Part 5: Developing a Rural Public Transportation Network

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Executive Summary

The following report discusses an original model and three step framework to develop a public transit system in any rural community equipped with a Geographic Information System (GIS). The report also analyzes and discusses potential rural transit routes for Prince Edward County (PEC) using the aforementioned model and framework. The model and framework used in this report will clearly show how Prince Edward County and other rural communities can optimize their future public transit systems.

Prince Edward County is a municipality in Southern Ontario and is located between Kingston and Toronto, Ontario. Some of the larger communities within the municipality include Picton, Wellington, and Bloomfield. The combined population of the municipality is approximately 25,000, with a population density of 24.3/km^2, and an area of 1,000 km^2. One of the main attractions for PEC is Sandbanks Provincial Park in Picton, which attracts thousands of tourists during its summer months. PEC has shown interest in further developing its public transit service in order to serve its aging and growing population, as well as its many tourists.

The Monieson Centre at Queen's School of Business was appointed in 2011 by the Economic Development Council of Ontario (EDCO) to develop a framework that will help PEC and other rural communities create rural public transit systems. The findings of the report will help economic developers and municipal leders foster economic development. Increased public transportation can help citizens access essential destinations such as hospitals, grocery stores, and pharmacies. It can also increase economic activity through local tourism and access to community retail outlets.

This report involves extensive research of existing practices and theories for urban and rural public transit development. Best practices, as well as models from top-tier journals, were used to develop a comprehensive model and framework to generate rural public transportation routes. The technical model and framework was then validated and applied to PEC to determine optimal public transit routes with the use of its GIS and Google Earth. This same model and framework may be applied to any rural community with active roadways and a community GIS.

This study is designed to provide a practical guide for rural community developers. Some of the technical components in this report are complex, however, the framework is clearly outlined with flowcharts and detailed steps that make analysis quite manageable. This report should be used by rural community leaders as a starting point when deciding which type of public transit to pursue, and how to generate potential routes for a new transit system. More importantly, this report will provide a very useful tool that will allow rural communities to prepare for future growth and foster economic development.

Introduction[8]

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[8] This section and the "Rural Public Transportation" section below have been adapted from Majkut (2011) available at www.economicrevitalization.ca.

Implementing effective rural transportation systems can increase accessibility to essential services, make personal travel easier, and increase the quality of life for citizens in rural communities. Rural transportation systems can lead to lower commuting costs for residents, thereby increasing intercity travel and fostering development of local and regional businesses. Rural community leaders must identify pressing issues of rural transportation systems before strategic plans are developed. Best practices and case studies may be used as a guideline for future transportation systems, while recognizing the need for local, provincial, federal, and stakeholder support. Policy leaders must recognize the need for rural transportation systems to better plan for the future (Majkut, 2011).

There are currently no comprehensive decision support tools available for rural community leaders who are interested in developing a rural transit system. This paper introduces a three step decision-making process for generating transportation routes for a rural transit system, provides detailed instructions for implementing a unique model, and validates this model through a case study done for a rural community. The model is based on access to a community's Geographic Information System, and uses information gathered from the system to create rural transportation routes.

The framework included in this paper shows rural community leaders with access to a GIS how to develop potential rural transit routes, compare existing and potential routes, and choose the optimal route for implementation. Step-by-step instructions are provided to guide community leaders in the planning, data gathering, model development, and route generation and testing phases. This paper offers a general framework for any rural community to develop and evaluate new and existing rural transportation networks.

There are very few rural accessibility and evaluation models available to rural community leaders. The most commonly used forms of spatial interaction methods are not customized for rural areas and are limited by the number of variables included in the model. Some rural transportation models have been developed, such as the Rural Public Transit Accessibility (RPTA) Model (Sanchez, 2002), but either lack the ability to properly scale variables in the model or have a subjective scaling method that compromises the accuracy of the model. This paper offers a GIS-based model that is customized for rural areas, uses an objective scaling method, and is applicable to any rural community.

Vehicle Routing and Scheduling (VRS) problems have been studied extensively for many years, including famous routing methods such as the "Sweep" method (Gillet and Miller, 1974) and the "Savings" method (Clarke and Wright, 1964). VRS methods are included in this paper, but only represent a small part of the overall framework. VRS methods focus on visiting a certain number of nodes in a network, while adhering to defined constraints such as capacity, time, distance, and vehicles available. These methods assume that the user already has transportation nodes in place, which will probably not be the case for upcoming rural communities. In addition, rural communities will often lack the data required to solve a transportation route using an advanced VRS method. This paper provides a detailed process to guide rural community leaders when developing nodes for a rural transit network, and VRS methods and iterative techniques are used to solve for optimal transportation routes.

Purpose

The purpose of this report was to develop a GIS-based framework to help rural community leaders generate optimal transportation networks with standardized routes and schedules. The framework will

serve as a general tool that may be applied to any rural area, as long as relevant data and technology are available.

Rural Public Transportation

According to Transport Canada (2009), senior citizens use public transportation more than any other age group in Canada. By the year 2031, approximately 25% of Canada's population will be 65 or older. In addition to this, many young Canadians aged 20 to 44 are moving to large urban centres, which is increasing the proportion of senior citizens in rural communities. This section will discuss some of the challenges, issues, impacts, best practices, and policies for rural public transportation in Canada.

Challenges

Two of the greatest challenges in rural mobility for Eastern Ontario and Western Quebec are residents' access to healthcare, and the fact that many elderly citizens are unable to drive (Kostiuk, 2009). Rural public transportation can also be important for disabled Canadians and low income families.

Healthcare is an essential service, so it is important that citizens in rural communities have access to sustainable transportation. Personal automobiles are used in many rural communities, obviating the need for public transportation; however, an increasing proportion of senior citizens in rural communities in the near future could create the need for sustainable public transportation. Many senior citizens become unable to drive as they get older. This makes tasks such as grocery shopping, regular pharmacy visits, doctor appointments, dentist appointments, and visiting friends and family increasingly difficult. Different forms of public transportation can provide simple solutions to these types of problems; however, rural public transportation can be quite expensive (Majkut, 2011).

Kings Transit Authority in Nova Scotia uses buses to transport rural citizens back and forth in five different rural communities: Wolfville, Kentville, Berwick, Kings County, and Brooklyn. These communities are challenged by the number of elderly people in need of transportation yet unable to drive. Public transportation to these communities makes personal travel much easier and increases the viability of small business in these communities. Challenges to the public transportation system include: a lack of sidewalks in rural Nova Scotia, large amounts of snow in the winter, higher fares than urban transportation, higher speed limits on rural roads, and inconvenience for residents using wheelchairs where long walks to bus stops are necessary. Another drawback to implementing this type of system is the community attitude towards change. Rural residents are not likely to change transportation modes immediately, so typically a three-year investment is needed to effectively implement the program (Majkut, 2011).

Policies and Government relations are yet another challenge faced by rural transportation initiatives. The process itself is very complex and includes a number of steps. The Municipal Government must first request funding for a rural transportation project. The amount of "red tape" will increase with the size of the municipality, so it is often more difficult for larger municipalities with more formal government structures to proceed, since more stakeholders and bureaucracy are required (Transport Canada, 2009). Next, approval is requested from the regional government, which is once again an extensive process. The US supports rural transportation at a federal level, while in Canada it is mostly a provincial mandate (Kostiuk, 2009). The Canadian Urban Transit Association (CUTA) is actively pursuing federal funding for

public transportation initiatives, and Infrastructure Canada's Public Transportation Fund has supported several rural communities in British Columbia and Nova Scotia. In cases where rural communities have one major employer, municipalities can partner with employers to create special transportation programs. Rabbit Transit in York, Pennsylvania uses this approach with the regional hospital (Transport Canada, 2009).

Financial barriers exist for rural transportation models, since it can be difficult to justify a transportation system that carries a small number of passengers over a large distance (Region of Durham Planning and Works Departments, 2004). The Durham Transportation Master Plan 2003 showed that rural communities in the Region of Durham were better off using demand-responsive transit services. These include public paratransit, van pools, school buses, and taxis. This is not surprising due to Canada's low population density, especially in rural areas, and the high operational costs of a full-service bus line (Majkut, 2011).

Economic Impacts

There are many economic impacts of public transit in rural areas. These impacts can be narrowed down to five major areas, including employment and business activity, increased mobility, cost impacts for users of the system, expenditure patterns, and growth impacts on local economies. Tools can be used to measure these impacts after a system has been implemented.

- **Employment and Business Activity**
  Most Canadians rely on employment as their primary source of income. Inability to travel to work in rural areas can create obstacles for rural community employees. Public transit systems can lead to increased employment and local business activity (Litman, 2011). Business activity can easily be monitored through revenues from non-local customers, and increases in employment can be measured in terms of salary or employment per capita.

- **Increased Mobility**
  Ability to access education and training programs can drastically increase citizens' long-term employment prospects (Transportation Research Board, 1998). Increased mobility can also help rural residents continue living independently, with access to essential services such as healthcare, post offices, and grocery stores. Mobility can be monitored by the number and frequency of riders in the rural community.

- **Transportation Cost Impacts for Users of the System**
  Rural transportation is typically much less expensive per traveller, when compared with other modes of transportation such as taxi service or friends with vehicles (Transportation Research Board, 1998). Cost savings of public transportation can be measured and compared to the baseline, and proven reductions in costs can lead to healthier budgets and improved services.

- **Impacts on Expenditure Patterns**
  Travelling to larger urban centres or rural communities via public transit can decrease the cost of travel. However, the net economic cost (for the local economy) may remain the same if the

local resident purchases lower priced products from a non-local merchant (Transportation Research Board, 1998).

- **Growth Impacts on Local Economy**
  Property in rural areas is generally less expensive, so operating costs like parking are generally lower than in urban areas. Traffic congestion and accidents are also less likely. Public transit can offer tourists and visitors an affordable way to visit rural communities and, as mentioned, support small and medium-sized businesses. Rural property value also has the potential to increase with sustainable rural public transit systems in place (Litman, 2011).

These five economic impact areas may be included in an Economic Impact Analysis (EIA) when introducing a new rural public transit system. An EIA may be developed to examine the effects of a potential or existing transit system on a rural community (See Appendix B for detailed steps). This may be useful for general community knowledge, advocacy for funding, or testing the feasibility of a project (Majkut, 2011).

Ontario's Vision

Canada's population is expected to rise from 33 million to over 40 million by the year 2040 (CUTA). This has sparked major national interest in public transportation initiatives. Specifically, the Vision 2040 initiative by CUTA aims to maximize the contribution of public transportation to quality of life, develop and support an efficient economy, and maintain a healthy natural environment. This will be accomplished by increasing service options, centralizing transit within communities, developing a national transit policy, ensuring financial funding is available, and maintaining a focus on customers (Majkut, 2011).

Currently in the US, all transportation systems are subsidized, including bus, train, air, and road. This is not the case for Canada, because not all are considered *vital community services* (Kostiuk, 2009). The goal for Eastern Ontario and Western Quebec has been identified as connecting local public transportation to other local transportation centres. This can be done through regional and intercity bus or rail, with a network of rural and urban transit operators (Majkut, 2011).

