones. Those are seven zones or DAs as per Table 6.14.

Assignments were based on area; moreover, these numbers were divided into main categories specified excluding institutional (376) which is assigned only to 35202013, 35204106 and 35202097, concentrating mainly on the first one. Although, the area of segment 7, covers till the Pond Street from north but there was no other source of information found so the numbers assigned as described by 250, 63, 63 jobs accordingly.

Table 6.14 - Commercial-Residential Land and Number of Employment Assigned.

DA	CR land Area(m ²)	Total Employment Assigned
35202013	12,097.3	25
35204014	28,446.2	52
35202007	5,685.8	10
35202006	5,114.4	9
35202004	14,994.3	27
35202002	4,877.9	9
35202001	26,296.8	48

In regard to real estate market, total mean monthly rent on apartments was \$928.00 (based on CMHC's database Zone17-North York (Canada Mortgage and Housing Corporation (CMHC), 2012)) or \$25/sqm average (for average size of 400 sqft unit or 37 sqm). Additionally, the average price of detached houses in the City on 2011 was \$658,063 (Canada Mortgage and Housing Corporation (CMHC), 2012).

Comparing the average prices mentioned for this section versus the ones mentioned in the City's Real Estate Market Study (N. Barry Lyon Consultants Limited, 2015), the average price for detached houses estimated in 2011 at \$478,063. By assuming an average floor area for each type, it was possible to calculate the price/unit per growth floor area (GFA). Then, considering construction cost per square meter from references available (Hanscomb Ltd., 2012) and deducting it from the overall price, we will reach an estimate of the land price as follows.

Furthermore, some of the assumptions were adjusted with a Metrolinx report (N. Barry Lyon Consultants, 2015). Finally, initial data assigned are as per Table 6.15, and not to mention that the average prices for the year 2016 (Toronto Real Estate Board, 2016) was added only for comparison here. Therefore, price per

hectare of residential land is \$1,350,000 and for mixed land, it was assumed to be \$1,800,000.00. The prices of construction per GFA of multistory-industrial and framed floor space buildings were estimated to be at \$0.84/sqm and \$0.98/sqm accordingly while the price for employment land to be at \$900,000/ hectare.

Table 6.15 - Initial Real Estate Data Assigned.

Dwelling Type	Average Price 2011	Average Price 2016	Average GFA(m²)	Construction Price/GFA (\$1000.00)	Price/Residential Land only(m²) (\$1000.00)
Detached	\$478,063	\$609,100	279	\$1.579	\$0.135
Semi-Detached	\$350,000	\$492,800	214	\$1.500	\$0.135
Attached Rows/Duplex	\$200,000	\$288,000	135	\$1.418	\$0.135
Condominiums	\$110,000	\$186,300	56	\$1.706	\$0.135

As per floor area needed per job, it was assumed that on average office jobs require 27 sqm/each job, Retail 40 sqm/each job, and Manufacturing 55 sqm/each job (City of Toronto, 2015). Additionally, for others (government jobs), this was considered 50. These average numbers were considered in a range of data applying elasticities for changes in each step. These assumptions were applied considering the location and as a result, the better the area higher the price.

The total GFA or floor spaces available were calculated based upon the averages numbers assumed for each type of dwelling and, multiplied by the number of houses and units from census 2011 and fitted by the 2016 profiles for DAs (Statistics Canada, 2016). As it was seen, a tremendous amount of information at DA level was required, and this collection process needed time and attention to details. It must be highlighted that, these assumptions were initial numbers and were adjusted to match the population data and employment which were the most accurate data in hand, later in the calibration process for reaching better convergence. A sample of data assigned can be seen in Table 6.17 for detached houses. Plus, an example of initial data extracted from the tables of Statistics Canada for DA number 35202007 is shown in Table 6.16 and it illustrates how the rest of the data is input.

Table 6.16 - Zone 35202007 Housing Data (Statistics Canada, 2016).

Types of Housing in Zone 35202007	Number of Units	Total GFA (m2)	Average House GFA
Single-detached house	80	23200	290
Apartment, building that has five or more storeys	0		
Semi-detached house	20	4600	230
Row house	30	4500	150
Apartment, duplex	30	6900	65
Apartment, building that has fewer than five storeys	5	400	80
Other single-attached house	0	0	0

Table 6.17 - Initial Detached House Floor Space Data Assigned.

Sector 23 Detach									
Base Year Increments									
Internal Data Imports Exports									
	Exog. Prod.	Base Prod.	Min. Prod.	Max. Prod.	Exog. Demand	Base Price	Value Added	Attractor	
10000 35202098	0	33350	33350	33350	0	1.58	1.58	33350	
10001 35202013	0	37700	37700	37700	0	1.58	1.58	37700	
10004 35202016	0	0	0	0	0	1.58	1.58	0	
10005 35202017	0	0	0	0	0	1.58	1.58	0	
10007 35202028	0	24650	24650	24650	0	1.58	1.58	24650	
10009 35204106	0	21750	21750	21750	0	1.58	1.58	21750	
10010 35202024	0	62250	62250	62250	0	1.58	1.58	62250	
10013 35202001	0	0	0	0	0	1.58	1.58	0	
10014 35202002	0	8700	8700	8700	0	1.58	1.58	8700	
10015 35202003	0	0	0	0	0	1.58	1.58	0	
10016 35202004	0	34800	34800	34800	0	1.58	1.58	34800	
10017 35202005	0	21750	21750	21750	0	1.58	1.58	21750	
10018 35202006	0	21750	21750	21750	0	1.58	1.58	21750	
10019 35202007	0	23200	23200	23200	0	1.58	1.58	23200	
10022 35204014	0	0	0	0	0	1.58	1.58	0	
10025 35202097	0	0	0	0	0	1.58	1.58	0	
10032 35202000	0	2900	2900	2900	0	1.58	1.58	2900	
10033 35202027	0	29000	29000	29000	0	1.58	1.58	29000	
10034 35202026	0	15950	15950	15950	0	1.78	1.78	15950	

