Climate change and energy security in transportation fuel, infrastructure and policy: An AHP approach

by

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Honours Thesis

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Contents

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I would like to hurriedly thank my supervisor Dr. Hughes for all the work he has done for this thesis.

Oh, and to my ADHD.

List of Abbreviations

AADT – Average annual daily traffic

ADT – Average daily traffic

AHP – Analytic Hierarchy Process

CO_2e – Carbon dioxide warming equivalent

EV – Electric vehicle

GHG – Greenhouse gas

HRM – Halifax Regional Municipality

IEA – International Energy Agency

IPCC – International Panel on Climate Change

MCDM – Multi-criterion decision making

RPP – Refined petroleum products

NSDTPW – Nova Scotia Department of Transportation and Public Works

NSDTIR – Nova Scotia Department of Transportation and Infrastructure Renewal

GIS – Geographic information system

ESI – Energy security index

VBA – Visual Basic for Applications

pkm – Passenger kilometers

PJ – Petajoule (10^{15}J)

1.0 Introduction

Transportation is fundamental to all societies. It affords access to a broad range of goods and services that has brought civilization to where it is today. Be it a trans-national flight, the delivery of a package, or a walk to the grocery store, resources—in the form of energy, infrastructure, and time—go into the provision of these activities and services which are fundamental to our high standard of living.

However, these benefits are not without cost. The transportation sector is heavily dependent on fossil fuels, particularly oil; for example, in OECD countries, 96 percent of the energy for transportation is derived from petroleum (IEA, 2008a). In 2006, the combustion of petroleum products accounted for 51.8 percent of final energy consumption in the OECD nations, with transportation taking 60.5 percent share of this in 2006 (IEA, 2008a; Figure 1). Thus, the transportation sector accounts for 31.3 percent of all energy used in OECD countries—derived almost entirely from petroleum. The repercussions of this dependence are numerous, but most significantly in the areas of climate change and energy security.

In their fourth assessment report, the IPCC (2007) stated that the “warming of the climate is unequivocal” and that it is “very likely due to the observed increase in anthropogenic greenhouse gas concentrations.” There is now near consensus among the scientific community that a 50 percent

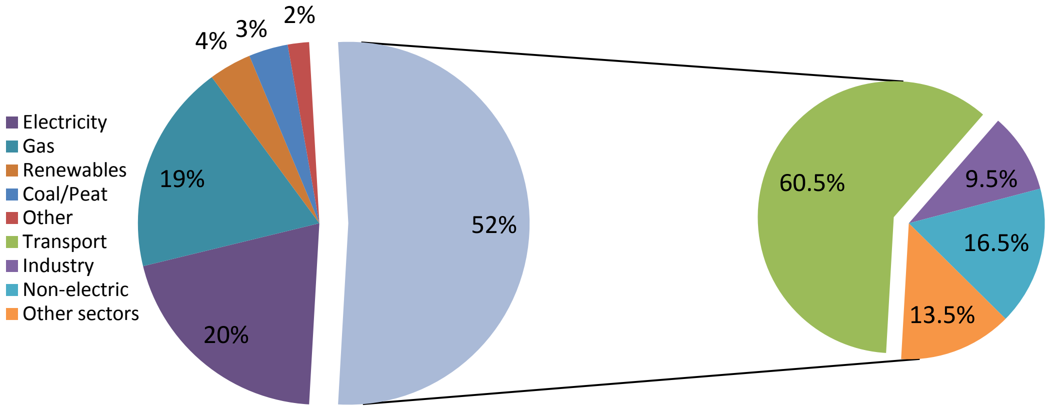

Figure 1 OECD final energy consumption by fuel; total oil energy consumption by sector (IEA, 2008a)

reduction in absolute carbon dioxide equivalents (CO_2e)[1] emissions from 1990 levels by 2050 is needed to stabilize the climate system (Joint Science Academies, 2008; IPCC 2007). The transportation sector, and its heavy reliance on petroleum, is a major contributor; transportation accounted for 20 percent of world GHG emissions in 2004 and is expected to continue on this path to 2030 if no action is taken (IEA, 2006). Furthermore, in Canada, emissions form transportation increased 37.5% from 1990 to 2007, far exceeding the national increase of 26.2% in that same period from all sectors (Environment Canada, 2008) . If the status quo is maintained and emissions from the transport sector continue to grow, the onus will be on other sectors to make up the large reductions needed to meet the 2050 target.

In addition to climate change, the transportation sector's heavy reliance on petroleum raises issues of energy security. Energy security can be defined as "the availability of a regular supply of energy at an affordable price" (Hughes, 2009). The world supply of oil is expected to peak, and while there is debate over when and at what output (Deffeyes, 2005; Energy Watch Group, 2007; ASPO, 2008; Laherrere, 1999; IEA, 2008b; Hirsch, 2008), there is widespread acceptance of its inevitability. Hirsch et al. (2005) recognizes this and says that mitigation too early would be "premature"—implying little consequence—while failure to initiate would be "extremely damaging". The world is not ignorant to the effects of sudden energy supply disruptions. In a more recent study study, Hirsch (2008) estimates a 1:1 relationship between oil supply and GDP, based on analyses of the oil shocks of the 1970s. While past energy crises provide a window of foresight into the initial effects of sudden energy supply shortages and cost increases, it provides little guidance pertaining to mitigation of the effects caused by the permanent supply shortages expected in the future. Still today, the transport sector's primary energy source is petroleum, and is therefore highly susceptible to disruptions in its supply.

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[1] A greenhouse gas emissions unit that consolidates the differing radiative forcing and residence time (warming potential) of GHGs. CO_2 used as a reference ($1CO_2$=1WP) (IPCC, 2007).

There are solutions to this problem. Hughes (2009) developed a methodology called the three 'R's of energy security—review, reduction, replacement (and restrict, if applicable)—which can be used to analyse a particular case and present alternatives. Since the issues of energy security and climate change have their common root in energy, the three 'R's methodology can be feasibly applied for gains in both areas. The first, review, involves an in-depth analysis of a jurisdiction's energy make-up. Questions to ask would relate to the source country, political stability, foreign relations, projected output peak (if applicable), and transport infrastructure. To apply the methodology to climate change concerns, a review would consider the fuel source's warming potential, fuel transport distance, and mining techniques. Based on the review, alternatives can then be proposed, and can fall into either reduction or replacement categories. Reduction alternatives would result in a decrease in energy use. This can be achieved through measures in efficiency and conservation; a decrease in energy per unit output or an absolute decrease in unit output, respectively. Alternatives in this stream could be, for instance, rail, bus, or carpooling—reducing energy use per passenger-kilometre. Conversely, replacement alternatives substitute one energy source for another that is more secure and less emission intense. The use of ethanol in the place of petrol could potentially decrease emissions while increasing security. The effectiveness of these alternatives ultimately depends on the individual circumstances identified in the review.

Although energy is the common root problem of climate change and energy security, the unit to which one gauges success are not congruent. Consequently, the potential arises for incompatible conflicting solutions. For example, a change in fuel composition to ethanol sourced in Brazil could potentially reduce net GHG output, but would compromise energy security by relying on a potentially volatile foreign source. Conversely, relying on domestic coal to power a fleet of electric cars could improve energy security while compromising emission targets. This perceived incompatibility has the potential to frustrate the efforts of even the most informed and well-intentioned decision-makers from determining the best alternative. Without a method to address this, future decisions are apt to be incomplete. This thesis will purport that a methodology is necessitated by the complexity and urgency posed by climate change and energy security. The Analytic Hierarchy Process (AHP)—a methodology developed by Thomas Saaty— will be employed and demonstrated on a case study in Nova Scotia, Canada.

The remainder of this proposal is organized as follows: Chapter Two, a literature review, will contextualize this study by examining decision-making in theory and practice at various levels of accuracy, with a focus on those studies which employ multi-criterion decision making tools (MCDM) such as AHP; Chapter Three, the methods section, the AHP methodology will be explained in theory and then as it will be applied to transportation related problems specifically; Chapter Four, results, will explain the specific application to a Nova Scotia case study; Chapter Five, discussion, will divulge into a critical analysis of the theory (AHP) and practice (cast study) of this idea; and finally, Chapter Six, conclusion and future work, will summarize the findings and suggest future additions to the research.

2.0 Literature Review

More often than not, government has a direct role in infrastructure investments. Large scale infrastructure projects which enter into the millions and billions of dollars have a lot at stake; these projects are usually long-term, and so are their effects. For instance, the twinning of a highway to allow an increase in traffic volumes has implications long beyond the completion of the project itself—GHG emissions from increased traffic, greater petroleum dependence, maintenance costs, etc. In such instances, an informed and complete decision-making process is vital. The Nova Scotia Department of Transport and Infrastructure Renewal (NSDTIR)—formally Department of Transport and Public Works (NSDTPW)—publishes an annual business plan, detailing what the department hopes to achieve. The second sentence in the most current report reads: "Improving and expanding our roads and highways will help us to ensure our economic and social well-being" (NSDTIR, 2009). Further in the document, two additional 'priorities' are outlined: "environmental sustainability is a priority"; "the development of the Atlantic Gateway continues to be a top priority" (NSDTIR, 2009). However, seemingly contradictory to this, the province, along with the federal government, announced a list of projects to receive funding through the 2009-2010 economic stimulus fund; none of which involve infrastructure that promotes the environmental sustainability the NSDTIRs business plan asserts (Infrastructure Canada, 2009). Although other 'priorities' could have been considered in the decision, there is no available documentation as to which criteria were included (or excluded), how they were prioritized, or the quality of data employed. This leads one to believe that decisions made at the top level of government are without a sound, rational backing—a disconcerting notion given the magnitude of the problems society faces today.