Types of Rural Public Transportation

Public transit using buses is present in 46 of Canada's 49 urban centres with populations of more than 30,000 (Transport Canada, 2009). Rural communities can also use this transportation model; however, operating costs are generally too high for sparsely populated communities. One successful case is Ottawa's rural routes initiative, which offers service to 13 small communities during peak hours. The additional routes were contracted through Ottawa's OC Transpo to serve a combined rural population of approximately 84,500. Rural passes cost 64% more than regular adult passes (Transport Canada, 2009). Another successful example is Deseronto Transit, which uses small buses to connect rural communities with small urban centres including Belleville and Napanee (see Appendix A) (Majkut, 2011).

Charter programs are effective for rural communities with smaller populations. Chartering buses and vans for daily routes can provide residents an alternate mode of transportation at a reduced cost. This type of service can also be contracted with large employers in rural areas. Ride sharing and car sharing

are two other popular alternatives. Ride sharing consists of carpooling with compatible matches found through websites such as Carpool.ca and eRideshare.com. Car sharing involves joining a co-op where many users have the opportunity to pay for shared vehicle use (Majkut, 2011).

Other approaches to public transportation include:

- Active transportation: This method of transportation promotes a healthy lifestyle by promoting cycling, walking and inline skating, and is useful for small communities.
- Vanpooling, Ride-On programs, and guaranteed ride services: Transportation Management Associations in the US provide such services through partial Federal Government funding (Transport Canada, 2009).
- Telework programs: Some companies establish remote offices to accommodate rural citizens, reducing the need for public transportation by allowing residents to work from home.
- Transit-Oriented Development (TOD): Community planning organizes new housing and essential services around a public transportation hub, in order to increase ridership and commutability (Majkut, 2011).

Evaluation Processes and Decision Making Tools

Transportation evaluation models are available to generate analyses for potential projects. They typically include government costs, vehicle operating costs, average travel speed, crash risk per kilometre, project construction, and environmental impacts (Litman, 2011). Those unfamiliar with these types of models may overlook many areas, including, but not limited to, parking, vehicle depreciation, project delays due to construction, land use impacts, and public health (Majkut, 2011).

Developing an *economic evaluation* is a best practice for evaluating a potential project. This includes quantifying the project and comparing different options for various sections of the project. Some of the major foci of the economic evaluation include defining the type of evaluation, evaluation criteria, modeling techniques, base case, and uncertainty (Litman, 2011). The second important evaluation is that of transit service quality. This separate evaluation defines themes such as availability, price structure, security, frequency, and reliability (Litman, 2011).   Finally, all stakeholders should be involved with developing plans and making decisions (Kidder, 2006). The range of stakeholders in rural communities is usually broad, since there is no transportation authority in place (Transport Canada, 2009). Other than the local municipal government, stakeholders may include schools, hospitals, transportation companies, employers, and churches, among others (Majkut, 2011).

Literature Review

Transportation / Land Use Models (TLUMs) have been developed to understand the behaviour of urban areas, transportation patterns, environmental impacts, and regional planning (Rodrigue et al, 2009). The Gravity Model and the first ever TLUM, the Lowry Model (Lowry, 1964), will be briefly discussed in this section. Transportation models specific to rural transportation such as the Transportation Land Use Model for Rural Areas (Kau, 1977) and more recently the Rural Public Transportation Accessibility Model (Sanchez, 2002) will also be discussed. The RPTA Model makes use of Geographic Information Systems, while the Lowry Model does not. The Integrated Rural Accessibility Planning (IRAP) model (International Labour Organisation) will show some further scaling and weighting techniques for rural accessibility

models. Finally, Multi-Objective Utility Analysis (de Neufville, 1990) and some Vehicle Routing and Scheduling problems (Ballou and Agarwal, 1988) will show methods which can be applied to the development of new rural transit systems.

Brief Overview of GIS

GIS systems are an integration of hardware, software, and data in order to analyze and display information that is geographically referenced. These systems are useful for quickly viewing employment areas, school locations, healthcare facilities, population densities, and areas with low-income families. These inputs can help determine optimal paths for new transportation networks. The amount of available information and the type of GIS software that a rural community is using will determine the amount of effort needed when gathering data from the GIS.

Land Use Models

Land Use Models can be used to determine spatial interactions between different points in any land-based region. This may be based on roads, land conditions, populations, and other attributes. Strong spatial interactions between points may suggest the need for transit routes between those points.

Spatial Interaction / Gravity Model

The Gravity Model is the most well-known form of the spatial interaction method. In this case, spatial interaction refers to the amount of people that travel from place to place based on supply and demand. The Gravity Model follows the same premise as Newton's Second Law of Gravitation. The Gravity Model states that the "attraction between two objects is proportional to their mass and inversely proportional to their respective distance" (Rodrigue et al, 2009). The basic form of the equation is shown below:

$$T_{ij} = k \frac{P_i P_j}{d_{ij}}$$

Where P_i and P_j measure the importance of the location of origin i and destination j (i.e., population), d_{ij} is the distance between the origin and destination, and k is a proportionality constant. The proportionality constant is higher for longer periods of time considered, and lower for smaller periods of time (e.g., one year versus one week). T_{ij} is the spatial interaction between locations i and j. An optimal transportation network can be created by maximizing a combination of spatial interactions that connect all the required nodes. Extensions of this model, such as transport friction, may be added simply by squaring d_{ij} to account for lower efficiency as distance increases.

One of the significant drawbacks to this method is calibration of the model. Parameters must be set in such a way to realistically mimic spatial interactions of the analyzed area. Another downfall is that this is a static model, meaning that it measures the system at a set point in time. However, this may not be an issue in rural transportation planning since traffic congestion will most likely be minimal.

Lowry Model

Based on the Gravity Model, the Lowry Model includes employment, population, and transportation all in one model. It focuses on three sectors: basic, which are businesses that export their products, retail, which are non-exporting businesses, and the household sector, which is the population and location of basic and retail employees. The Lowry Model splits a geographic area into different zones and determines total employment and population for each zone through an iterative process. This information can then be used to determine locations with the highest amount of spatial interaction to generate an optimal transportation network.

Rural Transportation Models

Rural Transportation Models have been developed specifically for rural areas, whereas the Land Use Models above can be generically applied to any area. Rural Transportation Models account for attributes, such as further travel distances, that urban models would not consider.

A Transportation Land Use Model for Rural Areas

The Transportation Land Use Model for Rural Areas (TLUMRA) analyzes the interaction of land use and transportation in rural areas. Specifically, it measures the impact of transportation costs on population density, employment density, household density, mean income, and percentage of single families. Transportation costs are measured by accessibility as shown below:

$$ACC_j = \sum_{i=1}^{n} \frac{P_i}{T_{ij}}$$

Where j is the community for which accessibility is being calculated, i = 1…n represents all other communities being analyzed, P_i is the population for community i, T_{ij} is the travel time between community i and j, and n is the total number of communities in the study. This model assigns accessibility (ACC) as an independent (exogenous) variable, along with other independent variables specifically related to the population of community j. These include but are not limited to population growth, retail sales, total sales, and the ratio of owners to renters. This regression model uses two stage least squares (2SLS) to isolate the impact of changing transportation costs (ACC) on the dependent (endogenous) variables mentioned above: population density, employment density, household density, mean income, and percentage of single families. For example, regressing ACC and the other independent variables against the dependent variable population density will result in a sensitivity measure for ACC. The result may conclude that a 1% increase in ACC is related to a 2% increase in population for community j. The model can then be used to forecast population density, and other dependent variables, as a result of increasing or decreasing accessibility.

This model could provide a good method for finding a starting point for a rural community's transportation system. It has the ability to rank communities based on positive effects from increased accessibility, which could help plan a phased approach to implementing rural transit in various communities within the region of study. However, this model requires significant amounts of data and

may be difficult to gather for many small communities. The calculations and analysis can also be tedious and time consuming, so the cost-benefit for such a task may be inefficient.

Rural Transportation Accessibility Model

The RPTA Model uses a gravity-type accessibility method to calculate scores for different segments of a geographic location.   Scores for different segments can be aligned with different transportation networks and compared to find an optimal network with the highest score. There are five major steps for this method. The first step is to define the area to be served by the transportation system. Step two is to determine and map all origins and destinations for the targeted population. The third step is to overlay a grid system onto the mapped area. This can be done using a GIS. Step four is to generate accessibility scores using the following formula (Sanchez, 2002, p. 58):

$$A_i = \sum_{j=1}^{n} \frac{(T_i \cdot T_j) \cdot ((W_j \cdot 0.107) + (S_j \cdot 0.028))}{D_{ij}^2}$$

where:

A_i = the accessibility of grid cell i

T_j = transit service in grid cell j (binary)

S_j = number of schools in grid cell j

T_i = transit service in grid cell i (binary)

W_j = number of jobs located in grid cell j

D_{ij} = euclidean distance from grid cell i to grid cell j

The model can be further expanded to include other variables in the numerator such as low income families, healthcare providers, and grocery stores. In addition, each of these variables is weighted in terms of relative importance to citizens' accessibility. The denominator's exponent can also be changed to reflect the friction of increased distance. The final step in the model is to evaluate different transportation networks and choose the model with the highest score. This method can be used to increase existing transportation systems or to create new transportation networks.

One of the issues with this model is scaling. There is no defined method to scale different variables in the above equation. For example, adding the number of schools to the number of jobs does not make sense, since they are not quantified with the same unit of measure. A standardized method for scaling should be used for this model to transform variables into comparable quantities. The following two sections discuss the IRAP model and Multi-Objective Utility Analysis, which offer some insight to the scaling issue.

IRAP Model

The IRAP model was initially developed by the International Labour Organisation (ILO) in African and Asian countries in the 1980s (International Forum for Rural Transport and Development, 2009). "IRAP has been suggested as a tool for rural road network planning in the development plan of 2025 by Government of India." (Sarkar, 2008, p. 12) The objective of the model was to allow underfunded rural areas to develop the most efficient transportation networks possible. While the model has many variations in different countries, it is comprised of three major steps:

1. Data Collection – Collecting information related to household proximity to essential services and population densities, and determining the feasible network area and perimeter.
2. Data Analysis and Prioritization – The first part of this step is to generate Accessibility Indicators (AIs) for each rural town in the transportation network. AIs measure the level of access for particular towns or groups in relation to essential services within the network area. The most basic form of the equation sets AI equal to the product of the number of households requiring access and the average travel time to get to the point of interest. The second part of this step is to locate areas with high AIs on a map. Transportation routes can then be visualized and prioritized.
3. Project Identification and Preparation – Decisions are made as to whether transportation routes and roads should be developed, or if new sites for essential services should be built closer to communities.

The IRAP model offers a scaling method, where the RPTA model does not, however, its scaling method is subjective in nature. This could lead to less meaningful scores for AIs, since they will be based on qualitative opinions of community developers. The following section describes a method that avoids the issue of subjectivity.