Inter-sectors menu in Tranus defines the relationship between production and consumption. Alternative choices (using logit choice probabilities, which follow an exponential function), if there is a competitor in consumption or alternate supply source, also can be defined in “Substitutes” sub-menu. In other words, input-output (I/O) matrices is formed in Tranus by inter-sectors. The relation follows the Equation 6.3. This is the most important part in model calibration to reach the convergence and equilibrium.

Equation 6.3 - I/O relations by Inter-sectors (Modelistica, 2018).

$$\forall j \sum_{i=1}^n C_{ij}(P^{ex}_i + P^{ind}_i) = P^{ind}_j$$

Where, C_{ij} is a fixed demand per unit or inter-sector coefficient,

P^{ex} is exogenous production,

P^{ind} is induced production.

This was done via an Excel spreadsheet having the mentioned data in previous sections. In order for demand to work as a function of price in the software, minimum and maximum demands were introduced, and the slope will be controlled by elasticity as illustrated earlier by Figure 6.5. Not to mention that, elasticity should not to be taken a very small number based on recommendations of Tranus. Smaller elasticities cause the function the become closer to the straight line. As an example, producing office job requires floor space, and jobs (employees) demand a certain household type. Inter-sectors are as of most importance in reaching convergence and also very sensitive in means of accuracy to at least some 5 or 6 digits. This avoids any errors in iteration steps. Some activities, as mentioned, are to be considered exogenously fixed, in order to start the land-use model and feedback to transportation model. Exogenous in this context means dependent on external elements while other induced employment means generated within the study area by other activities.

Other than previously mentioned employment sectors that were considered exogenous, office, health, institutional, retail and service considered as induced by households while household types induced by employment. This means that exogenous activities causes residents to settle, and those will induce employment and employment generates more households.

Another thing to be considered is that health and educational land usually will not be consumed by other activities and their prices are not to be taken into account as they are pre-assigned by the governments, typically. It is noticeable that density patterns and urban sprawling is a result of land prices. The relationship between the activities, floor spaces and land-use can be seen in Figure 6.8. Land categories defined were:

- 1- Empland: Employment Land,
- 2- Mixed : (Commercial and Residential),
- 3- ResL: Residential land.

Furthermore, floor spaces consuming these in a competitive way are:

- 1- ComerMultiS: Commercial multi-story buildings,
- 2- FramedFlat: Flat warehouses and commercial buildings,

- 3- Detach: Single-detached houses,
- 4- SemiD: Semi-detached houses,
- 5- Complex: Summation of total floor spaces in apartments having more and less than 5 stories,
- 6- Towns: Town houses.

In the case of floor spaces, a methodology would be of using building foot prints from University of Toronto's Online Library and map web-site (University of Toronto, 2010) with the help of ArcGIS and considering typology of structures from Google Earth. This process requires quite some times as it requires the calculations to be done in DA level and then every land-use category level inside the DAs, clipping and calculating areas of foot prints.

Figure 6.8 - Defined Relationship Diagram Between Activities - Floor Space - Land.

Moreover, as the DA map is from Statistics Canada and Zoning By-Laws map from City, any land-use calculation needs to be double checked as boundaries are different between two, so for instance a zone not completely residential might show some CR zones at one peripheral area, which is inside the neighbor zone and this will cause an error, if neglected.

Only for zone 35202098, these calculations were done and areas deducting roughly 10% for tank farms, considered to be 40% from commercial multi-story and 60% framed (flat) floor space. Hence, the numbers for available GFA for these two sections were considered to be: 785,782 m² and 1,222,329 m².

On the other hand, for calculation of land available for different land-use types inside the DAs, the process mentioned was performed using Arc-GIS having DA layer and Land-use layer to have an accurate number for land data. The results can be seen in Table 6.18.

Table 6.18 - Total Land Available Input in the Model.

Zone/Land type (Hectare)	Industrial (Employment Land)	Mixed	Residential
35202098	523	-	-
35202013	21	1.24	33.5
35202016	-	1.60	1.65
35202017	-	6.2	6.3
35202028	-	-	10
35204106	-	1.5	18.9
35202024	-	0.26	25.8
35202001	-	2.5	6.6
35202002	-	0.32	11.8
35202003	-	1.87	1.9
35202004	-	-	18.7
35202005	-	0.35	9.2
35202006	-	0.2	8.9
35202007	-	-	12.3
35204014	-	4.7	9
35202097	-	0.55	1.32
35202000	-	-	12.5
35202027	-	-	11.8
35202026	-	0.57	8

7. Calibration and Results

It was, as well, tried to create a realistic model with concentration on the land-use model. The most complicated and difficult part after data collection and organization is this step in Tranus. The problem is that the equilibrium is not easy to be reached, and it requires well calibration. If done so, model reaches convergence after some iterations. This step by itself can take months to fully accomplish since there are a high number of values and parameters to be taken into account. However, the concentration of this report was to show that it is not impossible, if enough trial-and-error procedures accomplished.