Accordingly, needed is a more inclusive method to make decisions. Multiple Criteria Decision Making (MCDM) is the broad term used to describe methods that allow for a decision-maker to operate in the presence of multiple objectives with incommensurable units (Huang, Poh, & Ang, 1995). One such MCDM methodology is the Analytical Hierarchy Process, published by Thomas Saaty in 1980. AHP equips a decision maker with a rational framework for structuring a problem, quantifying its elements in small scale hierarchies and for the amalgamation of this data together again to rank a set of alternatives selected by the decision-maker (Saaty, 1980). It lets the decision-maker “derive relative priorities on absolute scales … from both discrete and continuous paired comparisons” (Saaty, 2006). In other words, AHP has built into its essence, the means to rank aspects of any nature or relationship to the other. The problem is decomposed into a goal, followed by sub-goals, or criteria, which define the goal. Below this are the alternatives which will potentially work toward the attainment of the goal as they are filtered through each criterion (Saaty, 1980). The result is a ranking of alternatives which reflect the goal and the various importance of the criteria of which it composes. The elements of the hierarchy can relate to any aspect of the decision problem—tangible or intangible, carefully measured or roughly estimated, well- or poorly-understood—anything that applies to the decision at hand (Saaty, 1980). Forman and Gass (2001) say the best way to explain the methodology is to describe, what they claim to be its three basic functions: (1) structuring complexity, (2) measuring on ratio scale, and (3) synthesizing.

The hierarchical structure allows complex issues to be broken down into more easily ‘digestible’ sub problems (Forman & Gass, 2001). Second, the measurement of components on a ratio scale allows results to be multiplied and manipulated within the hierarchy (Forman & Gass, 2001). Third, it allows for a quick and intuitive synthesis of what would have been, under normal circumstances, too many elements for the human mind to synthesize intuitively (Forman & Gass, 2001).

Although seemingly unknown to some government bodies, the use of AHP in academia and the private sector is not new. Particularly in the area of energy and transportation, there have been a many applications of varying context, complexity, and scope.

In a Japanese government sponsored endeavour, Kagazyo et al. (1997) conducted an impressive study of alternatives for both environmental and energy improvement technologies using AHP—of both the replacement and reduction calibre. Its inception was rooted in concerns over environmental degradation, as well as the Japanese economic reality of slow economic growth and therefore the need for smart allocation of scarce financial resources. Spanning two hierarchies, eight perspectives, fourteen criteria, twenty-three sub-criteria, and over two dozen alternatives, the study made some significant findings. However, the most important aspect to draw from this case study—other than the displaying what a well-funded AHP study can achieve—is the varying perspectives applied. The investment of resources to achieve long term gains in the environment, economy and society depend on where each jurisdictions' priorities lie. The 'least developed county' perspective—as applied—placed a much higher priority on the technology's cost and lower on environmental or social burden in the short term.

Works focusing on policy include the Berrittella et al. (2007) study which applies AHP to determine the best transportation policy to mitigate GHG emissions, while accommodating other criteria as well as conflicting opinions in the scientific community about the importance of such measures. Zhang et al. (2006) employees a similar method, but applies it to six cities in the United Kingdom. Vold (2005) looks at road tolls and other disincentives to mitigate vehicle emissions in Oslo, Norway.

However, while these studies include climate change considerations in their criteria, energy security is often omitted, if acknowledged at all. Sheth's (2008) work incorporates this other key element to rank home heating fuels based on criteria. These involve: environment, energy security, public acceptance, technology, and cost. The reduction and replacement alternatives are separated into two different hierarchies. Sheth applied the hierarchies to a social-environmental viewpoint followed by the consumer viewpoint. The ranking of home heating alternatives from a social-environmental perspective were then compared to the rankings from the consumer's point of view. A sensitivity analysis was then conducted to both, determining which of the criteria could be influenced and by what alternative to change the order. Sheth's thesis illuminates the possibility of enacting policy to sway the ranking of the consumer viewpoint to better fit the desired socio-environmental alternatives. Sheth proposes potential policy to address the gap in social and individual perspectives.

Poh and Ang (1999) published a study which employed AHP to determine fuel alternatives for private vehicles in Singapore; replacement alternatives. The criteria employed were similar to Sheth's, but included safety. A pre-screening of alternatives narrowed the options down to: status quo (oil); oil and natural gas; oil and electric; and methanol. They followed much the same format as Sheth where a template hierarchy was constructed and then applied to the social-environmental and consumer perspective. The socio-environmental viewpoint ranked, in order, oil/EV, status quo, oil/NGV, and methanol. Conversely, status quo, oil/EV, oil/NGV, and methanol resulted from the consumer viewpoint. A sensitivity analysis was then conducted on the consumer viewpoint to determine the net change needed for each to overtake the top alternative, the status quo. Poh and Ang continued on to suggest the policy to favour the ideal socio-economic solution (oil/EV) so as it is accepted by the general public. Through the manipulation of the hierarchy, they determined the effectiveness of each policy and alternations, if needed, to obtain the desired ranking.

AHP has functioned as a tool to determine some sort of answer to problems of various size, complexity and nature. Its adaptability exhibited by the large number of studies on the issue, show and AHP can be used in any jurisdiction with any set of variables and criteria.

3.0 Methods

After an extensive review and identification of potential reduction and replacement alternatives, one can go further to determine which alternative is best suited to succeed in achieving the goal at hand. Although the potential exists to evaluate the goal from many different perspectives, the fundamental decision making methodology must remain consistent. As aforementioned, Saaty's (1980) Analytic Hierarchy Process serves as an effective methodology for ranking alternatives given a complex set of criteria while also accommodating many different perspectives and priorities. Section 3.1 will describe the empirical theory of the process as it would be applied to any circumstance of a similar nature. Section 3.2 will then outline how this methodology could be applied to transportation problems.

3.1 AHP in Theory

AHP is flexible, in that it can be applied to many different circumstances. The following subsections will outline five fundamental steps to using AHP. These are interpreted from Saaty's (1980) initial publication of the method.

3.1.1 Stage 1: Decomposition

The first step involves decomposition of the problem into a simplified hierarchy. This decision-making hierarchy forms the basis of evaluation. As previously touched on, the hierarchy is decomposed

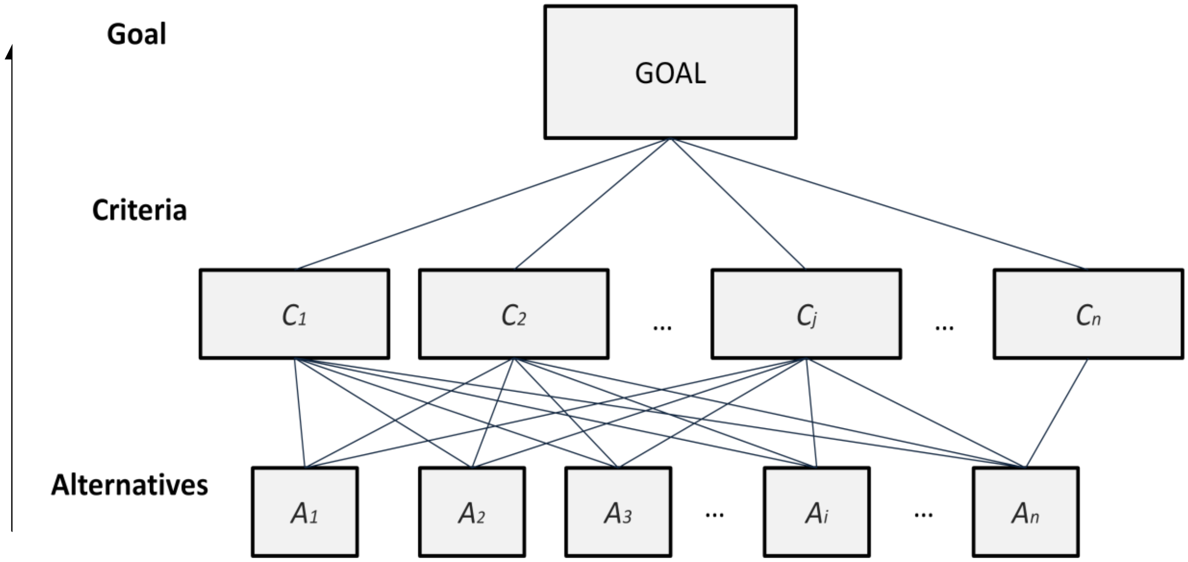

Figure 2 A theoretical decomposition of a problem with *J* criteria and *I* alternatives

into three stratified components: goal, criteria (and sub-criteria, if applicable), and the alternatives (Figure 2). The goal is at the top; it is a vision to which all subsequent levels work toward. Directly below are the criteria. Each criterion represents an aspect, quantitative or qualitative, that is related in some direct way to the achievement of the goal. Each criterion has a functional unit against which lower levels are evaluated. The alternatives, which make up the final level, are any solution that could possibly achieve the goal.