Conjoint Analysis

Conjoint analysis (Lilien and Rangaswamy, 2004) is a statistical technique commonly used for market research. The main objective is to determine the importance, or utility, of different options for several factors considered in a decision. For example, three factors considered for rural accessibility could include the number of hospitals, schools, and grocery stores in a given area. For each of these three factors, there are a finite number of options. The number of hospitals in a given area may be zero or one (two options), while the number of grocery stores may range from zero to five (six options). Conjoint analysis consists of generating different combinations of factors and options and having a respondent assign a unique score to each combination. Mathematical techniques are then used to estimate specific utility values (part-worths) for each option, based on overall respondent preference. The total number of part-worths to be estimated is equal to $\left\{ \sum_{i=1}^{N} (n_i - 1) \right\} - 1$, where N is the total number of factors and n_i is the number of options for factor i. For each factor, the lowest option can be set to zero. The maximum score for each combination can be restricted to 100.

If there are a large number of combinations to be ranked by the respondent, dummy variable regression can be used to calculate part-worths. When using regression to estimate part-worths, the number of combinations (data samples) ranked by the respondent will depend on the number of parameters (part-worths), desired probability level, desired statistical power level, and the anticipated effect size. This number will most likely be around 100, which means the respondent would have to rank 100 different combinations. This process can be tedious and tiresome, so another method such as linear programming may be used to solve for unknown part-worths when a smaller number of combinations are ranked by the respondent. Lilien and Rangaswamy, 2004, suggest that the number of combinations in the evaluation should be twice as many as the number of part-worths to be estimated, and should not exceed 25 in order to minimize respondent fatigue.

Vehicle Routing and Scheduling

Most of the methods and models mentioned above can help evaluate existing rural public transportation systems. However, if there is no public transit system in place, best practices must be used to develop an optimal system. VRS problems consist of visiting a certain number of nodes in a transportation network, while adhering to constraints such as time, capacity, safety, and number of vehicles available. Gillett and Miller (1974) developed the original Sweep heuristic in which routes are systematically constructed using a proximity rule. Individual routes are then optimized to minimize distance travelled. Initial routes are constructed by extending a straight line from a depot location in any direction and rotating the line until it intersects a stop. Using the vehicle with the largest capacity first, vehicles are filled with capacity until a full rotation of the line is complete or until vehicle capacity is exceeded. This method is ideal for most rural communities, since it is not very complex and may be accomplished without integration of GIS and other analytical software.

The "Savings" method (Clarke and Wright, 1962) is an alternative solution to the VRS problem and generally has better results than the Sweep method. However, the "Savings" method is extremely complex and difficult to solve, especially if road distances between transportation nodes are not integrated with the rural transportation model. For example, if software such as Microsoft Excel is used in collaboration with a community's GIS to analyze a rural transportation model, the "Savings" method will be nearly impossible to implement unless the GIS is integrated with Microsoft Excel. Other VRS alternatives such as the Insertion method (Jaw et. al, 1986) are subject to this limitation.

Methodology

This section is split into two parts – model formulation and the three stage decision-making process. The first section explains how the model was developed and the second section provides a three-step process that allows use of the model with any rural public transit candidate.

Model Formulation

The following model is applicable to any rural area, and may be customized to fit the specifications of different rural areas. The model's purpose is to generate accessibility scores for equally sized grid cells in a rural area. The rural area under consideration is split into equally sized grid cells which represent reasonable walking distances to potential bus stops. Grid cells in this report are measured 400m by 400m, since this is considered a reasonable walking distance for rural residents (Lam and Morrall, 1982). Grid cells with higher scores are better candidates for the public transit system and will lead to the identification of potential rural public transit routes.

Notation

Let the Rural Accessibility Score (RAS) of grid cell *i* be denoted by RAS_i such that:

$$RAS_i = \left[\sum_{n=1}^{N} \sum_{m=1}^{M_n} A_{n_{m_i}} w_{n_m} \right] \cdot Pop_i \qquad (1)$$

Where:

$N = Total\ number\ of\ factors\ that\ determine\ importance\ of\ accessibility, where\ N \in \mathbb{N}$

$n = Selected\ factor\ contributing\ to\ importance\ of\ accessibility, where\ n = 1,2,…,N$

$M_n = Total\ number\ of\ options\ for\ factor\ n, where\ M_n \in \mathbb{N}$

$m = Selected\ option\ for\ factor\ n, where\ m = 1,2,…,M_n$

*Options are listed from least appealing to most appealing, where option M_n is the most appealing option for factor n.

$A_{n_{m_i}} = Binary\ variable\ equal\ to\ 1\ if\ option\ m\ is\ selected\ for\ factor\ n\ in\ grid\ cell\ i, where:$

$$\sum_{m=1}^{M_n} A_{n_{m_i}} = 1$$

$w_{n_m} = Relative\ weight\ of\ factor\ n\ when\ option\ m\ is\ chosen, where\ \sum_{n=1}^{N} w_{n_{M_n}} = 100\ , and:$

(the above constraint is not necessary if the objective function is an equality)

$w_{n_m}\ is\ non-negative, \forall\ n,m$

$Pop_i = Population\ in\ grid\ cell\ i$

Figure 1:

$i = 23, N = 2, M_1 = 2, M_2 = 3, Pop_{23} = 25$

$A_{1_{1_{23}}} = 1, A_{1_{2_{23}}} = 0, A_{2_{1_{23}}} = 0, A_{2_{2_{23}}} = 1, A_{2_{3_{23}}} = 0$

$w_{1_1} = 5, w_{1_2} = 60, w_{2_1} = 5, w_{2_2} = 25, w_{2_3} = 40$

$$RAS_i = \left[\sum_{n=1}^{N} \sum_{m=1}^{M_n} A_{n_{m_i}} w_{n_m} \right] \cdot Pop_i$$

$$RAS_{23} = \left[\left(A_{1_{1_{23}}} w_{1_1} \right) + \left(A_{1_{2_{23}}} \cdot w_{1_2} \right) + \left(A_{2_{1_{23}}} w_{2_1} \right) + \left(A_{2_{2_{23}}} w_{2_2} \right) + \left(A_{2_{3_{23}}} \cdot w_{2_3} \right) \right] \cdot Pop_{23}$$

$$= [(1 \cdot 5) + (0 \cdot 60) + (0 \cdot 5) + (1 \cdot 25) + (0 \cdot 40)] \cdot 25 = 25 \cdot 25 = 625$$

Where: $Factor\ 1 = Hospitals$ and $Factor\ 2 = Schools$

In this case, there were two options for the number of hospitals ($M_1 = 2$) and three options for the number of schools ($M_2 = 3$); these options are defined by the user. For example, the discrete values for option one and two for hospitals could be 0 and 1, respectively. The discrete values for options one, two, and three for schools could be 0, 1, and 2 schools in the respective grid cell.

Calculation of Weights

Figure 2 – Calculation of Weights
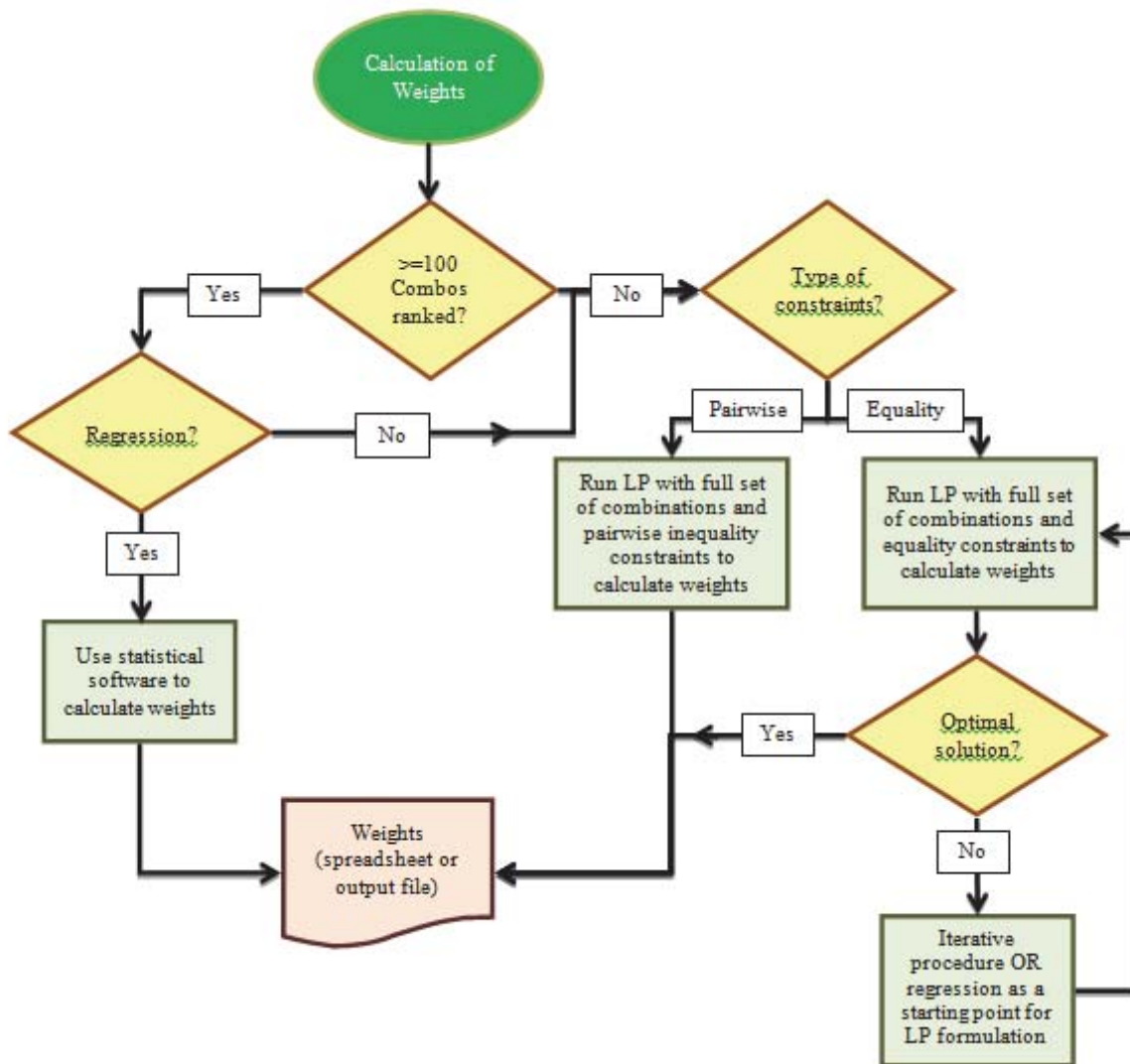
The process for calculation of weights can be seen above in Figure 2. Dummy variable regression may be used to calculate weights (w_{n_m}) if there are around 100 combinations of factors and options ranked by the respondent. The following formula can be used to find weights using regression:

$$S_j = \sum_{n=1}^{N} \sum_{m=1}^{M_n} A_{n_{m_j}} w_{n_m} + \varepsilon_j$$

Where:

$j = A\ particular\ combination\ of\ selected\ factors\ and\ options$

$S_j = Score\ provided\ by\ respondent\ for\ combination\ j$

$\varepsilon_j = Error\ terms, with\ normal\ distribution, zero\ mean, and\ variance\ equal\ to\ \sigma^2 for\ all\ j$