There are two types of relationship in the software, elastic and inelastic. Relationship between jobs and households is inelastic meaning each job requires a certain amount of households, which needed to be balanced. Furthermore, the elastic relationships between activities that consume floor spaces were defined by a minimum and maximum range and an elasticity. Consequently, if the price of a house highly increases, households relocate or choose smaller sizes. The same is for the relation between floor space and land-use, so the expensive land will accommodate in smaller lots.

Theories behind the calibration derive from the models mentioned in the Theoretical Background of Tranus. Every sector demands inputs from other sectors. Therefore, whether used internally or externally, some part of production goes to intermediate consumption while the rest go to final. By having a finishing demand in zones, and use of demand function, model calculates induced amounts. And, then it will be allocated to zones by spatial distribution functions.

As a result, this induced production, demands more inputs and generates a production chain while considering the location of activities. A consuming zone can be, at the same time, producing zone in relation to other zones. Money and people or goods flow necessitates transportation, and costs needed to be associated. The general process is as shown in Figure 7.1.

Figure 7.1 - Equilibrium Calculation Procedure. (Modelistica, 2018)

By the use of mathematical logit formulas as per Equation 7.1, attractors (such as production cost or land price) of zones were weighted for different variables, starting from exogenous data that are given to the model as input.

Equation 7.1 - Attractor Formula for Exogenous Variables. (Modelistica, 2018)

$$A_i^{n,t} = \exp(C + \sum_K (a1^{nk} X1_i^{k,t-1} + \dots + an^{nk} Xn_i^{k,t-1}))$$

Where, $A_i^{n,t}$ is the attractor of sector n in zone i for period t.

n is production in each sector,

k is the attractor sector in zone i,

$X1, \dots, Xn$ attracting activities which consume exogenous production of n.

The variables such as exogenous production, total production (adding induced production to exogenous one), exogenous demand, minimum and maximum restrictions, price and capacity should be defined in the model in inter-sectors and economic data. Therefore, starting from the calculated amount of the previous period, by application of any increments in the current period, they will be added to previous one.

For the case of induced production, attractors will be calculated before the initiation of iterations by Equation 7.2.

Equation 7.2 - Attractor Formula for Induced Production. (Modelistica, 2018)

$$A_i^{n,t} = \left(\sum_k b_k^n (\tilde{X}_i^{k,t-1}) \right) W_i^{n,t}$$

Where, X is total production (exg.+ind.) of sector k attracting production n in zone i ,

b is the relative weight of sector k as an attractor,

W is the initial attractor of zone i that attracts the location of n .

Generation of induced demand follows the previously mentioned Equation 6.2, considering fixed (inter-sector defined) demand, variable demand (defined by maximum, minimum and elasticity) and possible substitutes (which works as penalty factors) using the multinomial logit model. Hence, for the first step of iteration, algorithm of Figure 7.1 only have exogenous production and direct induced demand caused by it available. In proceeding steps, the induced production calculated in previous iterations of all sectors will be added. Then, the production costs will be calculated.

The demanded total production, then, must be distributed to production zones, which followed the transportable or non-transportable idea as noted. Again, the transportable ones, use multinomial logit applying utility function of each zone. In that, a shadow price of production is to be estimated in a trial-and-error process of calibration stage as required. Likewise, demand of all zones will be assigned to production zones and consumption costs will be calculated.

Equilibrium prices adjust only if production is outside the minimum-maximum ranges provided using demand-supply equilibrium. So, if the convergence price factors show a positive number, it means that maximum restriction is reached and vice versa. Such adjustments were made during the calibration process of this model as well. This variation, also affects distribution of production in proceeding iterations until it reaches the convergence criteria.

Transportation improvement reduces disutility (or improves accessibility), as trip generation is elastic and this affects allocation-interaction process. So, movement of products in transportation model which can be presented in terms of households for trip to works as well as physical units is facilitated or cost less.

After assignment of demand to production zones, the model checks for possible production constraints. For instance, if in a zone, more land of a certain type is consumed than is available, the model increases the price accordingly and this type of land will be less attractive in the next iteration. So, it will continue to either it converges or iteration steps defined maximum steps. If latter was the case, IMPLOC should be run to see what types are demanded, by which activity and compare them with input data (productions) and make adjustments on price and floor space quantities. An example of final calibrated data for detached houses can be seen in the Table 7.1 which was based on the information of Table 6.17.

Table 7.1 - Adjusted Numbers for Detached House Type.