At this stage, the elements at each level are void of a subjective 'potency', or weight; the hierarchy serves only as an objective, schematic display of the components of the decision-making process. Although the definition of 'ideal' differs across various subjective bodies—as will be represented in the ranking of criteria—all parties have a shared understanding of what the term fundamentally means (intersubjectively verifiable). With this in mind, it should be noted that the elements that can be included into the model are numerous, and that while some parties would devalue one criterion in practice, that does not in itself merit the element's exclusion from the process. It is this principle that gives AHP its objective credibility, as it permits the representation of any number of criteria. In essence, the AHP produced hierarchy is virtually transparent, tamper-proof, and non-exclusive.

3.1.2 Stage 2: Define perspective

In this step, the prospective viewpoints are identified. The interpretation of the goal is what separates one viewpoint from another. This is subsequently represented, first, in the priorities placed on each criterion, which in turn influences the ranking of the alternatives. Any number of viewpoints can be taken, and the more that are applied to the model, the greater the opportunity is for critical comparison of the respective results.

3.1.3 Stage 3: Priority Allocation

Once a perspective is identified, the model can be executed. There are two levels of comparison in a three level hierarchy: *criteria to goal* and *alternatives to criterion* (note grammatical number). Both levels are interconnected, however the procedure of comparison is independent of level but rather on the nature of the data itself—qualitative or quantitative. The nature of the data is determined by the upper most component in the comparison (i.e. the criterion when comparing alternatives and the goal with criteria). The purpose of this stage is to derive a *priority vector* for each comparison. This is simply a normalized list of numeric weights corresponding to each component of comparison.

3.1.3.1 Quantitative Priority Setting

Clearly, comparisons which can be weighed against each other with quantitative data are most 'cut-and-dry' in priority setting. For example, if a student is deciding the best route to school, quantitative comparisons could be distance, maximum slope of path or time of travel of each alternative. One need only normalize the predetermined numerical values. These data are then normalized and inputted directly into the priority vector. Only *alternative to criterion* comparisons can be quantitative, as per the fundamental principle of AHP.

3.1.3.2 Qualitative Pairwise Comparison

Qualitative comparisons pose a different challenge to the decision maker, as the priorities cannot be so easily rendered. All *criteria to goal* comparisons are fundamentally qualitative, as the goal is defined by the subjective ranking of the succeeding criteria of varying units of measurement. In the same walk to school example, the goal to find the 'best' route is determined by the importance level for the evaluator, and therefore changes with the perspective; in other words, the importance placed on each of the criteria in achieving the goal. *Alternatives to criterion* comparisons can also be qualitative:

perceived safety, aesthetics or appeal of odour[2]. Saaty (1980) developed a method of deriving priorities from qualitative data. It is based on the same procedure one would follow when comparing the weight of two rocks without a scale. To find the heaviest rock (goal/criterion), one would start by comparing the two in each hand; a *pairwise* comparison. In the absence of a scale, this is required. Applying this principle to a larger set of comparisons—four rocks, for example—one would compare all $\binom{n}{2}$ combinations. Saaty uses a 1-9 scale when comparing element *i* and *j*, where a value of 1 confers equal importance; and 9, extreme importance of *i* over *j* (see Table 1). These comparisons are placed in an *n* x *n judgement matrix* (Table 2).

Once this matrix is constructed, multiply the *n* elements in each row and take the n^{th} root. Normalize the resulting column to create the priority matrix.

Table 1 Absolute weights applied to qualitative paired comparisons (Saaty & Vargas, 2006, pp. 7)

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one activity over another
5	Strong importance	Experience and judgment strongly favour one activity over another
7	Very strong demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent values	Used when compromise is needed

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[2] Contrary to qualitative *criteria to goal* comparisons, all effort must be made to exclude bias from the *alternative to criterion* judgements. Qualitative alternative comparisons are intended to mimic the absolute nature of quantitative comparisons, which are constant regardless of the perspective utilizing the model.

Table 2 Judgement matrix with *n* comparisons

$$\begin{bmatrix} 1 & a_{1\,2} & \cdots & a_{1\,j} & \cdots & a_{1\,n} \\ a_{2\,1} & 1 & \cdots & a_{2\,j} & \cdots & a_{2\,n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ a_{i\,1} & a_{11} & \cdots & 1 & \cdots & a_{i\,n} \\ \vdots & \vdots & \cdots & \cdots & \cdots & \vdots \\ a_{n\,1} & a_{n\,2} & \cdots & a_{ij} & \cdots & 1 \end{bmatrix}$$

3.1.4 Stage 4: Rank alternatives

At this stage, the interconnectivity of the system is put to use. Now, each criterion has a priority vector representing the importance or influence of each alternative on the corresponding criterion. The goal has a priority vector of the *criteria to goal* comparison as well. According to the hierarchical structure, the goal must have a priority of one, and each level below must be a breakdown of that number. The alternative priority vector under each criterion is then normalized to equal the sum of its respective criterion's priority. The new priorities of each alternative are, in turn, summed, thus ranking the 'ideal' alternatives. The sum of the *n* alternatives must equal one.

3.2 AHP in a Transportation Context

Now that the theory of AHP has been made clear, a more specific methodology can be outlined and applied. Dr. Larry Hughes of Dalhousie University Faculty of Engineering created a program in Microsoft© Excel™ using the macros functionality, utilizing the Visual Basic programming language. This program includes the calculations aforementioned and was used in this models application. This section will serve as an explanation and justification for applying the AHP methodology to transportation planning.

The goal was to rank each alternative in its ability to achieve the 'ideal' transportation system (Figure 3). The goal is intersubjectively verifiable, in that all subjective individuals could agree on the need for an 'ideal' transport system. Three criteria were considered: (1) climate change, as represented by GHG equivalents; (2) the security of the energy source; and (3) the cost, as represented in conventional monetary instruments. As outlined in the theoretical description of the process, any criterion can be included. Also described above, the number of pairwise comparisons and computations increases exponentially with each new criterion considered. To clarify: this thesis was intended to be demonstrative of the capabilities of AHP rather than an exhaustive study and, as such, the three criteria chosen adequately represent the objectives of this thesis. The alternatives are not decided at this stage, as they are specific to the jurisdiction this model is applied.

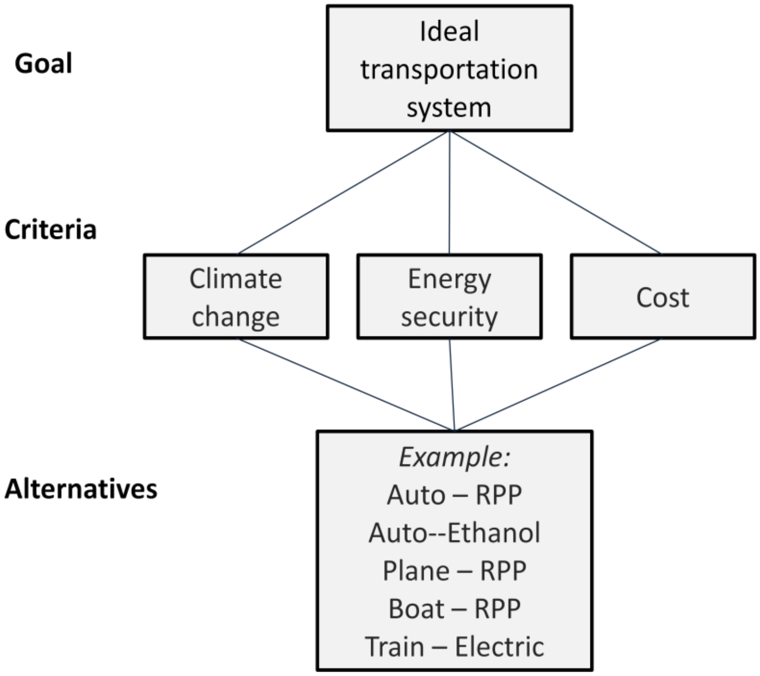

Figure 3 Decomposition of the decision to find the ideal transport system

The perspectives were then identified and applied to this model. All of the *alternatives to criterion* comparisons are quantitative, therefore the values were directly placed into the Excel matrix, requiring only normalization. It is necessary to note that the quantitative value of energy security was derived from Hughes and Sheth’s (2008) energy security index—the product of another application of AHP. Further explanation can be found in Appendix B. The pairwise *criteria to goal* comparisons were then conducted, allowing the program to calculate the final ranking. As the priority vectors of the each *alternatives to criterion* comparison remain constant across all perspectives, the user needed only to redo the *criteria to goal* pairwise comparison for a change in perspective. The model was then run again with the various perspectives, resulting in several different rankings.

