USING GIS TO IDENTIFY THE OPTIMAL SITE FOR PHASE 2 OF THE PROPOSED HIGH-SPEED RAIL IN THE TORONTO-WINDSOR CORRIDOR

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Contents

LIST OF ABBREVIATIONS

HSR High-Speed Rail

TWC Toronto-Windsor Corridor

MTO Ministry of Transportation of Ontario

GIS Geographic Information System

MCE Multi-Criteria Evaluation

ABSTRACT

The high-speed rail (HSR) project proposed for Southern Ontario in 2016 is anticipated to contribute to Ontario's goal of transitioning to a low-carbon economy by 2041. With a growing population in Southern Ontario, HSR is predicted to reduce congestion on major roadways and to improve land-use efficiency in the Greater Toronto and Hamilton Area. In a published report by the Ontario Ministry of Transportation, two phases were identified in the Toronto-Windsor Corridor (TWC), including Phase 1 between Toronto and London to be completed by 2025, and Phase 2, a proposed new-build track extending from London, through Chatham, to Windsor, to be completed by 2031. As a new-build, Phase 2 requires additional environmental and socioeconomic analysis to identify the most suitable route with limited impacts from construction and operation. Using geographic information system (GIS) based tools, Phase 2 is analyzed through a multi-criteria evaluation (MCE). Constraints and criteria both consist of the two same variables, socioeconomic and environmental. Based on existing literature on global inter-regional HSR, socioeconomic constraints include rail station sites and built-up areas, and environmental constraints include slope, and parks and protected areas. Furthermore, criteria consist of rail station sites (socioeconomic), and slope, waterbodies and environmentally sensitive lands (environmental). Criteria were standardized and weighted, including the proximity to existing rail stations, waterbodies, environmentally sensitive lands, and slope. Our study utilizes GIS to site Ontario's first HSR, as they are effective in transportation planning and the decision-making process. A suitability analysis is conceptualized using MCE in Figure 9 to show the most suitable areas for the Phase 2 new-build track construction in the TWC.

PROBLEM CONTEXT

INTRODUCTION

High-speed rail (HSR) represents a major technological breakthrough in passenger transport. HSR combines technical elements, such as infrastructure, rolling stock, telecommunications, power supply, and operating conditions, to form an integrated system (Baig et al., 2017). Most HSR systems are exclusive to passenger transport and use electric traction on dedicated tracks (Government of Ontario, 2020). There is no global standard over the speed of HSR. Trains typically reach 200 to 220 km/h on upgraded existing lines, and 250 km/h or more on new tracks (Janic, 2016).

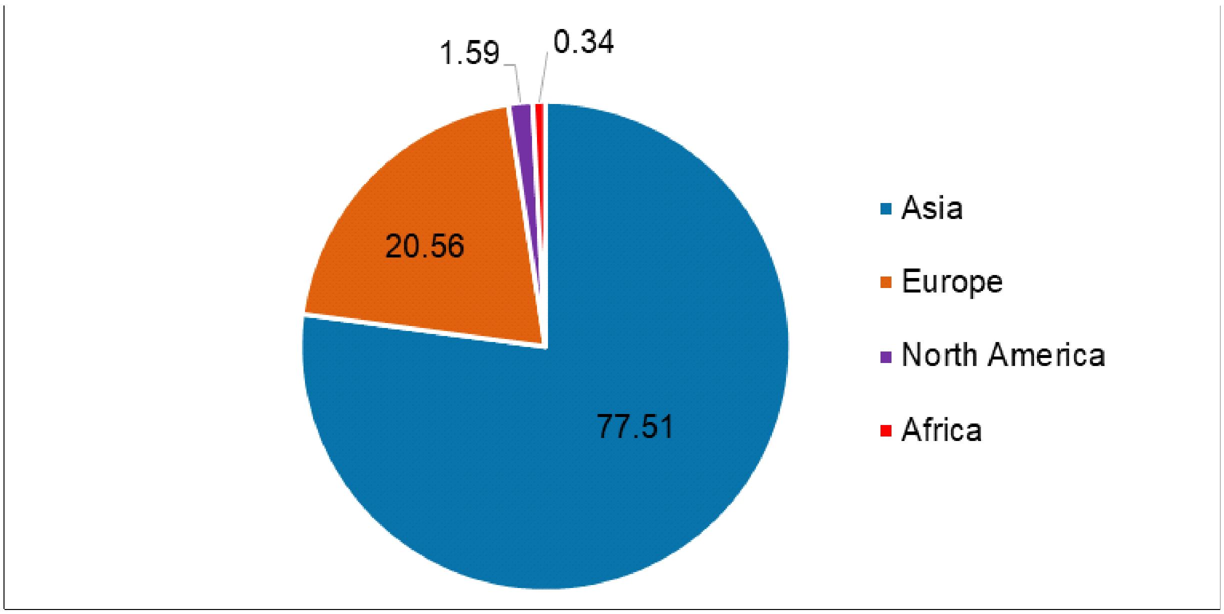


Figure 1. *The percentage of HSR in service and under construction in 2017, globally. Adapted from Chang et al. (2018).*