Sector 23 Detch									
Base Year		Increments							
Internal Data		Imports Exports							
		Exog. Pr	Base Prod.	Min. Pro	Max. Pro	Exog. D	Base Pri	Value A	Attractor
■ 10000 35202098		0	0	0	0	0	0	0	0
■ 10001 35202013		0	37700	37700	37700	0	1.5	1.5	37700
■ 10004 35202016		0	0	0	0	0	0	0	0
■ 10005 35202017		0	0	0	0	0	0	0	0
■ 10007 35202028		0	24650	24650	24650	0	1.48	1.48	24650
■ 10009 35204106		0	21750	21750	21750	0	1.56	1.56	21750
■ 10010 35202024		0	65250	65250	65250	0	1.55	1.55	65250
■ 10013 35202001		0	0	0	0	0	0	0	0
■ 10014 35202002		0	8700	8700	8700	0	1.48	1.48	8700
■ 10015 35202003		0	0	0	0	0	0	0	0
■ 10016 35202004		0	34800	34800	34800	0	1.55	1.55	34800
■ 10017 35202005		0	21750	21750	21750	0	1.57	1.57	21750
■ 10018 35202006		0	21750	21750	21750	0	1.57	1.57	21750
■ 10019 35202007		0	23200	23200	23200	0	1.57	1.57	23200
■ 10022 35204014		0	0	0	0	0	0	0	0
■ 10025 35202097		0	0	0	0	0	0	0	0
■ 10032 35202000		0	2900	2900	2900	0	1.58	1.58	2900
■ 10033 35202027		0	29000	29000	29000	0	1.4	1.4	29000
■ 10034 35202026		0	15950	15950	15950	0	1.4	1.4	15950

It is, moreover, possible that if some types of land or floor space had alternatives in a zone, model distributes the consumption based on cost preference of land types. As of this, high-income families will decide to settle in detached houses versus low-income households which they prefer complex apartments, so a penalty factor can be defined to reflect that. Therefore, lower the penalty means higher the preference. Moreover, this is the same for jobs and services that can accommodate in different floor spaces.

Many sources of error, stopping the model from reaching convergence, was found and responded to in the first trials. For instance, improvement in production and demand balances was done via introduction of better inter-sectors (via previously mentioned Excel sheet and as displayed in Appendix.), and adjustments on elasticities. Imported and exported, data mentioned earlier, are to be considering while adjusting the difference parameter between demand and production as to be added on the summation of production, and total demand for the specific sectors, accordingly. Table 7.2 displays how the mentioned coefficients define relationships of HhHigh sector to others. And also it shows the elastic relationship in which higher elasticities meaning less preference.

Table 7.2 - HhHigh Relationship towards other Demanding/Producing Sectors after Calibration.

Sector 11 HhHigh				
Inputs Substitutes Exog. Atractors Prod. Atractors Categories				
Input Sector	Min. Demand	Max. Deman	Elasticity	ASC
1 Manu				1
2 Govm				1
3 Retail	0.7510809			1
4 Office	2.3125			1
5 Service	0.4060233			1
6 EductnlInstitu	0.2705			1
11 HhHigh				1
12 HhMed
13 HhLow
21 ComerMultiS
22 FramedFlat
23 Detch	210	340	0.37
24 SemiD	160	190	0.4
25 ComplexDuplex	60	110	0.5
26 Towns	130	170	0.45
31 EmpLnd
32 Mixed
33 ResL				1

Validation menu is a beneficial option in the software which checks for some errors in transportation modeling such as lack of required input data about links, connection errors between links, etc. As a result, the model must be made valid and error free, before even iteration calculations can start.

In addition to the algorithm described, an idealistic approach in calibration can be to make a comparison from output data versus real-life data via introducing objective functions to measure distances with data observed, though as the data are mostly correlated defining such a function was impossible in the timeline of this study. Instead, a series of controls were checked to reach a qualitative measurable results that can be compared justifiably to the real-world while, again, focusing on land-use results (IMPLOC).

Controls that can be checked are:

1- LCAL :

Calculations or activities location indicator section, by checking last step of iterations and check what areas it is mentioning requires adjustments in price or production amounts.

2- TRANS :

Calculations or results of trip distribution, after last iteration of the transportation system to see if it had reached convergence or not. It should usually reach convergence in under 30 iterations.

3- IMPLIC :

Calculations to check the consumptions of land and floor spaces versus their inventory. It is an extension software outside the Tranus platform that translates the LCAL results to more meaningful results by showing production and consumptions by sectors and zones.

4- Path Choice Validity:

Path choice is the sections which can be checked via Google earth or ArcGIS. Paths are created by PASOS in the number of alternatives as mentioned earlier. Software creates output data, which can be visualized by itself when opening those.

*.T3S files contain such information about transportation and routes related data. A sample of paths checked can be seen in Figure 7.2.

Figure 7.2 - Path Checks.

Results of transportation system can be provided and visualized in this step which was not the intention of this study. But Figure 7.3 demonstrates an example of such results.

Figure 7.3 - An example of Transportation System Results (Finch West of Keele Street)

IMPLOC's results translate the land-use results and can be used to see what areas of error in assumptions of floor spaces exist. Some adjustments were considered and errors were rectified, which were resulted from input of data. And, as several sequences of land-use-transportation done, then the convergence after each one improved.