4.0 Case Study – Nova Scotia: Halifax to Kentville

Nova Scotia is a small province located on Canada's Atlantic coast. As of 2007, the population was 934 000, with an annual growth rate of 0.26% (CANSIM, 2009). The province is the second smallest and the fourth-least-populated, but exhibits the second highest population density in the country. Not unlike many other industrialized economies, fossil fuels—particularly petroleum—are heavily integrated into the provinces energy mix. As seen in Figure 4 **Nova Scotia 2004 energy use by final demand in petajoules (Hughes, 2007)**Figure 4, the transportation sector is the largest energy consumer and is almost entirely fuelled by petroleum. Adding to this, the petroleum primarily consumed in Nova Scotia is from out-of-province, leaving this jurisdiction highly susceptible to supply fluctuations that are beyond the province's realm of influence (Hughes, 2007). Furthermore, the high dependence on fossil fuels represents an energy situation contradictory to the urgent realities of climate change. Nova Scotians—its people and its government—have some difficult choices to make; these are decisions which go beyond a single unit or criterion. This is where the Analytic Hierarchy Process can be used to determine the most encompassing solutions.

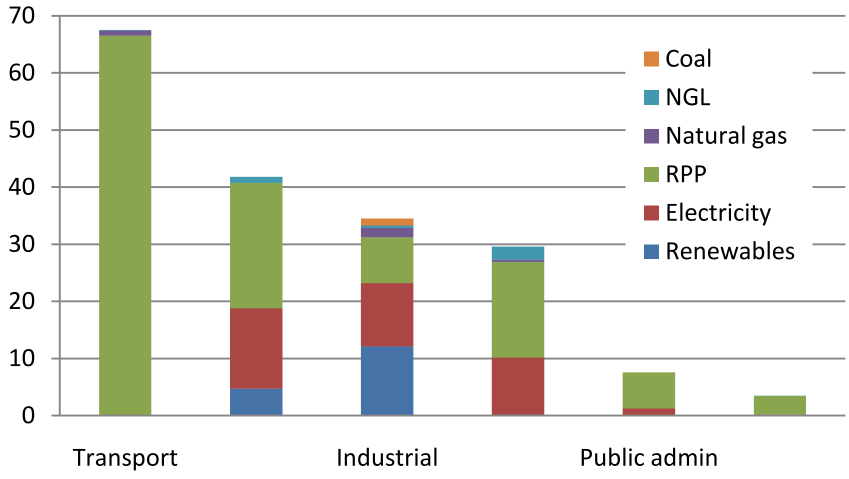

Figure 4 Nova Scotia 2004 energy use by final demand in petajoules (Hughes, 2007)

The case study was focused on the transportation corridor between the municipalities of Halifax Regional (HRM) and Kings County (via Hants County). This corridor was chosen for the strong population growth exhibited in the last two decades (see Figure 5). Therefore, it was intuitive to select this corridor as a focus for this application of AHP, as it can feasibly be predicted that transport traffic will increase in the future.

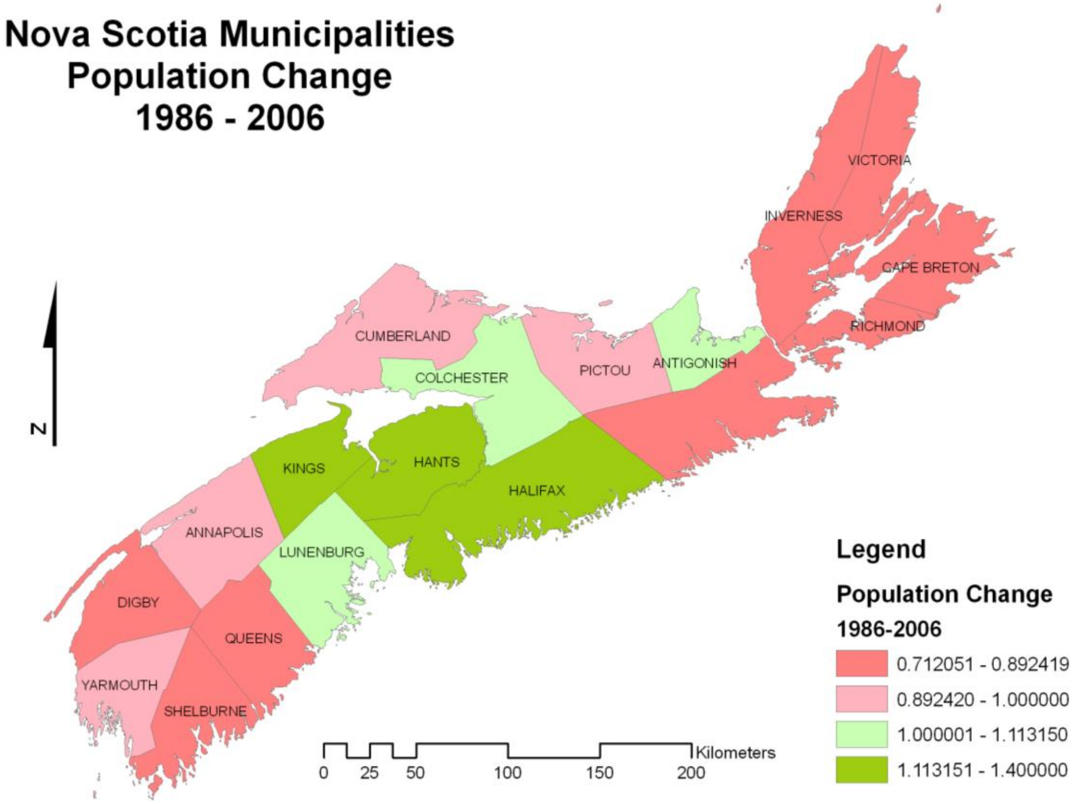

Figure 5

4.1 Alternative Selection

As aforementioned, the selection of alternatives to be inputted into the AHP algorithm is unique to each energy consuming jurisdiction. Using Hughes' (2009) 4Rs methodology, the most appropriate alternatives were identified for this corridor. The review defines the status quo in Nova Scoita—a baseline to which the subsequent review and replacement alternatives are referenced.

4.1.1Review

HRM and Kings County are separated by a direct distance of 87 kilometres (NRCan, 2009; GIS). The primary road-based infrastructure servicing the two municipalities is the provincial highway 101, while the provincial Trunk Highway 1 serves congruent as a secondary route (NSDTPW, 2008). Additionally, a rail line is currently maintained to serviceable standards by the Windsor Hantsport Railways Company (WHRC)—a short line subsidiary of Canadian National (CN) Railway (CN Rail, 2006). Currently, there is no passenger service along the WHRC rail corridor, insinuating that almost all transport is made on road infrastructure. A breakdown of Nova Scotia energy consumption by passenger transport mode is seen in Table 3. This breakdown reveals road-based passenger transport accounts for almost all of the energy used in this subsector (99.9%), with private vehicles (96.6%) accounting for most of this (NRCan, 2009)

Table 3 Final energy use by passenger transport mode on rail and road infrastructure in 2006 (NRCan, 2009)

Mode	2° Energy Use (PJ)	Proportion (%)
Passenger Light Trucks	15.01	41.4
Small Cars	13.17	36.4
Large Cars	6.70	18.5
Urban Transit	0.54	1.5
School Buses	0.35	1.0
Inter-City Buses	0.29	0.8
Motorcycles	0.12	0.3
Passenger Rail	0.04	0.1

Road

As nearly all passenger movement between Halifax and Kentville occurs on road infrastructure, an accurate depiction of total passenger movement can be determined from these routes. In particular, traffic counts serve as a good tool for estimating these counts. The NSDTPW keeps an extensive, up-to-date record of traffic vehicle counts along Nova Scotia's primary highway network. The count data provided is broken down into equidistant segments of ten kilometres, sometimes broken into 5 km.