Otherwise, an iterative approach using linear programming and Conjoint Analysis, as described above can be used with the following objective function and constraints:

$$\sum_{n=1}^{N} w_{n_{M_n}} = 100 \tag{1}$$

Constraints:

$$\sum_{n=1}^{N} \sum_{m=1}^{M_n} A_{n_{m_r}} w_{n_m} = U_r, where\ r \geq \left[\left\{ \sum_{n=1}^{N} (M_n - 1) \right\} - 1 \right] \cdot 2 \tag{2}$$

$$\sum_{m=1}^{M_n} A_{n_{m_r}} = 1, \forall\ n, r \tag{3}$$

$$\sum_{n=1}^{N} w_{n_{M_n}} = 100 \tag{4}$$

$$w_{n_1} = 0, \forall\ n \tag{5}$$

$$w_{n_2} \geq w_{n_1}, w_{n_3} \geq w_{n_2}, \dots, w_{n_{M_n}} \geq w_{n_{\{(M_n)-1\}}}, \forall\ n \tag{6}$$

$$w_{n_m}\ is\ non-negative, \forall\ n, m \tag{7}$$

Where:

$r = Combination\ under\ consideration$

$A_{n_{m_r}} = Binary\ variable\ equal\ to\ 1\ if\ option\ m\ is\ selected\ for\ factor\ n\ for\ combination\ r$

$U_r = Utiliy\ score\ given\ by\ the\ ranker\ for\ random\ combination\ r$

There are two options for the types of constraints that compare different combinations and their relative rankings. The first are equality constraints, as shown in Constraint (2) above. One drawback to this method is that when large numbers of unknown weights are considered, it is nearly impossible to satisfy all equality constraints due to algebraic restrictions. This drawback can be overcome by using an iterative process that eliminates combinations one by one based on the LP's solution and the unsatisfied

constraint with the highest deviation from its equality. Combinations can be removed until the minimum number of combinations required $\{\sum_{n=1}^{N}(M_n - 1)\} - 1$ (since this number is the same as the number of unknown weights) has been reached, or when all equality constraints are satisfied. Another way to overcome the problem of unsatisfied equality constraints is to run a regression to provide a starting point the LP. This can help find a solution where the answer corresponds to a global maxima instead of a local maxima.

The second option for the types of constraints that can help compare different combinations are pairwise inequality constraints. As outlined by Lilien and Rangaswamy, 2004, pairwise evaluations of combinations are completed by asking the respondent to allocate 100 points between two different combinations. This method will always return an optimal solution in the LP, however, a larger sample size is required from the respondent. For example, if there are 12 combinations, the respondent must rank [(12*11)/2] = 66 pairs.

The number of combinations used as constraints in the initial LP – for both equality and pairwise inequality constraints – should be roughly double the number of unknown weights, or part-worths, as described in the Conjoint Analysis section above.

Calculation of Population

Population for each grid cell can be gathered directly from a community's GIS, however, it is unlikely that such specific information will be available. Estimates based on land parcel areas, number of houses, and Statistics Canada data may be used for this part of the analysis. For example, the number of houses per grid cell may be multiplied by the average number of people per household, according to the Statistics Canada Community Profile. Another method for approximating population is shown in the case study below.

Calculation of Distance

Distance calculations between potential bus stops should be calculated using a measuring tool in the community's GIS or Google Earth. Distances must follow roadways, which makes them difficult to calculate using an automated algorithm. If analysts are able to integrate this model with their GIS and incorporate distances through roadways, it would be much less tedious. However, rural areas will typically have few enough points that manual calculation will be feasible.

Evaluation of Existing Routes

If there is currently an existing bus route in the rural community, the route may be evaluated by summing the accessibility scores for the grid cells containing bus stops and dividing by the total road distance of the route. This will be referred to as the Total Route Score per Distance (TRSD), which can be useful for comparing existing routes to new potential routes in order to choose the route with the maximum impact. Grid cells for the community under consideration are labelled from i = 1, 2,…, T, where T is the total number of grid cells in the community.

$$TRSD = \frac{\sum_{i=1}^{T} RAS_i\, S_i}{D}, where\ S_i = \begin{cases} 1, if\ a\ bus\ stop\ exists\ in\ grid\ cell\ i \\ 0, if\ no\ bus\ stop\ exists\ in\ grid\ cell\ i \end{cases} \quad (1)$$

Where:

$T = Total\ number\ of\ grid\ cells\ in\ the\ rural\ area$

$S_i = Binary\ variable\ that\ equals\ 1\ if\ a\ bus\ stop\ exists\ in\ grid\ cell\ i$

$D = Total\ distance\ travelled\ to\ connect\ all\ bus\ stops\ on\ the\ route$

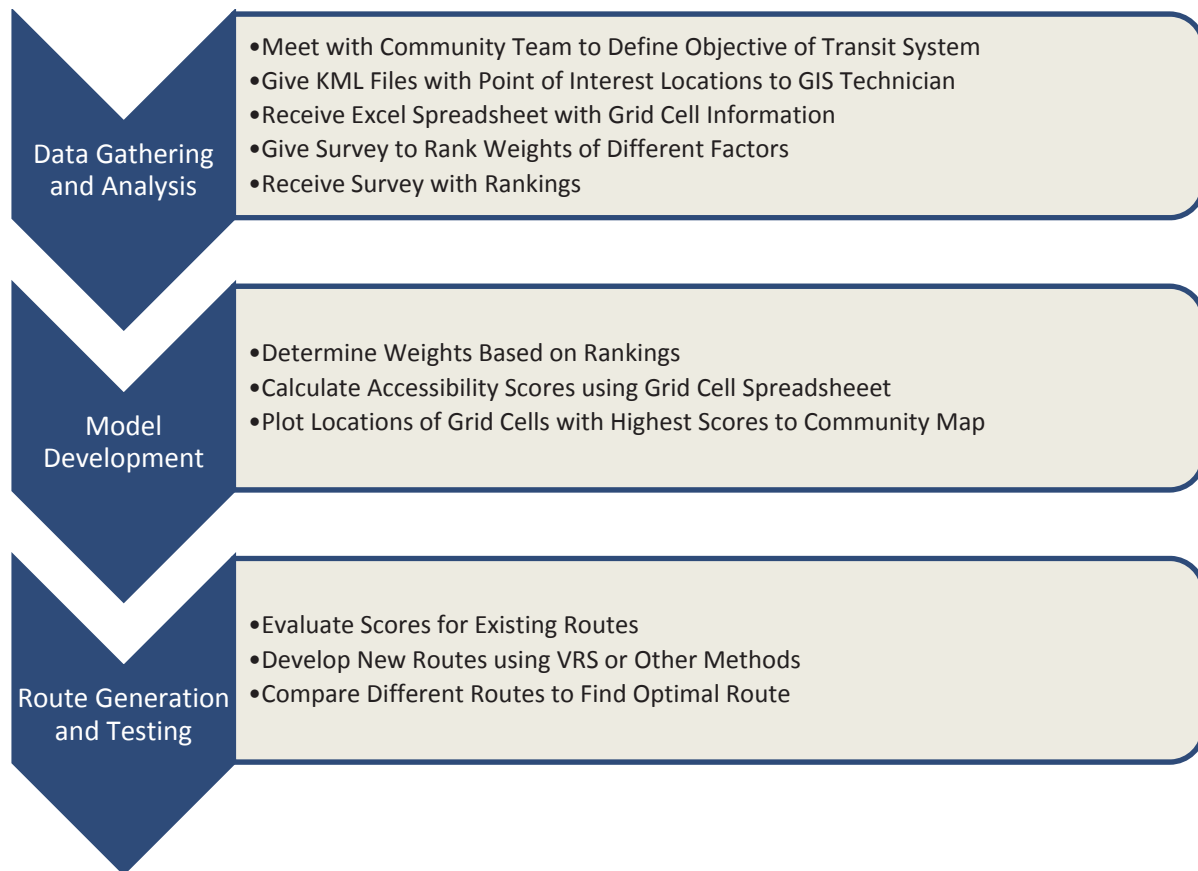### *Development of Potential Routes*

If there are no existing routes in the rural community, VRS techniques can be used to determine potential routes. The Sweep Method can be implemented with the constraint of total bus route time, since community officials may require the bus to run an entire route in one or two hours exactly. Time can be calculated based on distance and speed limits in the area. Other methods such as the Savings or Insertion Method could be used if road distances between points were integrated with this model, however, this will most likely not be the case.

Another simple alternative to finding an optimal route is to assume there will be a maximum of one or two buses running the route, since rural transit budgets are usually restrictive. This will limit the number of grid cells under consideration with a time restriction, leaving only a select number of grid cells with the highest scores. The Traveling Salesman Problem or the "tear drop" approach can then be used to solve for the optimal route that connects all grid cells. Grid cells can be added to the new route one by one with Rural Accessibility Scores in descending order until the time constraint is reached. Keep in mind that when adding grid cells one by one, there may be a grid cell that is geographically distant from the constructed route and may not be feasible. Common sense should be used with this approach, which means a grid cell with a lower score may take precedence over one with a higher score due to geographic location. This approach may be more realistic for communities with no public transit system in place. If specialized transit, such as charter services, already existed, the community might benefit from a combination of scheduled transit and specialized transit. Further analysis would need to be done by community leaders to realized the risks and benefits of such a venture.