IMPLOC, also, makes it possible to see the final productions and consumptions after the analysis finished each time. A sample of how to run this program is presented in Figure 7.4. The option 6, when chosen, extracts a file which can be easily open in Excel and then compared to the mentioned earlier data input in Economic Data menu for each section.

```

I M P L O C : DISPLAY LOC RESULTS

Path for TRANUS.CTL? -----> C:\T2\With

IDENTIFY YEAR AND POLICY (3 characters) -----> 11A

Display options:

[1] All information by sector and zone
[2] Total production by sector and zone
[3] Total production by year/policy
[4] Internal information by sector and zone
[5] Consumption coefficients by sector
[6] Total consumption by sector and zone
[7] All information, comma-delimited

Option ---> 6

```

Figure 7.4 - IMPLOC Environment to Extract LCAL Results.

For instance, if the results show that actual demand for floor space of different types is more than the amount considered in some zones and less for others (as per inter-sector relationship, population and employment considered), then, the average amounts input in the model for floor space in previous sections decreased or increased to resolve.

The results have to be calculated from the beginning to the end for almost 200 iterations each time adjusting a parameter and observing the effect on the overall system of convergence. It takes a remarkable amount of time to find the source of error, adjust, redo calculations and revise as needed. As for the experience of the base scenario, in order to reach a good set of results, hundreds of iteration sequences and more than 50 trial files were created. Not to mention that, adjustments needed to be made one parameter at a time as correlative relations in calculations may impose conflicts.

One of the biggest causes of error was derived from 2011 surveys. It was showing residential establishments of semi-detached and complex buildings exist in the zone 35202098, which could not be balanced as such thing does not exist, and the whole area is employment/industrial buildings. So, the amount for these sections set to zero.

Other than that, the amount of residential land includes for streets and etc. which was not considered part of lot consumption of different house types earlier and this was causing a lot of work to be adjusted. One more thing is the understanding of the relationship between the activities to floor space and to land-use. For instance, when trying to reach convergence and it errors in the price of mixed land-use, when retail is consuming it, the floor space requirements (inter-sectors) needs to be revised not actually the price of land.

The shorter the ranges of maximum and minimum and the more appropriate same range elasticity, also helps reaching a fast convergence. Many of the assumptions that were made in the initial stages needed to be adjusted and, moreover, land-use-floor space relationship as well as prices of sectors, which made it very difficult to reach the convergence. As such, land-use prices mentioned before were set to be the price for all of the zones but were adjusted to more and less as required based on the information provided in the software reports after each iteration and plus results of IMPLOC.

The best systematic approach experienced was to start balancing exogenous demands of floor space; therefore, it attracts households and in the meantime they compete with retail and office in some types of floor spaces then other sections, and households consume floor spaces and land-use. The whole theory behind the convergence is that all supply and demand in all activities reach equilibrium and also no price change occurs from previous iteration step.

PASOS analysis for the situation without LRT and Subway working is shown in Figure 7.5, showing 945 links and creating 4949 multimodal network. Moreover, from the calculations of the software for the situation having the subway and LRT, it is shown in Figure 7.6 that 969 links combined with transit routes and other modes of transportation (operators in Tranus) to create 4985 multimodal network of links.

```

P A S O S :   PATH SEARCH BY MODE
-----

READING PARAMETERS AND DATA
-----

TESTING FOR DUPLICATE LINKS...

Total number of links in the network:
      945              4949

PATH SEARCH BY MODE
ADY  Mod    1 (100%)  a=( 13%)
ADY  Mod    2 (100%)  a=(   5%)
PAS  Mod    2 Z 100063=(100%) h=(**%)

Run time:
      0.067 mins
NORMAL END OF

```

Figure 7.5 - PASOS Results - Without Subway and LRT.

```

P A S O S :   PATH SEARCH BY MODE
-----

READING PARAMETERS AND DATA
-----

TESTING FOR DUPLICATE LINKS...

Total number of links in the network:
      969              4985

PATH SEARCH BY MODE
ADY  Mod    1 (100%)  a=( 13%)
ADY  Mod    2 (100%)  a=(   5%)
PAS  Mod    2 Z 100063=(100%) h=(**%)

```

Figure 7.6 - PASOS Results - With Subway and LRT.

The convergence criteria reached after 150 and 70 iterations as shown in Figure 7.7 and Figure 7.8 for land-use sub models of the conditions without and with the major named project.

The results of the land-use model show the calculations and balance of supply and demand and adjustments. Exogenous sector does not have any adjustment factors as for the reasons mentioned earlier.

```

Convergence indicators
Sector    ConvPric  Zon    ConvProd  Zon    ExogProd  InducProd
1 Manu    0.00003210022  0.000000  0  9970.  0.
2 Govm    0.00003210022  0.000000  0  530.  0.
3 Retail  0.14621810034  -0.02298410014  0.  4737.
4 Office  0.00621510034  -0.010692*****  0.  14078.
5 Service -0.00005110000  -0.00003810001  0.  2966.
6 EducatnIn -0.00004810000  -0.00003910018  0.  1976.
11 HhHigh -0.00018910004  0.00049010007  0.  2044.
12 HhMed  0.00576910004  -0.00029610004  0.  2363.
13 HhLow  -0.00013910010  0.00003910010  0.  2898.
21 ComerMul -0.00087610001  0.00007910000  0.  814913.
22 FramedFl -0.00111510001  0.00047410001  0.  1270494.
23 Detch  -0.04331710014  -0.01315910034  0.  285221.
24 SemiD  -0.03938710014  -0.00899910013  0.  151380.
25 ComplexD -0.01686110014  0.03806910014  0.  294627.
26 Towns  -0.01354010014  0.02012610034  0.  86160.
31 EmpLnd  0.00072810000  0.00032610001  0.  544.
32 Mixed  -0.32359210019  0.03806910014  0.  22.
33 ResL   -0.02949710034  0.01141110025  0.  202.

Iter      150

Run time:
          0.250 mins
NORMAL END OF
L C A L