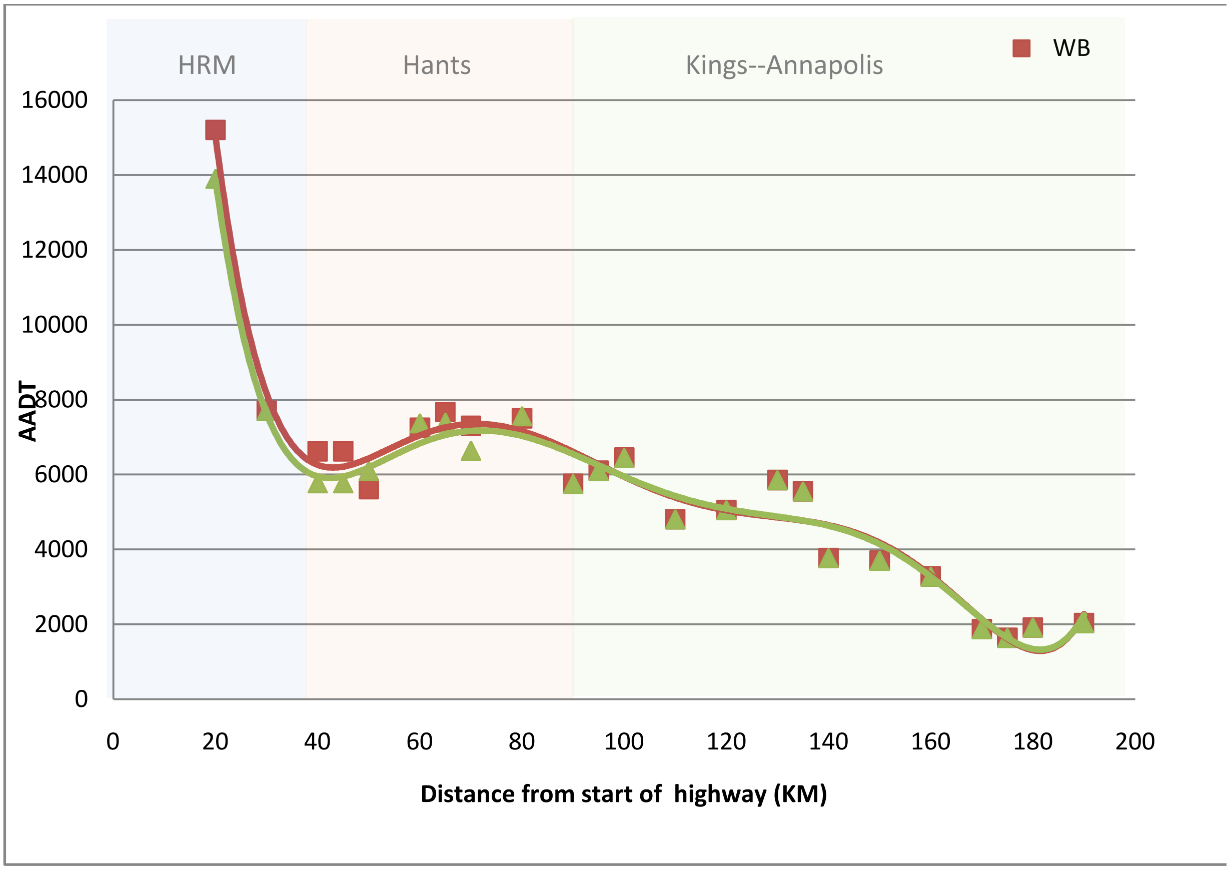

Figure 6 Highway 101 traffic volumes by distance from Halifax (AADT) (NSDTPW, 2008)

Figure 6 displays vehicle counts obtained from a portion of highway 101 between approximately 20 and 190 kilometres, transverse HRM, Hants, and Kings. Traffic near the urban centres—within HRM; between Kentville and Wolfville—show modest to extreme fluctuations in counts. This can logically be explained by short distance travel between or within the specific area. As there are no significant settlements between Kentville and Halifax, intercity traffic was determined from the counts located at d=40, or the distance between exit 3 and 4—the longest distance between exits along this portion of the corridor. Averaged over a year, the 2007 daily movement of vehicles moving east to Halifax and west to Kentville were 6640 and 6440, respectively, totalling 13080 per day (NSDTPW, 2008). In Nova Scotia, the ratio of light vehicles to medium trucks to heavy trucks in 2005 was 97:1:2 (NRCan, 2007). Given these data, the following assumptions were made: medium and heavy trucks are commercial; all light vehicles carry passenger traffic; there are 1.15 passengers per vehicle; these proportions are constant throughout Nova Scotia; and all vehicles counted in sections 040 and 045 continue to the specified centres. From this, the count was estimated at 14591 passengers per day (13080*0.97*1.15 = 14591).

Rail

The rail line servicing Halifax and Kentville runs a distance of approximately 116 kilometres, rarely deviating far from the its roadway counterpart. However, unlike the highway 101, the line is only utilised for infrequent short line freight trips, made by the aforementioned WHRC. Carrying mainly grain, gypsum rock, lumber, vegetable oil between Hantsport and the Windsor Junction or toward the valley, the railway is maintained to service standards (CNRail, 2006).

4.1.2 Reduction

In this circumstance, reduction occurs through improvements in energy efficiency through either (1) reduction in overall passenger-kilometres travelled or; (2) increases in efficiency per passenger-kilometre. Many potential alternatives exist to satisfy the former, such as: road tolls; gasoline taxes; effective urban planning and; policies which encourage telecommuting. These alternatives are mostly policy based, but this case study will address the infrastructure itself, which inherently encourages the private vehicle lifestyle. The use of intercity buses and passenger rail are two alternatives which can potentially yield reductions in energy consumption passenger-kilometre. The potential of these two is anecdotally feasible to use in the Halifax-Kentville corridor, given the available infrastructure.

4.1.3 Replacement

Given the alternatives above, reduction alternatives strip away efficiency gains and look solely at the fuel itself. The options here are numerous, including, but not limited to: conventional diesel or gasoline, ethanol, secondary sources (ex. Hydrogen, electricity), natural gas, and methane. This case study will examine the use of electricity and conventional gasoline.

4.1.4 Final Alternatives

Four alternatives were selected based on the principals of reduction and replacement and are summarized in Table 4. Yet, alternative modes of transport cannot realistically be implemented to one hundred percent of the modal split—a level each alternative implies if they were applied to the AHP evaluation. Given the complexity of climate change and energy security, extremes of 100 percent to zero will likely not solve the problem, but rather a mix of techniques and solutions. A 'blend' of alternatives provides a more realistic vision of alternatives for this corridor. The blends evaluated were based on modal split statistics from Denmark—a country with a similar area to Nova Scotia. The 2006 passenger split breaks down to: 78.8 percent auto; 11.2 percent bus; 9.1 percent train; and 1 percent other (Eurostat, 2009). The blended alternatives are summarized in units of passenger-km in Table 5. The status quo, as well as the theoretical 100 percent split alternatives, were included for comparison.

Table 4 Considered alternatives

Alternatives	Mode	Fuel	Short	Route (km)	Return (km)
A1	Automobile	Diesel	AD	101	202
A2	Train	Diesel	TD	118	236
A3	Train	Electric	TE	118	236
A4	Bus	Diesel	BD	101	202

Table 5 Blend alternatives included in NS application: broken down by passenger-km separated by base alternative

Passenger-km	A1	A2	A3	A4	Total	Short
B1	2947382	0	0	0	2947382	Status Quo
B2	0	3443476	0	0	3443476	TD theory
B3	0	0	3443476	0	3443476	TE theory
B4	0	0	0	2947382	2947382	BD theory
B5	2357906	309913	0	324212	2992030	DK TD
B6	2357906	0	309913	324212	2992030	DK TE

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[3] Distances retrieved from GIS spatial data represented in ArcMap (NRCan, 2009).

4.2 Implementation

This application employs the Excel-VBA software to assign rank to the above alternatives.

4.2.1 Step 1: Decomposition

With the alternatives established, all the elements of the decision-making process can be placed in the hierarchy (Figure 7). As per section 3.2, the goal is to rank the alternatives to best match the ‘ideal’ transportation system, which includes considerations of energy security, climate change, and cost. This stage only requires the alternatives to be inputted in the “Start” worksheet of the VBA software.

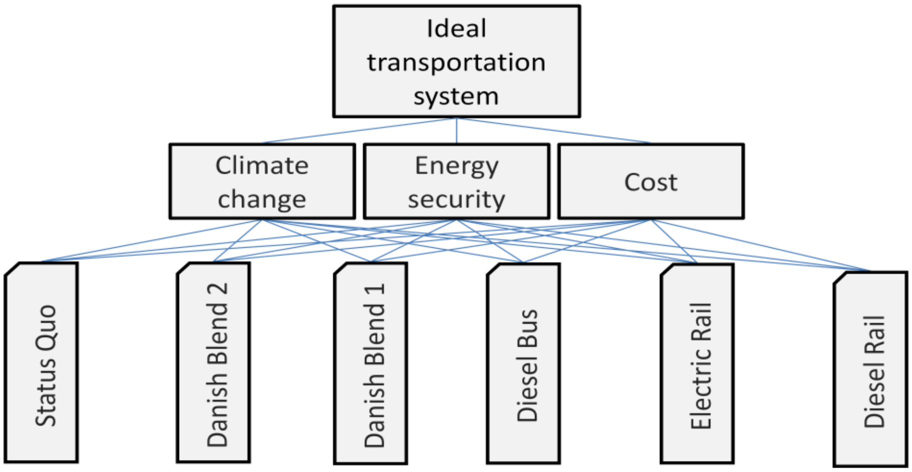

Figure 7 Schematic decomposition of Halifax-Kentville transport alternatives.

4.2.2 Step 2: Define Perspective

Any number of perspectives can be taken and applied to this hierarchy. For this case study through, four theoretical perspectives were chosen which are thought to give the best idea of the varying definitions of ‘ideal’ existing in society.

Table 6 Breakdown of the four perspectives applied to the Halifax-Kentville alternative selection process

Focus	Definition of 'ideal'
Cost	Ideally, a decision would focus mainly on costs of the alternative, with little consideration for climate and energy security issues. The cost of building and maintaining new infrastructure and rolling stock will quickly make an alternative look unattractive.
Climate	The ideal transportation alternative would look almost exclusively at the alternative's greenhouse gas emissions. The greater the GHG emissions, the less attractive the alternative will be.
Security	Energy security is society's main priority. The window for climate change abatement has closed. All our resources, regardless of cost, should go toward securing energy for the future stability of the economy
Cost and Security	Cost and energy security are held on a high pedestal when it comes to determining alternatives. The ideal transport alternative equally considers the security of the fuel itself and its consumption, as well as cost.
Climate and Security	Climate change and energy security are two issues which cannot be played down when determining alternatives for transportation. Cost is no object when trying to find solutions to these urgent problems.

4.2.3 Step 3: Priority Allocation

Priority vectors for each level were then determined. Priority allocation occurs at the criterion level (with respect to the goal) and the alternative level (with respect to each criterion). The five perspectives individually applied to the Excel-VBA program.