As Figure 1 shows, HSR is prominent throughout Asia and Europe. There is a sentiment that Canada is lagging, as it remains the only G7 nation without HSR (Katz-Rosene, 2014). HSR has been debated and proposed in Canada since the 1970s. The province of Ontario, particularly the Toronto-Windsor Corridor (TWC), has been considered for HSR development (Katz-Rosene, 2014). In 2016, the Ministry of Transportation of Ontario (MTO) released a Special Advisory Report that outlined two phases for an HSR project in the TWC. Phase 1 between Toronto and London would be completed by 2025, through retrofitting of existing passenger and commercial rail lines for an electric HSR. Phase 2 would be completed by 2031, through a proposed new-build line extending from London, through Chatham, to Windsor (MTO, 2016). The provincial environmental assessment for transportation projects is the Transit Project Assessment Process. Given a speed of 250 km/h, an HSR would also require a federal process through the Canadian Environmental Assessment Agency (MTO, 2016). In 2018, former Ontario Premier, Kathleen Wynne, pledged to begin preliminary design and environmental assessments for an HSR between Toronto and Windsor (Scotti, 2018). There was an initial investment of $11 billion (Scotti, 2018), but capital funding was paused with a subsequent change in government. The halt of the project raises concerns over the future of Canadian inter-regional travel (Wong & Habib, 2015).

The TWC connects southwestern Ontario and belongs to the most densely populated area in Canada (Valli, 2010). Figure 2 illustrates the transportation network in the TWC, including its major airports, railway lines, and roads. This includes Ontario's primary transportation route, the heavily congested Highway 401, which expands from Windsor and extends east beyond Ontario's borders (MTO, 2016). The existing regional passenger transport is limited to personal vehicles, GO Transit trains and buses,