Three Stage Decision-Making Process

The process flowchart below, Figure 3, shows the three step decision-making process to determine optimal rural transportation routes.
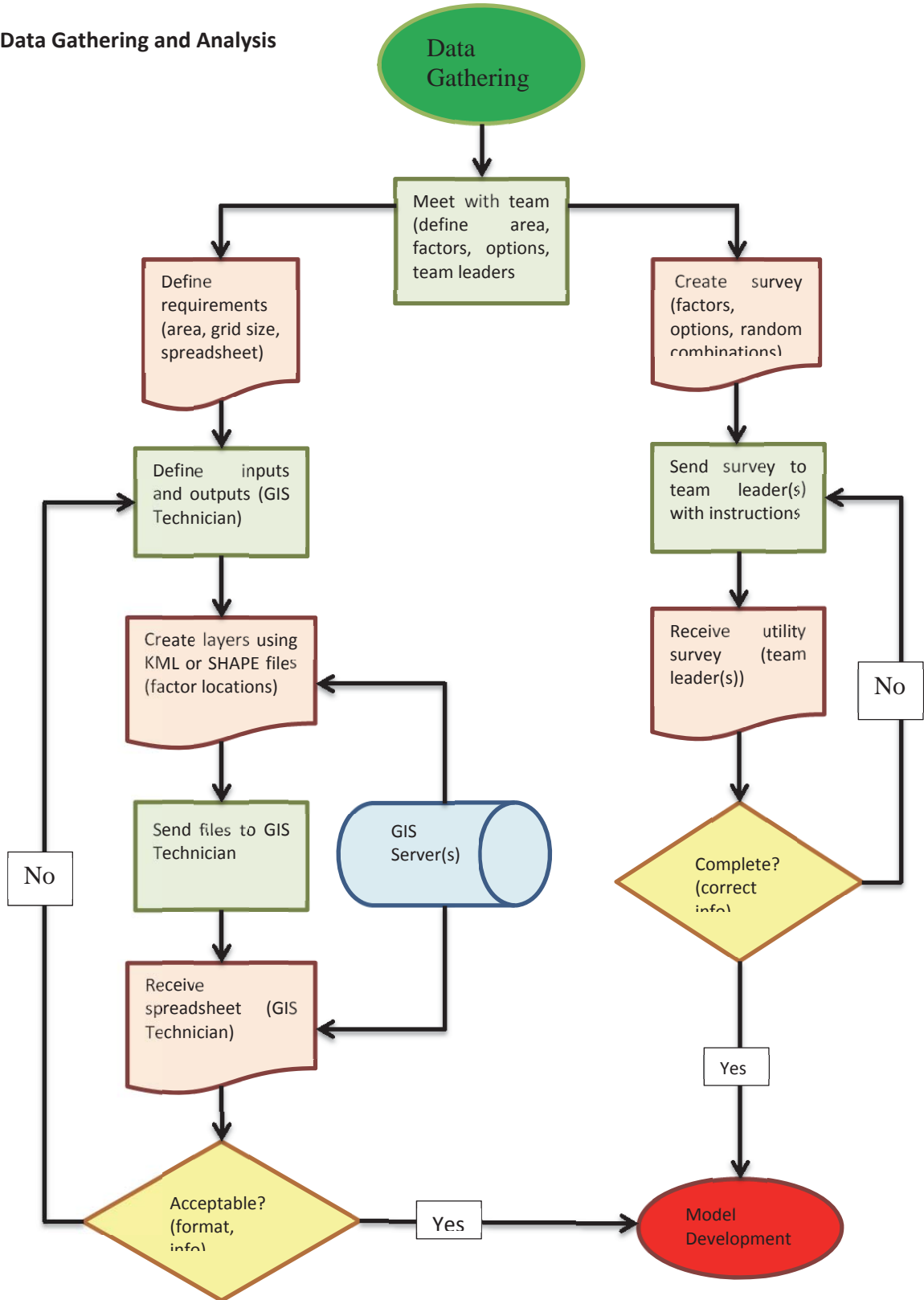
Figure 3 – Three Stage Decision-Making Process

Data Gathering and Analysis
- Meet with Community Team to Define Objective of Transit System
- Give KML Files with Point of Interest Locations to GIS Technician
- Receive Excel Spreadsheet with Grid Cell Information
- Give Survey to Rank Weights of Different Factors
- Receive Survey with Rankings

Model Development
- Determine Weights Based on Rankings
- Calculate Accessibility Scores using Grid Cell Spreadsheeet
- Plot Locations of Grid Cells with Highest Scores to Community Map

Route Generation and Testing
- Evaluate Scores for Existing Routes
- Develop New Routes using VRS or Other Methods
- Compare Different Routes to Find Optimal Route

Data Gathering and Analysis

The first step of this phase is to meet with the community team responsible for implementing the rural transit system. The three step decision-making process and model applications should be clearly described to community leaders, making it clear how the model will work for their rural community. Once an agenda has been set, the GIS Technician for the community's GIS must be asked to develop an Excel spreadsheet that contains information on each 400x400m grid cell in the community. Relevant factors such as hospitals, schools, grocery stores, retirement residences, national parks, and pharmacies may be included in the spreadsheet. Other factors may also be considered important to community leaders, so they may be included in the spreadsheet as well. The spreadsheet should include the latitude and longitude coordinates, the number of relevant factors (e.g., hospitals, schools), and the population for every grid cell within the rural area. In order to develop the spreadsheet, the GIS Technician must be able to overlay the locations of all relevant factors onto the community's GIS. This can be accomplished by the Technician if these layers are available in the GIS, otherwise Google Earth can be used to pinpoint locations which are labelled and saved as a KML file. The Technician can then overlay the KML file to the community's GIS and create the desired spreadsheet.

The next step in this phase is to determine the weights for all relevant factors, which is done through Multi-Objective Utility Analysis. Depending on the number of relevant factors and possible options for each of these factors, a utility survey must be submitted to community officials to determine the importance of each factor. The community team should be responsible for ranking different random combinations of factors and options, and a detailed ranking scale should be provided to ensure consistency among rankers. An example of a ranking scale is shown in Figure 10 in the case study. The process flowchart for this phase is shown in Figure 4.

Figure 4 – Data Gathering and Analysis

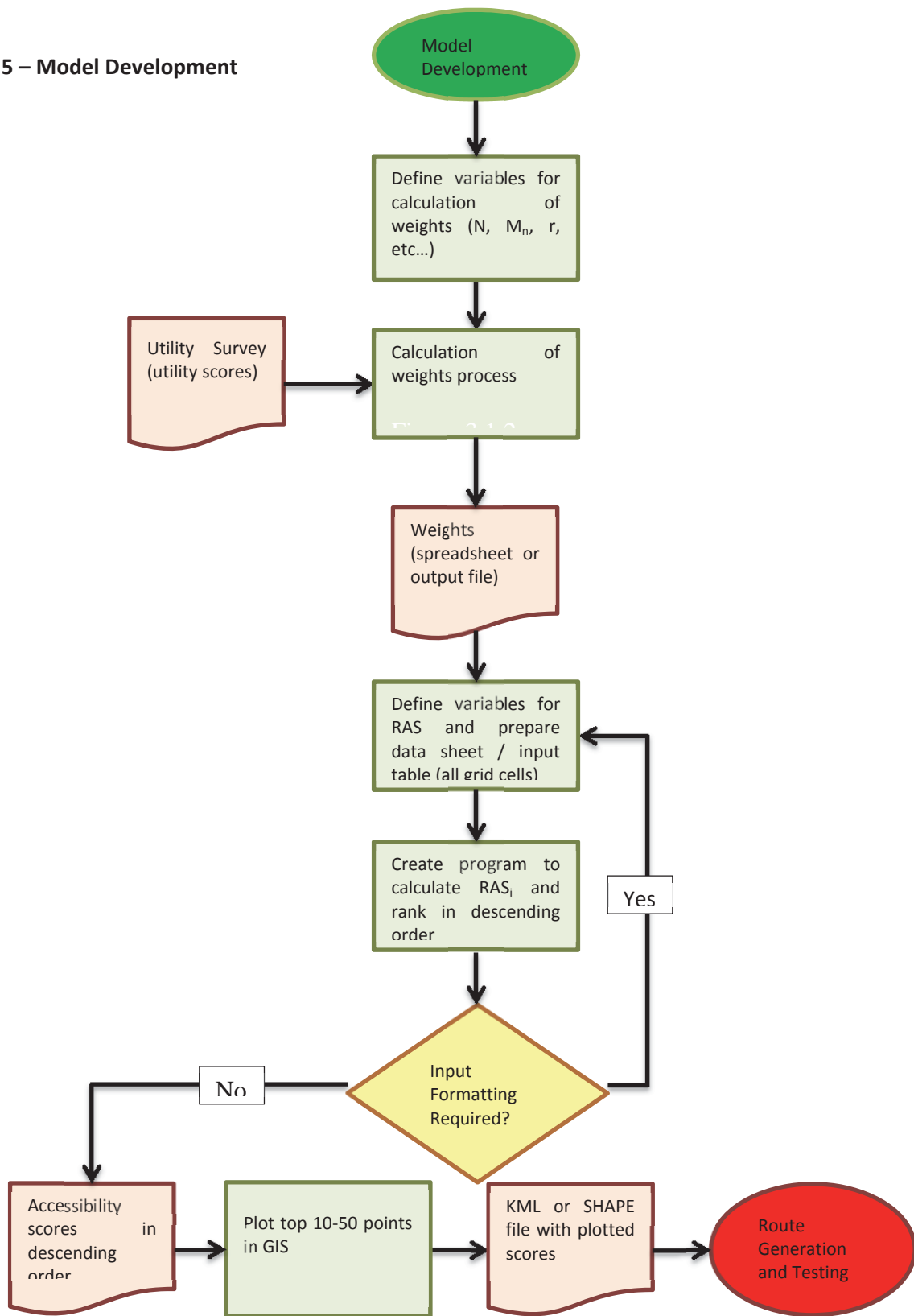Figure 4 – Data Gathering and Analysis

Data Gathering → Meet with team (define area, factors, options, team leaders)

Define requirements (area, grid size, spreadsheet) → Define inputs and outputs (GIS Technician) → Create layers using KML or SHAPE files (factor locations) → Send files to GIS Technician → Receive spreadsheet (GIS Technician) → Acceptable? (format, info)

GIS Server(s)

Create survey (factors, options, random combinations) → Send survey to team leader(s) with instructions → Receive utility survey (team leader(s)) → Complete? (correct info)

No / Yes

Model Development

Model Development

Weights for different factors can be calculated using the linear program described in the Calculation of Weights section above. The results from the utility survey are used to solve for the associated number of unknown weights. The weights may be calculated using software such as AMPL, Excel Solver, or by using the GIS directly. Once the weights are determined, accessibility scores can be calculated. An example of a linear program in Excel is shown in the case study below.

The Excel spreadsheet provided by the GIS Technician will contain all the necessary information to determine accessibility scores for each grid cell. Equation (1) in the Model Formulation section must be implemented using software such as Visual Basic for Applications (VBA) in Excel, AMPL, or GIS software. Accessibility scores are then calculated for each grid cell, at which point the scores can be ranked from highest to lowest. Since the coordinates for each grid cell are provided in the spreadsheet, the top 25 to 50 grid cells can be plotted on the GIS, which is the final step. The process flowchart for this phase is shown in Figure 4.

Route Generation and Testing

If rural transit routes already exist, they can be evaluated with their relative accessibility scores and distance between points. In order to evaluate a route, simply sum the accessibility scores for grid cells where bus stops are present. Next, divide by the total distance for the bus route, which can be found using a measuring tool in the GIS. This will give the Total Route Score as outlined in the Evaluation of Existing Routes section above. New routes can be created and compared with existing routes by comparing the TRSD for each route. New routes may be generated using VRS methods as described in the Development of New Routes section above.

Figure 5 – Model Development

Model Development

Define variables for calculation of weights (N, M_n, r, etc…)

Utility Survey (utility scores)

Calculation of weights process

Weights (spreadsheet or output file)

Define variables for RAS and prepare data sheet / input table (all grid cells)

Create program to calculate RAS_i and rank in descending order

Input Formatting Required?

Yes

No

Accessibility scores in descending order

Plot top 10-50 points in GIS

KML or SHAPE file with plotted scores

Route Generation and Testing

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Results for potential transportation routes should be analyzed and evaluated by the research team, as well as the community team. Changes to relevant factors, ranking methods, and population calculations may be changed to provide a more accurate result. The flowchart for this process is shown in Figure 6.