Criteria to Goal

Taking any one of the five perspectives above, qualitative judgements using Saaty's scale were made in the 'criteria' workbook. The vectors are summarized in Table 7.

Table 7 Criterion priority allocation by perspective

Focus Priority	Cost	Climate	Security	Cost and Security	Climate and Security
Priority of Climate	0.11	0.70	0.15	0.07	0.47
Priority of Security	0.11	0.21	0.72	0.47	0.47
Priority of Cost	0.77	0.09	0.13	0.47	0.07

Alternatives to Criterion

Contrary to the criterion level priority assignment, the alternative level priorities are independent of perspective and therefore remained the same for the five runs of the software. Table 8 contains a summary of the findings, while specific numbers and their sources can be found in the accompanying software spreadsheet.

Table 8 Input data to be inputted into VBA-Excel program

	CC	**ESI**	**Cost**
B1	220.82	69263	$ 4,328,567.10
B2	235.40	80922	$ 21,625,414.72
B3	442.00	136017	$ 42,572,259.76
B4	175.89	69263	$ 5,849,625.91
B5	217.19	70313	$ 25,609,528.73
B6	235.79	75271	$ 46,683,260.73

Climate: The alternatives were judged against their respective CO_2e emissions per passenger-kilometre. To determine the GHG intensities of each blend, the emissions intensity per passenger kilometre (CO_2e/pkm) was determined. Natural Resources Canada achieves up-to-date GHG and energy statistics. Data for GHG and energy use by passenger transportation mode enabled the determination of GHG intensity per unit energy. Energy intensity per pkm was also provided, allowing the GHG/pkm to be determined. For the rail based alternatives, national statistics were used, as rail transport numbers were too small to accrue an accurate GHG count. All other alternatives used smaller scale provincial statistics, as the sample size was large enough to extrapolate to the 101 travelling vehicles. While rail infrastructure alternatives—A2 and A3—share the same energy intensity per pkm, GHG emissions varies for A3, as the fuel is electricity—a secondary source with multiple sources. To determine the GHG/MJ for Nova Scotia electricity, NRCan's electricity emissions stats for Canada were consulted and a weighted mean of emissions from various sources were determined. For further details, refer to Appendix B.

Energy Security: Already stated, Hughes and Sheth's (2008) energy security index was used to assign a quantitative value to an otherwise multi-faceted qualitative issue. Conveniently, the authors chose Nova Scotia as their demonstrative case study. As such, the ESI values synthesized were employed for this case study. As under the climate change criterion, a secondary energy source—electricity—required some special attention. The same method was used above where the provinces electricity source was disaggregated, attached the appropriate ESI value, and then normalized.

Cost: The alternatives were ranked against each other based on annual running cost and then initial infrastructure and rolling stock investment. Both the road system and rails were assumed to be adequate to meet demand at the point of study. Maintenance costs include routine repairs, litter pick-up, line painting and signal maintenance as well snow and ice removal, accident clean-up, natural disasters. This was averaged over a 60 year period to reflect the long term nature of an infrastructural investment.

4.3 Results and Interpretation

The data were synthesized in the Excel-VBA software, yielding one preliminary priority matrix (Table 9) and five final priority matrices for each perspective. The results are summed up below.

Table 9 Preliminary and final Priority Vectors of NS Case Study

Preliminary	Climate	Security	Cost
Priority of alternative Status Quo	0.18	0.14	0.43
Priority of alternative Rail - Diesel	0.17	0.16	0.09
Priority of alternative Rail - Electric	0.09	0.27	0.04
Priority of alternative Bus - Diesel	0.22	0.14	0.32
Priority of alternative Realistic (RD)	0.18	0.14	0.07
Priority of alternative Realistic (RE)	0.17	0.15	0.04

Final

Cost *11:11:77*	Rank
Final priority: Status Quo	0.37
Final priority: Bus - Diesel	0.29
Final priority: Rail - Diesel	0.10
Final priority: Realistic (RD)	0.09
Final priority: Rail - Electric	0.07
Final priority: Realistic (RE)	0.07

Security *15:72:13*	Rank
Final priority: Rail - Electric	0.21
Final priority: Status Quo	0.18
Final priority: Bus - Diesel	0.17
Final priority: Rail - Diesel	0.15
Final priority: Realistic (RE)	0.14
Final priority: Realistic (RD)	0.14

Climate *70:21:09*	Rank
Final priority: Bus - Diesel	0.21
Final priority: Status Quo	0.19
Final priority: Realistic (RD)	0.16
Final priority: Rail - Diesel	0.16
Final priority: Realistic (RE)	0.15
Final priority: Rail - Electric	0.12

Cost-Security *7:47:47*	Rank
Final priority: Status Quo	0.28
Final priority: Bus - Diesel	0.23
Final priority: Rail - Electric	0.15
Final priority: Rail - Diesel	0.13
Final priority: Realistic (RD)	0.11
Final priority: Realistic (RE)	0.10

Climate-Security *47:47:07*	Rank
Final priority: Bus - Diesel	0.19
Final priority: Status Quo	0.18
Final priority: Rail - Electric	0.17
Final priority: Rail - Diesel	0.16
Final priority: Realistic (RD)	0.15
Final priority: Realistic (RE)	0.15

4.3.1 Preliminary Priority Vectors

Notes on Climate

Perhaps one of the most notable divergences from pervious assumptions is the ranking of the status quo. The 'do nothing' status quo alternative tied for second place in the ranking with the realistic blend B5. Just as surprising, both rail options occupied the lowest place in the ranking, with electric rail in a notable last. Electricity turned out to be the most emission intense fuel energy unit analyzed; this is may seem counterintuitive as there is no 'tailpipe' emissions emitted from its users, but makes sense when the fuel make-up and inefficiency of conversion and transmission are considered in their entirety. Therefore, the small energy intensity advantage per passenger kilometre enjoyed by rail travel is eclipsed by the drawbacks in GHGs as well as the overall length of the track compared to road.

Notes on Energy Security

Initial observations of the energy security ranking reveal that electricity—contrary to the previous criterion climate change—is significantly more energy secure than the primarily diesel fuel source in the other options. The remainder of the results are as predicted and are relatively equal in weight.

Notes on Cost

The significant capital needed for the investment in, and the maintenance of, an electric rail system is clearly seen in the rankings of both 100 percent B4 and blended B6—they exhibit the lowest ratio ranking across all criteria. In fact, alternative that involves rail received a low rank for the same reasons. Blend B5 and B6 —encompassing both road and electric/diesel rail infrastructures—is significantly burdened with the weight of two systems that demand constant maintenance and continued investment.

4.3.2 Final Priority Vectors

As mentioned, there were five perspectives applied to the hierarchy, therefore there are five syntheses of those alternative-criterion vectors discussed above. The single focus perspectives—cost, security or climate-centric—yielded results similar to the their respective preliminary vectors, as the relative weight was placed quite high on that aspect. The double-focused perspectives—cost-security and climate-security—exhibited a ranking that, at first glance, is not instantly intuitive. Examining the cost-security focus (7:47:47; $x_{climate}$:$y_{security}$:z_{cost}:), the status quo ranked the highest, while the 100 percent electric rail alternative ranked third, despite its significant lead over the alternatives in the security criterion. However, the ranking proved the cost to be too high given the priority settings. Slightly more complicated is the placement of the realistic blends. The high cost of the two continues to devalue their place in the corridor's transportation alternative ranking. Even in the climate-security perspective rankings, diesel status quo remains a close second place behind a 100 percent diesel bus system.

5.0 Conclusion and Future Work

This thesis presented a solution in response to two major issues of that will define this period—climate change and energy security—and to the disconcerting lack of action and method being taken and applied in high stake decision-making offices. Using the well tested AHP methodology, these two issues, which were once seen as incomparable, were able to be internalized and applied to a suite of alternatives which pose a possible solution. However, any which employs the analytic hierarchy process cannot be rightly claimed as complete; on the contrary, the work done here, as with any other study, is a work in progress. The very nature of AHP encourages re-evaluation and re-application, as the conditions which merited one decision may not hold true for another. The structure of AHP makes the strengths and shortcomings of one's particular application very apparent. This thesis is no different and future work that responds to the accepted limitations is welcomed and encouraged.

5.1 Limitations

Starting at the bottom of the hierarchy, there were acknowledged shortcomings in the selected alternatives to be evaluated. Limitations occur both in the attributes attached to the alternatives, as well as the alternative's very inclusion or exclusion. Most of the alternatives evaluated had little logistical information attached to them—station location, speed of travel, an agency-to-consumer cost breakdown, potential ridership, fleet size, etc. For example, the GHG data collected for the 100 percent diesel train alternative was derived from averaged, nation-wide data for passenger rail in pkm, GJ consumption, and CO_2e—thus suppressing possible representation of a train system that employed, say, more efficient locomotives or a smart trip planning program to identify improvements that could decrease the number of vacant seats—increasing efficiency. Second, the inclusion of the more-or-less 'realistic' blended alternatives with the theoretical 'pure' alternatives was done to exhibit rankings of a good variation of alternatives. However, the comparisons, although compatible, were somewhat redundant. Under the selected criteria, the ‘pure’ alternative was almost always favoured; this was particularly apparent with cost, where the realistic blend was heavily weighted down by the real-life reality of multi-modal transport (i.e. many forms of expensive infrastructure); meanwhile, the theoretical easily pushed out the blends as it skipped the phases of implementation.