```

Figure 7.7 - Results of LCAL or Land-use Model - Without Subway and LRT.

```

Convergence indicators
Sector    ConvPric  Zon    ConvProd  Zon    ExogProd  InducProd
1 Manu    0.00039610022  0.000000  0  9970.  0.
2 Govm    0.00039610022  0.000000  0  530.  0.
3 Retail  0.03244410034  0.00967810014  0.  4737.
4 Office  -0.005004*****  -0.037648*****  0.  14076.
5 Service 0.00041210001  -0.00031110022  0.  2965.
6 EducatnIn 0.00046110018  -0.00019710018  0.  1975.
11 HhHigh 0.00291610022  -0.00541110007  0.  2044.
12 HhMed  0.00062410010  0.00056910004  0.  2363.
13 HhLow  0.00023610013  0.00034710010  0.  2897.
21 ComerMul 0.00014110000  0.00009510000  0.  816012.
22 FramedFl 0.00014410000  0.00008710000  0.  1272691.
23 Detch  -0.01186110018  0.00199910014  0.  282171.
24 SemiD  -0.01104410018  0.00132910014  0.  152415.
25 ComplexD -0.01114010018  0.00145010001  0.  291577.
26 Towns  -0.01082010018  0.00124410001  0.  85878.
31 EmpLnd  0.00089510000  0.00008910000  0.  545.
32 Mixed  -0.25494510019  0.00145010001  0.  22.
33 ResL   -0.01413210034  0.00150310014  0.  201.

Iter      70

Run time:
          0.233 mins
NORMAL END OF
L C A L

```

Figure 7.8 - Results of LCAL or Land-use Model - With Subway and LRT.

Finally, the results of TRANS for transportation sub model is as displayed in Figure 7.9 and Figure 7.10 reaching convergence after 20 iterations.

Iter	Categ	Origin	Convobj	ConvFlows	Worst	ConvSpeed	Worst
1	7	34	0.0001000	F 1.00000	(1196 1213)	V 0.07018	(1625 1505)
2	7	34	0.0001000	F 0.50642	(1318 1240)	V 0.15648	(1625 1505)
3	7	34	0.0001000	F 0.27755	(10000 2598)	V 0.16764	(1625 1505)
4	7	34	0.0001000	F 0.17218	(10000 2598)	V 0.13982	(1625 1505)
5	7	34	0.0001000	F 0.11525	(10000 2598)	V 0.09833	(1625 1505)
6	7	34	0.0001000	F 0.07846	(10000 2598)	V 0.05943	(1625 1505)
7	7	34	0.0001000	F 0.05190	(10000 2598)	V 0.03109	(1625 1505)
8	7	34	0.0001000	F 0.03276	(10000 2598)	V 0.01403	(1625 1505)
9	7	34	0.0001000	F 0.01967	(10000 2598)	V 0.00559	(10148 10149)
10	7	34	0.0001000	F 0.01126	(10000 2598)	V 0.00327	(10148 10149)
11	7	34	0.0001000	F 0.00618	(10000 2598)	V 0.00188	(10148 10149)
12	7	34	0.0001000	F 0.00347	(1016410165)	V 0.00107	(10148 10149)
13	7	34	0.0001000	F 0.00196	(1016410165)	V 0.00060	(10148 10149)
14	7	34	0.0001000	F 0.00108	(1016410165)	V 0.00033	(10148 10149)
15	7	34	0.0001000	F 0.00059	(1016410165)	V 0.00018	(10148 10149)
16	7	34	0.0001000	F 0.00032	(1016410165)	V 0.00010	(10148 10149)
17	7	34	0.0001000	F 0.00017	(1016410165)	V 0.00005	(10148 10149)
18	7	34	0.0001000	F 0.00009	(1012310124)	V 0.00003	(10151 10150)
19	7	34	0.0001000	F 0.00005	(1012310124)	V 0.00002	(10151 10150)

Run time:
0.317 mins
NORMAL END OF
T R A N S

Figure 7.9 - TRANS Analysis - Without Subway and LRT.