Figure 6 – Route Generation and Testing
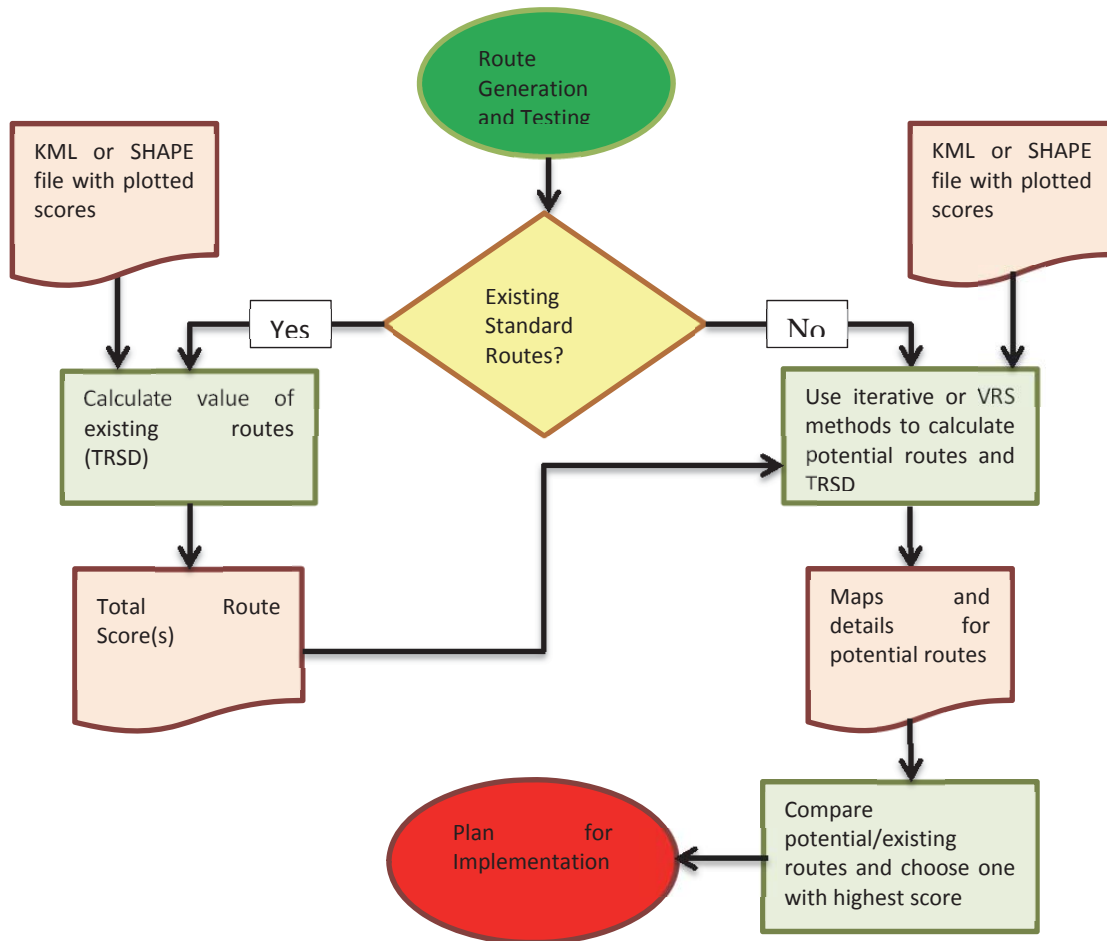
Analysis and Findings

This case study was performed to test and validate the methodology outlined above. The case study for Prince Edward County focused on developing a potential rural transit route for regularly scheduled transit, which could complement its already existing charter-type transit.

Prince Edward County

Prince Edward County is part of Southern Ontario and is located in between Kingston and Toronto, Ontario. PEC is not officially a county by Ontario standards; it is a municipality with a single government

which handles all municipal services. Communities within the municipality include: Ameliasburg, Bloomfield, Carrying Place, Cherry Valley, Consecon, Demorestville, Fawcettville, Glenora, Hillier, Milford, North Port, Picton, Rednersville, Rosehall, Rossmore, Waupoos, Wellington, and West Lake. According to the Statistics Canada 2006 Census, the combined population of the municipality is approximately 25,000, with a population density of 24.3/km^2, and an area of about 1,000 km^2. The main attraction for PEC is Sandbanks Provincial Park in Picton, which attracts thousands of tourists during the summer. As can be seen from the map in Figure 7, PEC is an island community. Lake Ontario provides PEC with a mild climate that supports its many wineries and vineyards.

Figure 7 – Prince Edward County Geography

PEC is interested in implementing a rural public transportation system to provide a sustainable and affordable transit option for its citizens. Providing public transportation is vital for senior citizens to have access to essential services, offer low income families cost-effective local travel, and deliver transportation to employment and business centres to foster local economic growth.

Existing Public Transportation

Quinte Access provides public transportation in the cities of Quinte West, Brighton, and PEC. The service is intended for people who are mentally or physically challenged, unable to walk reasonable distances, or seniors who need transportation assistance. The service has four buses and five vans, all of which are wheelchair accessible. Routes and schedules change daily, based on rider demand, since vehicles pick up passengers at their homes. Subscription fees are paid for riders who need regular access to employment, education, or healthcare. Non-subscription service requires a rider to call at least 24 hours in advance to book a trip at a determined rate.

PEC Specialized Transit is also used for PEC`s physically disabled and elderly population. This door-to-door transit service requires riders to register through an application process and schedule trips one day in advance. Priority is given to riders with physical disabilities, and medical trips take precedence over social trips. The service currently operates four days per week from Tuesday to Friday.

Developing a Rural Public Transit Route

This section outlines and discusses the application of the three phase methodology discussed in the Methodology section above and shows how any rural community can develop a rural transportation route.

Data Gathering and Analysis

The first step of the process was to arrange a meeting with members of PEC on May 26, 2011 in Picton, Ontario to discuss the scope of the study. Attending members included PEC`s Public Works Commissioner Robert McAuley, Planning Services Manager Jo-Anne Eagen, and other members of the Planning Services Department including GIS Technicians. The main objectives of the meeting were to discuss the rural transportation model, ensure data would be available for analysis, and to learn about PEC`s existing transportation network. Six factors were selected to determine PEC's accessibility per grid cell: hospitals, schools, pharmacies, grocery stores, national parks, and retirement residences. Each of these factors had two options – either 0 or 1 factor located in each grid cell – except for schools, which had the option of 0, 1, or 2 schools per grid cell.

After determining the inputs and outputs required from PEC and the area to be served, the GIS Technicians were asked to prepare a spreadsheet that shows information for each 400x400m grid cell in PEC. Information for each grid cell included the number of factors per grid cell, in terms of the option chosen (e.g. 0 or 1 hospitals). Population for each grid cell was also calculated, and is described in detail in the following paragraph. Two separate KML files were sent to the GIS Technician (created in Google Earth). One file included locations for five of the six factors, and the other included polygon overlays for the sixth factor – national parks. A screenshot of the former is shown in Figure 8.

Population for each grid cell was calculated by using Municipal Property Assessment Corporation (MPAC) property codes that show land use for each individual parcel of land. This was combined with the average population per dwelling of 2.4 from Statistics Canada Community Profiles. For example, if the MPAC code said that two households were within a grid cell, then the estimated population for that grid cell would be 4.8. Centroids were created for each parcel in order to prevent parcels from overlapping into more than one grid cell. A screenshot of the finalized spreadsheet provided by the GIS Technician can be seen in Figure 9.

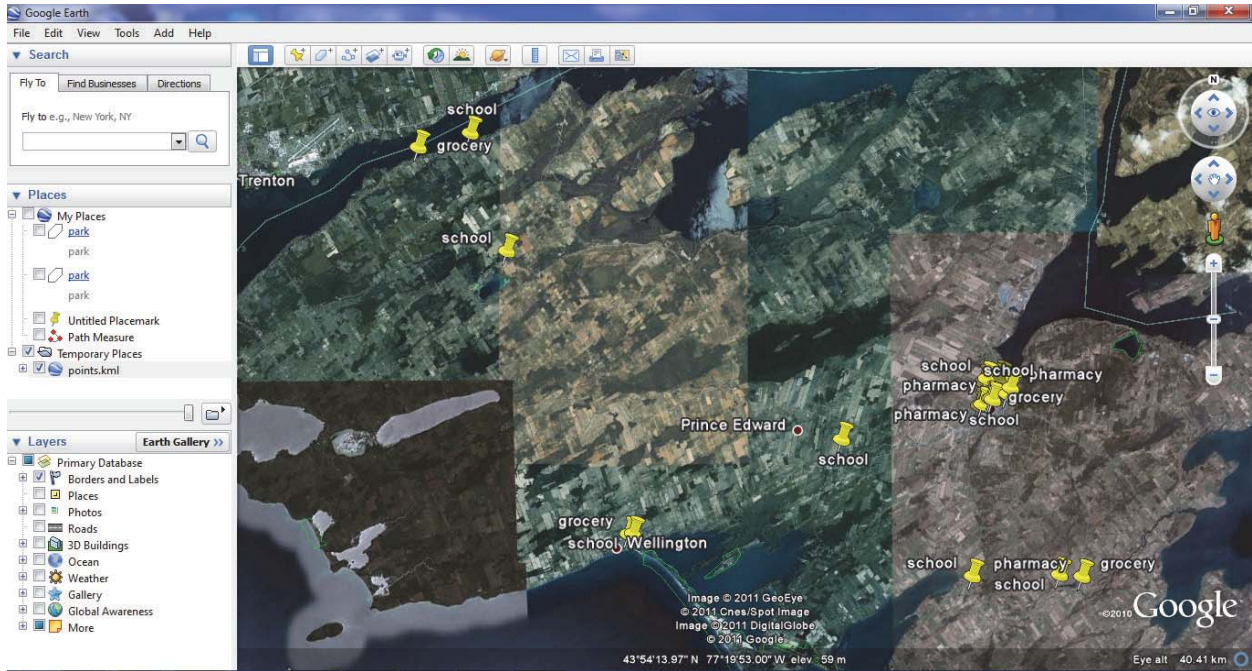**Figure 8 – Locations for Relevant Factors of Accessibility**

Figure 9 – GIS Data Table

Next, the utility survey for ranking different combinations (r) of factors was customized to include PEC's six factors. Linear programming (LP) was used as opposed to multiple regression in order to reduce respondent fatigue when ranking different combinations. Thirteen random combinations of factors and options were generated, since the recommended number of combinations corresponds to $r \geq [\{\sum_{n=1}^{N}(M_n - 1)\} - 1] \cdot 2$ as described in the Conjoint Analysis and Calculation of Weights sections above. Random combinations were created in Excel using a pseudo random number generator. The survey was then sent to the Planning Services Manager, Jo-Anne Eagen. After viewing the spreadsheet shown in Figure 10, following the detailed instructions, and filling in the fields that are highlighted in yellow, she returned the updated spreadsheet and it was time to move to the model development phase.

Figure 10 – Respondent Survey to Rank Combinations

Combination	Hospitals	Schools	Pharmacies	Grocery Stores	Parks	Retirement Residences	=	Utility
1	0	0	0	1	1	0	=	?
2	1	2	1	0	1	1	=	?
3	1	1	1	1	0	1	=	?
4	0	2	0	1	0	0	=	?
5	1	0	0	1	0	1	=	?
6	0	1	0	0	0	0	=	?
7	1	1	1	0	0	0	=	?
8	0	0	1	0	1	0	=	?
9	1	2	0	1	1	1	=	?
10	1	1	1	0	0	1	=	?
11	0	1	1	1	1	1	=	?
12	1	2	1	1	1	0	=	?
13	0	2	1	1	0	1	=	?
MAX	1	2	1	1	1	1	=	100

NOTE: Combinations for the different options above were randomly selected.