This point leads to the next limitation: criteria selection. As just mentioned, the criteria selected for the application favoured the more unrealistic ideals. Common sense would tell anyone that switching from 100 percent auto to 100 percent bus would be unfeasible. As the AHP hierarchy can be broken down whatever way the decision-maker likes, any set of criteria can be chosen to define the goal. This is not a bad thing, nor a shortcoming of AHP, as the criteria selected are always visible in the hierarchical structure. Therefore, this limitation is represented more as a loss in potential functionality of the model than a comment on its accuracy. Understandably, there more criteria that can be included, the more substantial and well-rounded the solution would be. However, looking into the methodology, the number of pair-wise comparisons increases exponentially with each additional criterion. The decision-maker must wary of what exactly they are trying to portray and for what purpose before they immerse themselves in tedious data collection and input.

5.2 Future Work

It is appropriate to end a thesis such as this one with a section that implies continuity. As mentioned, much room exists to expand on the methodology built in this thesis. Future additions to this could include:

- Expanding detail attached to each alternative. This would result in the final ranking of alternatives to be more precise.
- Separate like-alternatives into different their own sub-groups, and evaluate them separately. The larger the scope of the study, the more this will be logically required. Both Sheth (2008) and Kagazyo (1997) did this to separate alternatives into their own specific

hierarchies. This will expand the conclusions which can be drawn from the work without suppressing important considerations.

- Include more criteria to expand the functionality of the model. One such criterion which can be included is public participation: this would succeed in bridging the gap between the often thick divide between academia and real world scenarios of rational and emotional thought. AHP is more than apt to accommodate the qualitative judgements characteristic of public involvement.

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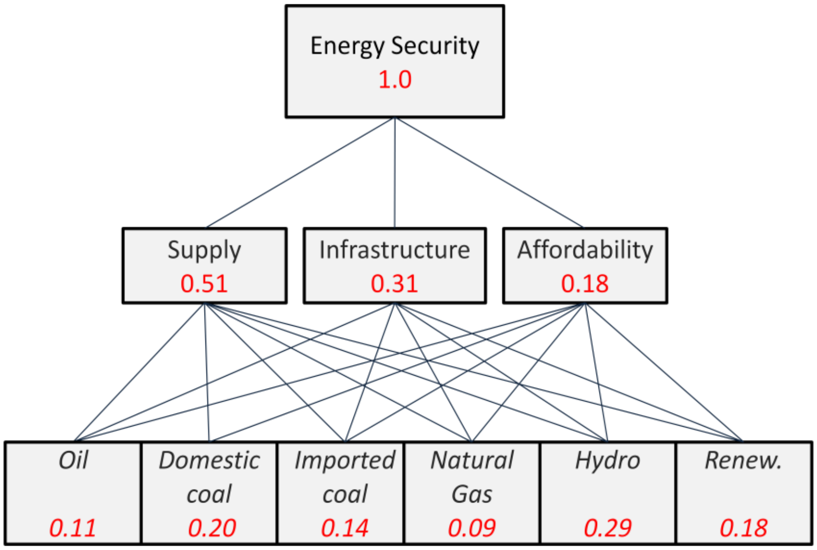
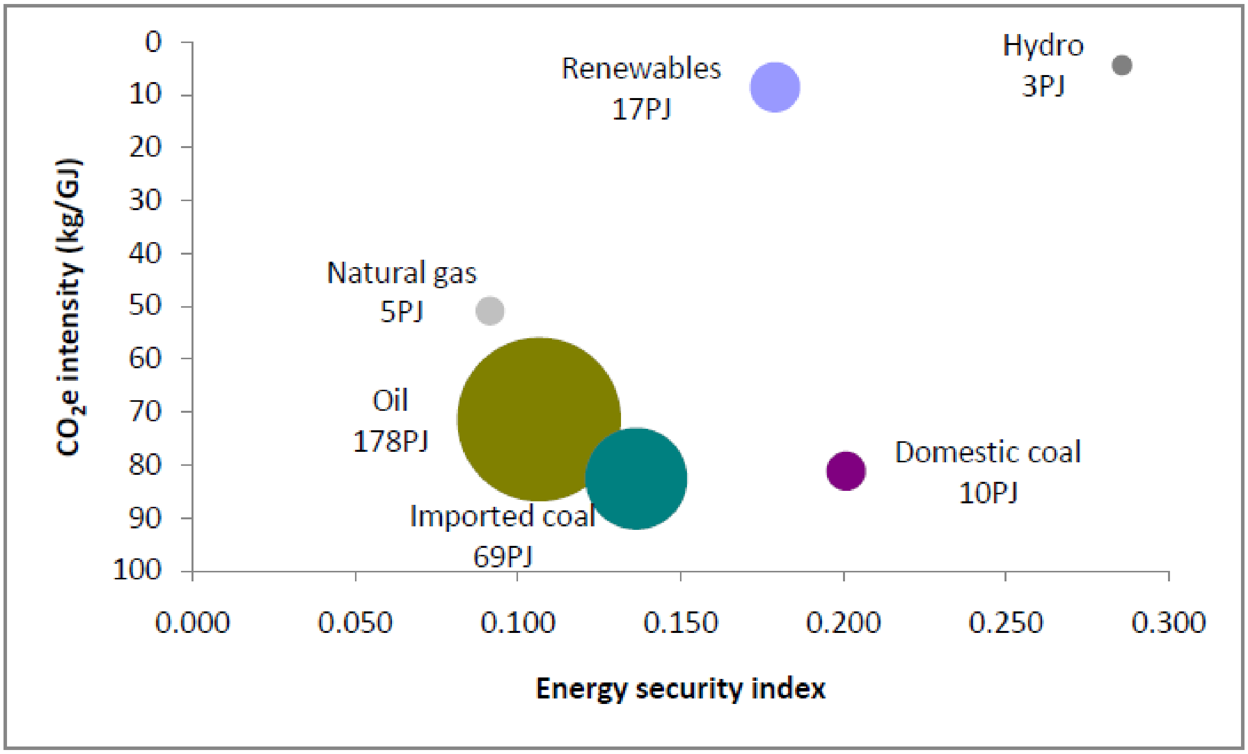
Appendix A - Energy Security Index (Hughes & Sheth. 2008)

In their study, Hughes and Sheth used AHP to decompose the problem of energy security. One of their case studies was in Nova Scotia, Canada, whose primary energy sources were listed as alternatives. The objective was to determine the energy security from a ‘scientific’ perspective. To achieve this, the ranking of the criteria were decided by a panel of academics, which came to a consensus on each pairwise comparison. The results are shown below. The graph displays their findings relative to CO_2eq intensity (y-axis) and consumption (area of point).





Appendix B – Data Source: Climate Change

CC-1 Energy intensity by mode, Canada totals in 2006

Mode	2006 PJ º	pkm º	MtCO2e¶	MJ/pkm	
Small Cars[1]	309.02	176896621982	21.5	1.75	69.67
Large Cars[1]	322.62	132404003040	22.4	2.44	69.55
Passenger Light Trucks[1]	433.70	169805610587	30.4	2.55	70.15
Motorcycles[1]	4.05	3126449699	36.4	1.30	68.75
Inter-City Buses	12.90	7764504804	0.2	1.66	71.87
Passenger Rail	2.49	1450000000	0.9	1.72	80.28

º NRCan (2009) Comprehensive Energy Use Database
¶ NRCan(2009) Canada Table 8

[1] Consolidated as one GHG intensity for 'auto' in CC-2

CC-2 Light vehicle breakdown

Body Type	Number (in millions of km) §	Passenger-km (in millions of km) §	Passenger-km §	Proportion	HRM-Kings pkm (of 2947382) μ
Car	10,021,194 B	154,315.3 A	249,688.00	0.5057219	1490556
Station wagon	F	5,118.4 E	7,947.90	0.016097798	47446
Subtotal – Passenger vehicles	**10,327,397 B**	**159,433.8 A**	**257,635.90**	**0.52**	**1,538,001.98**
Van	2,890,313 C	53,565.2 B	111,704.20	0.226247398	666838
SUV	1,414,012 D	23,323.5 C	45,039.40	0.091223491	268870
Pickup	3,290,579 C	49,490.2 B	76,839.30	0.155631495	458705

Other	F	1,909.7 E	0	0	0
Subtotal – Light trucks	**7,666,071 B**	**128,288.7 A**	**236,090.00**	**0.48**	**1,409,380**
Total – Light vehicles	**17,993,468 A**	**287,722.4 A**	**493,725.9**	**1.0**	**2,947,382**

§ NRCan (2007) Canadian Vehicle Survey, 2005

µ NSDTPW (2008) Traffic counts

CC-3 Auto (A1) weighted mean energy intensity

	Proportion from CC-3	MJ/pkm	Weighted (MJ/pkm)	gCO2/MJ	Weighted (gCO2/MJ)
Small Cars	0.5057219	1.75	0.88	69.67	35.23333169
Large Cars	0.016097798	2.44	0.04	69.55	1.119527494
Light Trucks	0.48	2.55	1.22	70.15	33.54284982
Total Light Vehicles	1	6.74	2.14	209.36	69.895709