Iter	Categ	Origin	Convobj	ConvFlows	Worst	ConvSpeed	Worst
1	7	34	0.0001000	F 1.00000	(1196 1213)	V 0.07002	(1625 1505)
2	7	34	0.0001000	F 0.50649	(1318 1240)	V 0.15619	(1625 1505)
3	7	34	0.0001000	F 0.27766	(10000 2598)	V 0.16734	(1625 1505)
4	7	34	0.0001000	F 0.17243	(10000 2598)	V 0.13956	(1625 1505)
5	7	34	0.0001000	F 0.11556	(10000 2598)	V 0.09814	(1625 1505)
6	7	34	0.0001000	F 0.07877	(10000 2598)	V 0.05931	(1625 1505)
7	7	34	0.0001000	F 0.05216	(10000 2598)	V 0.03104	(1625 1505)
8	7	34	0.0001000	F 0.03296	(10000 2598)	V 0.01401	(1625 1505)
9	7	34	0.0001000	F 0.01981	(10000 2598)	V 0.00604	(10148 10149)
10	7	34	0.0001000	F 0.01176	(1004410070)	V 0.00358	(10148 10149)
11	7	34	0.0001000	F 0.00683	(1004410070)	V 0.00208	(10148 10149)
12	7	34	0.0001000	F 0.00385	(1004410070)	V 0.00119	(10148 10149)
13	7	34	0.0001000	F 0.00212	(1004410070)	V 0.00068	(10148 10149)
14	7	34	0.0001000	F 0.00114	(1004410070)	V 0.00038	(10148 10149)
15	7	34	0.0001000	F 0.00061	(1004410070)	V 0.00021	(10148 10149)
16	7	34	0.0001000	F 0.00032	(1004410070)	V 0.00012	(10148 10149)
17	7	34	0.0001000	F 0.00019	(1012310124)	V 0.00006	(10148 10149)
18	7	34	0.0001000	F 0.00011	(1012310124)	V 0.00004	(10151 10150)
19	7	34	0.0001000	F 0.00006	(1012310124)	V 0.00002	(10151 10150)
20	7	34	0.0001000	F 0.00003	(1012310124)	V 0.00001	(10151 10150)

Run time:
0.333 mins
NORMAL END OF
T R A N S

Figure 7.10 - TRANS Analysis - With Subway and LRT.

8. Comparisons

After completion of calibration and performing the analysis, comparisons must be done between the two established scenarios. It was seen that, software calculated fewer floor spaces in general after implementation of transit projects, which shows moving towards the intensifications. Furthermore, analysis shows that demand for semi-detached units increased in the zone 10001 (38202013) by almost 1414 sqm in total, which was demanded by all households and the office employment. This is interesting as software calculated that being close to employment and institution provides a good condition for future settlements, and this specific type was chosen based on the availability, preferences, attractiveness and prices defined over the rest. Moreover, comparisons show that there is a slight demand increase towards semi-detached units in zones 10034 (35202026) by households having medium and high incomes. Please see the Figure 8.1 for comparisons.

Figure 8.1 - Differences in Semi-Detached Floor Space and Zones Demand versus Map TOD guided Service Area.

In addition, complex or high-rise buildings show an inflation of total 1346 sqm in zone 10022 (35204014) demanded by again all households and office section. A slight increase was seen for this type on zone 10019 (35202007) by all households, but it is rather small and shows that preference will be towards this area in the future. Results are displayed in Figure 8.2. Not to mention that, since no addition of households or

employment was considered results derived from the relocation of households in these areas and lowered down costs of transition and disutility.

Figure 8.2 - Differences in Demand for Complex or High-rise Floor Space and Map.

Other than mentioned above, manufacturing or industrial shows increase in consumption or demand for floor spaces of commercial multi-story and framed warehouse types in the zones 10000 (35202098) and 10001 (35202013) as can be seen in Figure 8.3. Interestingly again, a multi-story commercial building at 34 Tangiers Road is under construction, which accommodates one floor to retail and the rest to offices as per Keele-Finch Plus studies, which will balance the consumptions. So, for zone 10001(35202013), it is predicted that there will be a tendency towards building multi-story mixed use complexes.

Figure 8.3 - Demand Differences for Commercial Multi-story Buildings and Flat Warehouse Units and Map.

In addition, based on these mentioned analysis and also environmental assessments, it is predicted that in order to have safe developments in these areas, hazardous industrial areas needs to be relocated as well.

9. Conclusions and Suggestions

Influence of transit improvement projects on land-use and development patterns was on debate among researchers. Urban developers and policy makers need to consider such potentials for land-use changes and prioritize development permits. Rather than approaching this only with qualitative guidelines, it is possible to measure the demand changes via a quantitative and rational method of LUTI.

The results of two scenarios, one with and the other one without having the subway and LRT implemented investigated. Capacities reaching the limits caused land prices in land-use model and waiting times in transit model to increase. Former, affects the location of activities and the lands relative attractiveness and latter, changes the preferences in path choice and case's disutility. While, relocating towards areas with the best value added as per access to transit and employment, less land (and floor space) would be available for population to settle, then households tend to occupy in denser areas or dense floor spaces. In other words, considering disutility of trips and path changes, tendency moves toward living closer to areas with better transit access.

The performed analysis, as cited, proved that access to transit not only plays a big roll in new locations of future developments, but also, while integrating all the facts about the system of land-use and transportation, it can show grounds for development and demands in zones even a bit further than just walking-shed service areas. Majorly, this was the case for households having higher levels of income. Furthermore, LUTI investigates changes in employment patterns, which are to be considered in future growth and would not be possible to overlook otherwise in a reasonable manner.

Implementation of integrated land-use and transportation model is not an easy task as it requires so many details to be considered and calculations be in need of iteration times and adjustments. In this study, many assumptions needed to be made that could have been estimated more accurately if a team of different disciplines had worked on it in a larger time frame. However, in accordance with the availability of time and data, this report shows the results are promising. Tranus was seen as capable of performing analysis in micro-scale, or in here DA level.