Instructions

1. Rank all 13 options and assign them a utility score between 0 and 100.
2. The combination MAX shows that a score of 100 can only be attained from having the highest option for each factor.
3. Ranking guide:

Utility	Description
0 - 20	Negligible importance to PEC
21 - 40	Not very important to PEC
41 - 60	Important to PEC
61 - 80	Very important to PEC
80 - 100	Very very important to PEC

4. Place score in highlighted column with "?"

Example 1: Option 1 corresponds to an area of PEC that has 0 hospitals, 0 schools, 0 pharmacies, 1 grocery store, 1 park, and 0 retirement residences. If you think that the combination of these items found in Option 1 are important to PEC then a score between 41 - 60 should be assigned as the utility.

Example 2: Option 2 shows that 1 hospital, 2 schools, 1 pharmacy, 1 park, and 1 retirement residence are located in a specific area of PEC. Bob thinks that hospitals are very very important to the accessibility of people in PEC, and he also thinks that retirement residences and pharmacies will increase the importance of an area in PEC. Bob gives a utility score of 95 for option 2.

Model Development

Using the utility survey and previously gathered information, variables were defined in order to calculate weights:

$N = 6, M_1 = 2, M_2 = 3, M_3 = 2, M_4 = 2, M_5 = 2, M_6 = 2$

$U_1 = 41, U_2 = ,85 U_3 = 75, U_4 = 70, U_5 = 65, U_6 = 60, U_7 = 73, U_8 = 45, U_9 = 90, U_{10} = 92,$

$U_{11} = 82, U_{12} = 95, U_{13} = 80$

*All 13 combinations and their $A_{n_{m_r}}$ values can be seen in Figure 10.

Equation (1) from the Calculation of Weights section was used as the objective function for the linear program, with LP constraints (2) to (7) found in the same section above. A linear program was constructed in Excel corresponding to the objective function and related constraints and solved using Excel's Solver tool and the iterative procedure shown in Figure 2. The spreadsheet and results can be found in Appendix C.

Next, variables for the RAS equation were located in the spreadsheet provided by the GIS Technician. Previously calculated values for weights were also copied into this spreadsheet for easy reference. VBA was used to calculate scores using Equation (1) from the Notation section and the top 50 scores were ranked in descending order using another VBA algorithm (Code can be found in Appendix D). The top 25 grid cells were plotted with their corresponding coordinates in PEC`s GIS, exported as a SHAPE file, and converted to a KML file to be opened in Google Earth. A screenshot of the Google Earth image with the top 25 points can be seen below in Figure 11.

Figure 11 – Top 25 Locations with Highest RAS

After the top 25 grid cells were plotted in Google Earth, it was time to generate and test potential routes.

Route Generation and Testing

PEC did not have existing standard routes, so evaluation of existing routes was not feasible. PEC's specialized transit service changes routes on an ongoing basis and offers custom service to individual riders. The RAS method is not an appropriate measurement of such service, since transit schedules are based on customized routes and not accessibility. On the other hand, VRS methods could still be used on a daily basis to evaluate daily transit routes and choose routes that minimize distance or time.

When designing potential routes, some assumptions were made for PEC. The first assumption is that PEC will only have enough money in their budget for one bus with a regularly scheduled route. They will also want to test the service and rank its success before implementing service with a second bus. The second assumption is that PEC will offer a bus route with a reliable schedule that is attractive to its citizens. The constraint of 90 minutes was used, which means the bus must leave the depot, stop at every bus stop, and return to the depot within this time limit. The third assumption is that the depot – the starting and ending point – will be the grid cell with the highest accessibility score. The fourth assumption is that the travel speed for the bus is 37 km/h, which is the recorded service speed of PEC's specialized transit in 2009. Finally, since this is a regularly scheduled route, it is assumed that the bus will stop at each node on the route for one minute.

Different scheduling methods were used in collaboration with rural accessibility scores. The first method used an iterative approach that added grid cells from highest to lowest RAS to the route, one by one, until the 90 minute constraint was exceeded. The second method added the ten grid cells with the highest RAS to the route. Other grid cells were added to the route in order of descending RAS, but only those points located in close proximity to the existing route were added. Finally, the third method uses the same approach as the second, but travels to grid cells in southern PEC within the top 25 to simulate an alternate rural route (e.g., perhaps a route with a standardized schedule could visit southern areas twice per week to serve the more rural population).

The Sweep method was used to develop the routes in all three methods. The Sweep method simply extends a straight line from the depot in any direction and rotates in either direction, adding the next scheduled stop every time a point is intersected by the line. The "tear drop" method is also used to ensure that routes do not cross over themselves. A screenshot of the three potential routes can be seen in Figure 12.

Routes one and two both go through Picton, Bloomfield, and Wellington. The depot or starting point for all three routes is denoted by the green push-pin icon in Picton; it is the point with the highest accessibility score. The yellow and red paths show routes one and two, respectively. All of the bus stops in route one are also found in route 2, since route 2 was constructed using a similar approach. A close-up of routes one and two through the town of Picton can be seen in Figure 13. Route three is shown by the blue pathway in Figure 12 and visits more rural areas of PEC.

Figure 12 – Three Potential Transit Routes
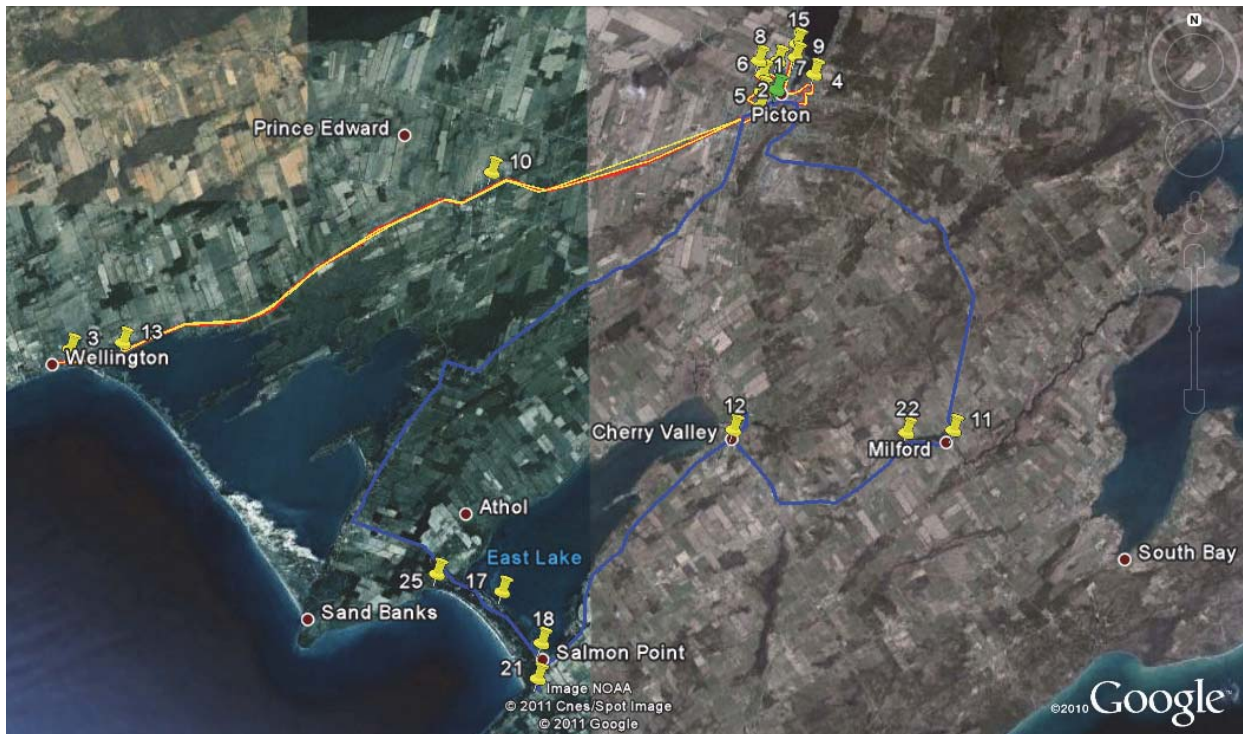

Figure 13 – Routes 1 and 2 through the Town of Picton

Data for the three routes is shown in Table 1 below.   As can be seen in Table 1, the three routes share a similar total distance, and all fall within the 90 minute route constraint (an example of duration calculation can be found in Appendix E). Route one has 10 bus stops, route two has 12 bus stops, and route three has eight stops. The Total Route Scores per Distance (TRSD) were calculated for each route using Equation (1) found in the Evaluation of Existing Routes section above, which divides total the total score by total distance of the route. Route two has a slightly higher accessibility score than route one, which can be expected since route two has more bus stops but equal distance. Route three has a considerably lower score than the other two routes, since fewer bus stops are visited. When comparing these three options, it is easy to see that PEC should choose route 2, since it has the highest TRSD, has more stops than the other routes, and falls within the time constraints.

Table 1– Route Summary

Bus Stop	Route 1		Route 2		Route 3	
	RAS Rank	*Score*	*RAS Rank*	*Score*	*RAS Rank*	*Score*
1	1	19645.8	1	19645.8	1	19645.8
2	4	9741.6	4	9741.6	11	1260
3	9	2868	9	2868	22	223.2
4	7	5964.4	15	530.4	12	892.8
5	8	3978	7	5964.4	21	226.8
6	6	8035.2	8	3978	18	421.2
7	2	12240	6	8035.2	17	453.6
8	10	1264.8	2	12240	25	64.8
9	3	10530	10	1264.8		
10	5	8893.5	13	680.4		
11			3	10530		
12			5	8893.5		
	Route 1		**Route 2**		**Route 3**	
Total Score:	83161		84372		23188	
Total Distance:	42.5 km		43 km		50 km	
Duration:	79 mins		82 mins		89 mins	
TRSD:	1848		1875		483	

Sensitivity analysis for different routes may also be studied. For example, stopping twice at select bus stops on a route might increase interest for new riders. On route 2, stopping twice per route at points 9, 10, and 13 would prevent potential riders from having to ride the bus in the opposite direction of their destination. While this option could increase ridership, it also adds an additional minute for each extra stop, making the total duration of the trip 85 minutes. PEC would have to determine which element is more important. A possible solution to overcome tight time constraints is increasing average speed per trip. If buses run faster, then more stops can be visited. This could also apply to route three, since the majority of driving is done on rural highways. The average speed per route is 37 km/h, however, route three's actual average speed may be closer to 60 km/h because buses will travel on rural highways. Increasing the average speed of travel when a route has a lower TRSD may be a reasonable trade-off, since more riders may be captured per hour. Finally, if slack is available with regards to time

constraints, additional potential stops can be added to the PEC map in order of descending RAS. For example, the 28th highest RAS may fall directly on the path of the proposed bus route, so accommodating the extra stop would be feasible.

Conclusion and Recommendations for Future Work

The purpose of this paper was to develop a GIS-based framework for developing optimal transportation routes in rural areas. The three-step decision-making process described in this paper outlines steps for data gathering and analysis, model development, and route generation and testing. As part of the process, a unique model was developed to determine the importance of specific factors to a community's accessibility, scores for different grid cells within a rural community, and total scores for existing and potential routes within a community. This three-step process can be used by any rural community with a GIS in order to create optimal public transit routes.