CC-4 Primary energy intensity of each electricity generating fuel, Canada (and Nova Scotia, as indicated)

	PJ¤	Mt CO2¤	MtCO2/PJ	tCO2/PJ	PJ used in NS (Primary)¥	tCO2 in NS
Natural Gas	321.1	16.1	0.050136552	50136.55204	1.04	52142.01412
Diesel Fuel Oil, Light Fuel Oil and Kerosene	6.1	0.5	0.082603668	82603.6676	-	-
Heavy Fuel Oil	52.1	3.8	0.072879308	72879.30803	39.33	2866343.185
Coal	1,086.9	95.9	0.088232426	88232.42574	78.24	6903304.99
Hydro	1,266.9	0.0	0	0	-	-
Nuclear	1,068.7	0.0	0	0	-	-
Wood and Other	73.1	0.0	0	0	-	-
Petroleum Coke, Still Gas, Coke and Coke Oven Gas	44.9	3.3	0.07348193	73481.93013	-	-
Average/Import ð			0.0305	30511.4020	2.68	0.081770557

CC-4 Summary of final energy demand per unit of electricity supplied to source

Total NS Primary (PJ)	Total NS GHG (tCO2)		
121.29	9821790.27	**80977.74153**	tCO2e/PJ (primary energy input)
		1.843	1° to 2° loss coefficient
		149253.4564	tCO2e/PJ (electricity produced) (see CC-5)
		149.2534564	gCO2e/MJ

CC-5 GHG intensity at differing stages of production, 2006 ¤

GHG Intensity [2] (tonne/TJ [electricity generated])	56.2
GHG Intensity [3] (tonne/TJ [energy used])	30.5
Inefficiency loss coefficient	**1.843**

¤ NRCan (2009) Electricity Sector, Canada, Tables 1 and 2

¥ StatsCan (2007), as cited in Hughes (2007)

ð Assume imported NS electricity is from a source similar to Canadian average

CO-1 Nova Scotia Freeway Cost ℓ

Unit	**$/lane-km-a****	2009$
Pavement - Initial Construction	$ 18,994.00	$ 22,222.98
Pavement - Maint/Rehab	$ 3,447.00	$ 4,032.99
Bridges - Initial Construction	$ 12,497.00	$ 14,621.49
Bridges - Maint/Rehab	$ 2,076.00	$ 2,428.92

Other Inf. - Initial Construction	$ 30,445.00	$ 35,620.65
Other Inf. - Maint/Rehab	$ 389.00	$ 455.13
Routine Maintainance	$ 1,513.00	$ 1,770.21
Winter Maintainance	$ 2,475.00	$ 2,895.75
Total Road Cost	$ 71,836.00	$ 84,048.12

*** Averaged over 60 years*

Initial Investment	$ 61,936.00	**$ 72,465.12**	86%
Maintainance	$ 9,900.00	**$ 11,583.00**	14%

CO- 2 Rail Cost - Montreal-Ottawa VIA ª

Unit	**$**	**Note**
Fixed/Allocated	$ 28,559,000.00	in 2000
Marginal/Avoidable	$ 0.31	per pass-km

Rail Nova Scotia	**$**		2009$
Fixed/Allocated	$ 18,021,187.17		$ 21,084,788.98
Marginal/Avoidable	$ 0.31	per pass-km	$ 0.36

ℓ Transport Canada (2008)

ª Transport Canada (2007)

Maintenance

Initial Investment

CO-3 Split

	A1	**A1**	A2	A2	**A3**	**A3**	**A4**	**A4**
B1	$ 4,328,567.10	-	$ -	$ -	$ -	$ -	$ -	$ -
B2	$ -	-	$ 540,625.73	$ 21,084,788.98	$ -	$ -	$ -	$ -
B3	$ -	-	$ -	$ -	$ 42,038,520.98	$ 533,738.78	$ -	$ -
B4	$ -	-	$ -	$ -	$ -	$ -	$ 4,508,567.10	$ 1,341,058.81
B5	$ 4,328,567.10	-	$ 48,656.18	$ 21,084,788.98	$ -	$ -	$ -	$ 147,516.46
B6	$ 4,328,567.10	-	$ -	$ -	$ 42,038,520.98	$ 48,656.18	$ 120,000.00	$ 147,516.46

ES-1 Energy Security Index (Hughes & Sheth, 2008)

Fuel	**Energy Security**
Geo, Solar	0.037
Crude (imp)	0.047
Ngas (imp)	0.061
Coal (imp)	0.079
Crude (dom)	0.082
Ngas (dom)	0.098
Renewables	0.121
Nuclear	0.125
Coal (dom)	0.152
Hydro	0.198

ES-2 Electricity breakdown and weighted mean

Fuel	**PJ in production**	**Proportion**	**ESI €**
Coal[1]	78.24	65%	0.079
RPP®	39.33	32%	0.047
Imports[2]	2.68	2%	0.079
NatGas[3]	1.04	1%	0.098
Total	*121.29*	*100%*	*0.303*
		WtMean	**0.07575**

[1] Coal (imp), as most coal used in NS is imported (Hughes, 2007)

[2] Assume all imports have security of coal (imp)

[3] Natural gas is domenstic (Hughes, 2007)

® Assume all RPP is imported

€ Hughes & Sheth (2008)

Appendix C – Case Study Map

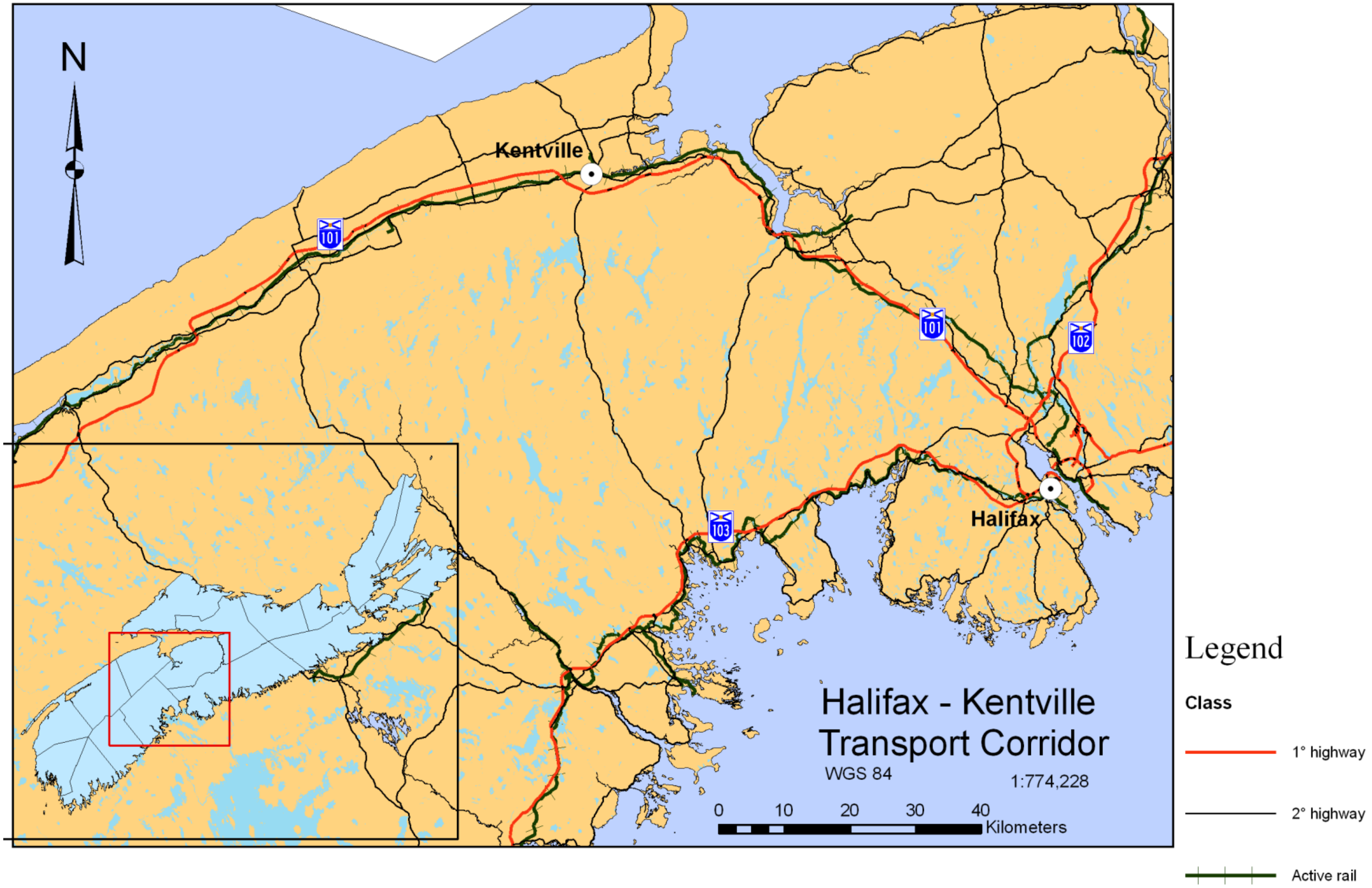


Figure 8 The case study will focus on the objective of moving people from point A (Halifax) to point B (Kentville) (NRCan, 2008; [GIS])