General system of integration as was seen, included recognition of differences between types of activities, their relationship with each other; floor spaces; land prices while also considering preferences towards specified travel means and dwelling types as per reality. In an iterative approach, software balanced the demand and supply (production) of all the factors involved; provided boundaries of possible outcomes, which can be estimated and converged to.

There are always grounds for improvements and best approach dealing with such phenomena is to calibrate more consequential future scenarios in order to apply land price changes, policies, immigration, growth or decrease in activities, etc. and observe the predictions. Unfortunately, in this study's timelines, due to the increased complexity while reaching towards the equilibrium point(s) of all data, this was impossible to be accomplished. Such tasks of adjusting all the involved data in the step-by-step iterative process require plenty of time to oversee the multi-disciplinary parameters and close attention to details.

Another thing that was a concern is that, real inventory of the houses (dwellings in general) in detail and in accordance with total land and floor areas; moreover, information about other forms of floor spaces consumed by employment was not available, hence, better results would have been achieved having them all presented in the beginning to make the process and comparisons easier.

In addition, it is suggested that institutions, government and local municipalities that collect information about socio-economical characteristics, use same geographic data boundaries, while considering a standardized approach at micro levels to make it possible to establish such models easier and more reliable in results.

Furthermore, to have more realistic results on streets and route's volume-capacities a wider area could have been considered as it provides more choices of transportation and travel path between each origin-destination pair. It was seen, as well, in the transportation model that the volume of users using the subway to travel between regions (having small distances from each other) was low versus LRT users. In other words, LRT proved to be more influential in short-term and on local areas, although the results were not investigated in longer periods.

Last but not least, as it was proven its validity at DA level, consequently, if the information about individual units and properties is available, it is possible to implement such a model on even smaller scales to investigate development potentials for a single property or piece of land use.

Appendix.

A. 1 - Service Areas of Stations in the Study Area.

A. 2 - Land Use Map

A. 3 - Building Footprints, Land Use, Property Boundaries & 2011 DAs.

A. 4 - Internal and External DA Zones based on Statistics Canada 2011.

Annual Wage Zone 35202207	Number of Households
Under \$5,000	0
\$5,000 to \$9,999	5
\$10,000 to \$14,999	5
\$15,000 to \$19,999	5
\$20,000 to \$24,999	10
\$25,000 to \$29,999	5
\$30,000 to \$34,999	5
\$35,000 to \$39,999	10
\$40,000 to \$44,999	5
\$45,000 to \$49,999	10
\$50,000 to \$59,999	15
\$60,000 to \$69,999	15
\$70,000 to \$79,999	15
\$80,000 to \$89,999	20
\$90,000 to \$99,999	15
\$100,000 and over	45
\$100,000 to \$124,999	
\$125,000 to \$149,999	
\$150,000 to \$199,999	
\$200,000 and over	

A. 5 - Annual wage of residents in the DA zone 35202007, fitted for 2011 from 2016 data.

Sectors/Demand	Manufacturing	Government	Retail	Office	HealthService	EducationInstitu	HH High	HH Med	HH Low	Calculated Demand	Difference
1 Manu											
2 Govm											
3 Retail							0.751080880	0.655052000	0.571050000	4738.00009	0.00009
4 Office							2.312500000	2.055930730	1.551118380	14080.05538	0.05538
5 HealthService							0.406023272	0.406023272	0.406023272	2966.00000	0.00000
6 EducatnInstitu							0.270500000	0.270500000	0.270500000	1976.00250	0.00250
11 HH High	0.024546000	0.024546000	0.024546000	0.024546000	0.024546000	0.024546000				2044.00483	0.00483
12 HH Med	0.060728000	0.060728000	0.060728000	0.060728000	0.060728000	0.060728000				2362.99644	0.00356
12 HH Low	0.076915000	0.076915000	0.076915000	0.076915000	0.076915000	0.076915000				2897.93733	0.06268
Internal Zones Raw Production	9970	530	4738	13675	2966	1976	2044	2363	2898		
Import				405							
Total Production + Import				14080							
Export							1213	307.05	293.98		
Total Production + Export							3257	2670.05	3191.98		
Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10		
	Sector 1 - Manu	Sector 2 - Gov	Sector 3 - Retail	Sector 4 - Office	Sector 5 - Service	Sector 6 - EducatnInstitu	Sector 11 - HhHigh	Sector 12 - HhMed	Sector 13 - HhLow		
Zones											
35202098	9050	530	4710	13600	2870	1600	0	0	0		
35202013	920			22	22	250	263	168	292		
35202016							47	142	161		
35202017							192	490	742		
35202028							40	35	25		
35204106							147	133	325		
35202024							131	92	58		
35202001					48		122	175	398		
35202002			9				91	64	80		
35202003							97	153	144		
35202004				27			110	66	40		
35202005							48	70	48		
35202006			9			63	51	40	30		
35202007			10				80	60	45		
35204014				26	26		371	479	312		
35202097						63	26	58	73		
35202000							92	51	51		
35202027							57	33	29		
35202026							79	54	45		
Totals	9970	530	4738	13675	2966	1976	2044	2363	2898		

A. 6 - Inter-sectors Coefficients (Left) and Production Amounts Considered in each Sector (Right).

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