The models are relatively simple to use and can be designed to work with Microsoft Excel, with the help of VBA. If desired, a community can develop tools in Excel or other software that can easily be re-used to evaluate existing routes and potential routes for the future. A user-friendly Excel template for any rural community could also be developed with customizable settings for the number of factors and options, destination cells to retrieve the information from the spreadsheet, and VBA programs to calculate and rank accessibility scores.

While this framework offers some great advantages to rural communities, there are some limitations as well. The model in this paper is GIS-based, so if a community does not have a GIS, or is unable to speak with Technicians who support the system, this model will be more difficult to use. Rural transit authorities and rural communities are also faced with resource constraints, which could make it difficult to find time for a full analysis. Finally, demand for rural public transit systems is difficult to predict and community leaders must make a serious time commitment to build ridership.

There are numerous opportunities for future work in this area. As discussed above, a user-friendly template in Excel could be developed for general use by any rural community. This would allow community leaders to develop routes with a basic understanding of rural transportation networks and VRS methods. Another opportunity for future work lies with the GIS software. Instead of simply generating an Excel spreadsheet for manual calculation, GIS Technicians could program the models and equations directly into their GIS software to calculate scores, rank options, and plot points directly in their GIS. An extension of this application would be integrating roadways with grid cells in the rural area so that more advanced VRS methods such as the "Savings" method, Insertion method, and other advanced optimization techniques could be used to find optimal routes. This would need to be customized based on the GIS software used by each community, but a general program template could be developed for all rural communities.

The framework outlined in this paper should be very useful for rural communities. The step-by-step process will help transit authorities implement the models described in this paper and design optimal transit routes. This can serve as a starting point for rural transit planning, cost-benefit analysis of rural transit systems, and may help secure operating and capital grants from various levels of government.

This study will help increase stakeholder awareness on the importance of sustaining and growing rural public transit systems to meet the needs of an aging and growing population.

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Appendix A – Rural Communities with Public Transit Systems[9]

Deseronto Transit – Deseronto, Ontario

http://deseronto.ca/departments/deseronto-transit

Deseronto's transit system provides service to Deseronto, Belleville, Napanee, and Prince Edward County. The service operates from Monday to Saturday and uses small buses to serve rural communities.

Green Rider – Hantsport, Nova Scotia

http://www.greenrider.ca

This vanpool service has been running since 1981 and offers rural residents along a commonly travelled route the opportunity to schedule rides to work and school. The service also transports people to Halifax and Dartmouth.

Kings Transit – Berwick, Kentville, Wolfville, and County of Kings, Nova Scotia

http://www.kingstransit.ns.ca

This rural public bus system was established in 1981 and serves the above listed county and towns, who jointly fund the service. In September 2007, the service was expanded to serve Hants County and parts of Annapolis County.

Kootenay Rideshare – Nelson, British Columbia

http://www.kootenayrideshare.com/index.html

This free service helps connect rural residents to share cars and save costs. The website includes emissions calculators and the ability to form ridesharing groups.

Ottawa's Rural Routes, OC Transpo – Ottawa, Ontario

http://www.octranspo1.com/community-events/rural_communities

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[9] Adapted from Majkut (2011).

OC Transpo introduced service to rural communities in 2002, and now serves 13 communities in the greater Ottawa area. The buses operate during peak hours to serve these small communities.

Specialized Transit – Prince Edward County, Ontario

http://www.pecounty.on.ca/government/rec_parks_culture/properties/transit.php

In 2007, this specialized transit system for elderly and disables citizens was developed. Riders must be eligible and register through an application process. Trips are scheduled at least one day in advance and serve social and health needs.

Trius Transit – Charlottetown, Prince Edward Island

http://www.triustransit.ca

This public bus system started in 2005 and serves Charlottetown, Cornwall, Stratford, and some county lines. Ridership for the transit system is continuing to grow and revenues from transit fares are offsetting the costs for the system.

Appendix B – How to Develop an Economic Impact Assessment (EIA)[10]

The following methodology is adapted from the Rural Economic Development Data & Intelligence (REDDI) program, developed by the Ministry of Agriculture, Food, and Rural Affairs. This Government of Ontario guide for creating an EIA uses seven essential steps. The full guide may be found at the following website: http://www.reddi.gov.on.ca/guide_ecimpactassessment.htm.

Step 1: Define the scope.

The objective of an EIA is to compare changes to the status quo to determine economic effects. Defining the scope involves identifying the work that needs to be performed, outlining the purpose of the EIA, and stating feasibility constraints.

Step 2: Define decisions and questions to be answered.

It is important to identify decisions that municipal council or staff will make based on the EIA. Outlining important questions to be answered will focus the analysis on areas of interest and help make better decisions.

Step 3: Determine level of detail.

The level of detail for the EIA will depend on time, budget, and staffing constraints, the size of the local community, information available, and expertise of the project team.

Step 4: List assumptions and limitations.

Assumptions may include topics such as population growth, employment levels, and income levels. Limitations might include time constraints, lack of expertise, and unavailability of information.

Step 5: List economic impacts.

Five economic impact areas were listed in the knowledge synthesis for rural transit systems: employment and business activity, increased mobility, transportation cost impacts for users of the system, impacts on expenditure patterns, and growth impacts on the local economy. This list may be expanded to include other impacts such as existing user impacts, benefits from reduced traffic, and changes in land use patterns (Litman, 2011).

Step 6: Define required and available data.

Key data requirements include, but are not limited to: infrastructure and construction costs, projected number of employees, employee's annual wages, estimated number of employees living in the local community, and estimated cost of inputs from local suppliers.

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[10] Adapted from Majkut (2011).

Step 7: Analyze direct impacts for each impact area and compute indirect and induced effects.

Direct impacts include initial project effects such as job levels and salaries, as a direct result of the rural transit system. Indirect impacts are the changes that occur to job levels, production, and salaries in other businesses in the local community, as a result of the new transit system. Induced impacts include household spending in the local economy as a result of direct and indirect impacts. For example, a bus driver may purchase a new television from a local vendor using the salary provided by the transit system.

Direct impacts are responsible for indirect and induced impacts. This is referred to as the *multiplier effect*. Multipliers for each impact area can be used to calculate indirect and induced impacts. For example, an economic multiplier of 2.2 for salaries would mean that for each dollar spent on salaries in the rural transit system, a total of $2.20 is generated. Subtracting the initial $1 spent by the rural transit authority means that the indirect and induced impacts, for the local economy, are $1.20 for every dollar spent. These multipliers may be developed through econometric models, input-output models, or simply by contacting an economic impact consultant in the region.

Appendix C – Output for Weights for PEC using Excel Solver

Optimal weights (top summary row):

	Hospitals		Schools			Pharmacies		Grocery Stores		Parks		Retirement Residences		Sum		Utility
	0	1	0	1	2	0	1	0	1	0	1	0	1			
	A_{11} / w_{11}	A_{12} / w_{12}	A_{21} / w_{21}	A_{22} / w_{22}	A_{23} / w_{23}	A_{31} / w_{31}	A_{32} / w_{32}	A_{41} / w_{41}	A_{42} / w_{42}	A_{51} / w_{51}	A_{52} / w_{52}	A_{61} / w_{61}	A_{62} / w_{62}			
	0 / 0	6.5 / 1	0 / 0	31 / 1		43 / 0		10 / 1		28 / 0		14 / 1		=	=	100

Enumeration of combinations (detailed block):

Attribute part-worths: Hospitals $A_{11}=0$, $A_{12}=7$; Schools $A_{21}=0$, $A_{22}=0$, $A_{23}=31$; Pharmacies $A_{31}=43$, $A_{32}=10$; Grocery Stores $A_{41}=0$, $A_{42}=0$; Parks $A_{51}=28$, $A_{52}=0$; Retirement Residences $A_{61}=14$, $A_{62}=0$.

Sum	Utility	Difference	Iterative Removal Order
41	41	0	
73	85	13	6
75	75	0	
70	70	0	
34	65	31	1
31	60	29	3
48	73	26	4
24	45	22	5
90	90	0	
48	92	45	2
82	82	0	
100	95	-5	7
80	80	0	

Legend:
- (green) Selected combinations based on iterative removal of unsatisfied equality constraints
- (red) Eliminated combination due to unsatisfied equality constraint

Note: The seventh iterative removal (since there there should be 6 combinations based on 7 part-worths) can be combination 1, 3, 4, 9, 11, 12, or 13. It doesn't matter which one as long as an optimal solution is found where all constraints are satisfied.

Appendix D – VBA Code for RAS and Ranking

```
Option Explicit

Sub accessibility()

Worksheets("Pop_Table").Activate

Dim row As Long
Dim column As Long
Dim Score As Double

Score = 0

For row = 2 To 4076

    If Cells(row, 24) = 0 Then 'parks
        Score = Score + Cells(2, 41)
    Else
        Score = Score + Cells(2, 42)
    End If

    If Cells(row, 25) = 0 Then 'grocery stores
        Score = Score + Cells(2, 39)
    Else
        Score = Score + Cells(2, 40)
    End If

    If Cells(row, 26) = 0 Then 'hospitals
        Score = Score + Cells(2, 32)
    Else
        Score = Score + Cells(2, 33)
    End If

    If Cells(row, 27) = 0 Then 'pharmacies
        Score = Score + Cells(2, 37)
    Else
        Score = Score + Cells(2, 38)
    End If

    If Cells(row, 28) = 0 Then 'schools
        Score = Score + Cells(2, 34)
    ElseIf Cells(row, 28) = 1 Then
```

```
      Score = Score + Cells(2, 35)
   Else
      Score = Score + Cells(2, 36)
   End If

   If Cells(row, 29) = 0 Then 'retirement homes
      Score = Score + Cells(2, 43)
   Else
      Score = Score + Cells(2, 44)
   End If

   Cells(row, 30) = Score * Cells(row, 23)

   Score = 0

Next row

End Sub
```

```
Option Explicit

Sub top50()

Worksheets("Pop_Table").Activate

Dim row As Long
Dim row2 As Long
Dim maxrow As Long
Dim max As Double
Dim count As Long

max = -100

For row = 2 To 4076
   Cells(row, 31) = Cells(row, 30)
Next row

For row2 = 6 To 55
   For row = 2 To 4076
     If Cells(row, 31) > max Then
        max = Cells(row, 31)
        maxrow = row
     End If
```

```
    Next row
    Cells(row2, 33) = Cells(maxrow, 30)
    Cells(row2, 34) = Cells(maxrow, 21)
    Cells(row2, 35) = Cells(maxrow, 22)

    Cells(maxrow, 31) = 0
    max = -100
Next row2


End Sub
```

Appendix E – Route One: Duration Calculation for PEC

$$\frac{Total\ Distance}{Average\ Speed} = Driving\ Time$$

$$\frac{42.5\ km}{37\frac{km}{h}} = 69\ minutes$$

Route 1 has 10 stops, with a one minute duration for each stop, making the total duration of the trip:

$$69\ minutes + 10\ minutes = 79\ minutes$$