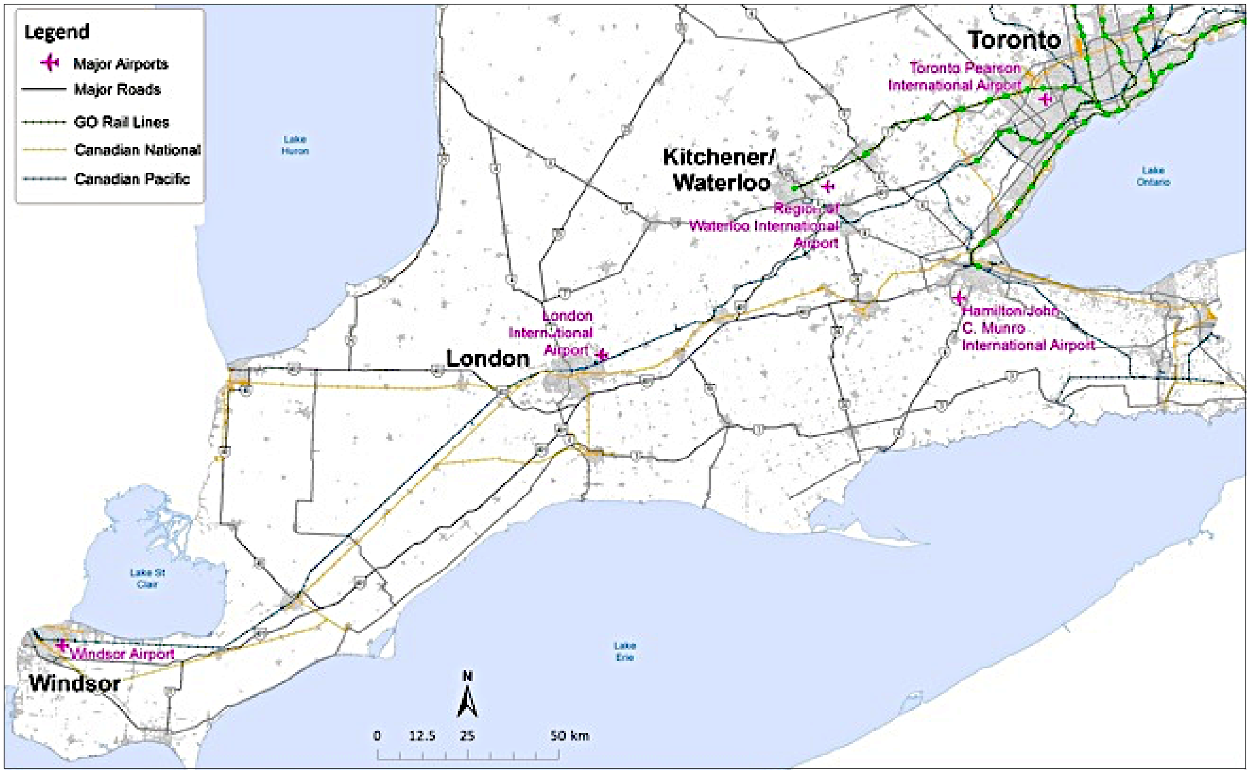


Figure 2. *The current transportation network in the TWC (MTO, 2016).*

Greyhound Canada buses, Via Rail, and airliners (Valli, 2010).

Currently, Via Rail trains in the TWC can reach up to 160 km/h (Vaughan, 2016), while GO Trains reach up to 150 km/h (Metrolinx, 2017). Under HSR systems, commuting time would significantly decrease (The Canadian Press, 2018). Table 1 shows the commuting time from Toronto to Windsor using various passenger transport modes. Comparably, the commuting time from London to Kitchener-Waterloo would be reduced from 46 minutes by vehicle, to 25 minutes with HSR (MTO, 2016).

Table 1. Commuting times for passenger transport modes from Toronto to Windsor.

Travel from Toronto to Windsor		
Transport Mode	**Service Provider**	**Commute Time**
Auto	Individual	4 Hours 10 Minutes
Rail	GO Rail VIA Rail	3 Hours 59 Minutes
Bus	GO Bus Greyhound	4 Hours 32 Minutes
Air	Porter Airlines Air Canada	1 Hour 3 Minutes
High-Speed Rail	MTO	2 Hours 4 Minutes

Note: Adapted from *MTO, 2016*.

LITERATURE REVIEW

Baig et al. (2017) found several benefits to HSR. The primary economic benefits of HSR include a reduction in congestion on existing road networks (Baig et al., 2017). Transport Canada stated the cost of recurrent congestion to Canadians is between about $2.3 and $3.7 billion annually, through a loss of time and productivity (Valli, 2010). Studies show HSR provides greater levels of land-use efficiency in comparison to highway operations, as they carry more passengers per hour on less land (MTO, 2016). As populations increase in Southern Ontario, there will be an increasing need for HSR to improve efficiency. HSR could support wider economic benefits through improved labour mobility and business connectivity (Gormick, 2018).

There are environmental benefits to HSR, such as improved air quality and reduced dependency on foreign oil (Chang et al., 2018; Chester & Horvath, 2012). It is estimated that HSR in the TWC could lead to reductions in greenhouse gas emissions by over 7 million tonnes over a 60-year time horizon. In the long run, this would contribute to Ontario's goals to transition to a low-carbon economy and help to address climate targets (MTO, 2016).

The development of HSR infrastructure is influenced by several socioeconomic, ecological, and political aspects (Loukaitou-Sideris et al., 2013). Numerous feasibility studies of HSR in the TWC have been published (Lukasiewicz, 1979). Examples of these studies include *Inter-City Passenger Transport Study* (Canadian Transport Commission, 1970), *High-Speed Passenger Rail Analysis: Environmental and Socioeconomic Impacts* (IBI Group for Transport Canada, 2003), and *Infrastructure and the Economy: Future Directions for Ontario* (Martin Prosperity Institute, 2009) (Katz-Rosene, 2014). However, the planning and design of an HSR largely draw on existing systems from Asian and European countries (Guirao & Campa, 2015). Studies, such as those conducted by Lovett et al. (2013), Saat et al. (2015), and Loukaitou-Sideris (2013), prioritize key socioeconomic factors to determine the optimal corridor for an HSR. These include metropolitan cities with a large population and areas with greater highway congestion. Hagler & Todorovich (2009) add that implementing HSR in metropolitan regions with existing transit systems, such as commuter rail, is beneficial in connecting local and regional transit networks, and supporting increased ridership (Hagler & Todorovich, 2009). Other literature, such as Yokoshima et al. (2017), cite noise and vibration pollution from fast and frequents train movements as an important consideration in HSR development. HSR emits a higher level of ground vibration than conventional railways at the same noise level (Yokoshima et al., 2017).

The natural environment and culturally sensitive lands are important throughout the implementation of HSR (MTO, 2016). In the TWC, concerns over the impacts of

HSR on the environment include the loss of grasslands and woodlands; the spread of invasive species; soil contamination and leaching posed by construction; protection of wildlife, including wildlife overpasses and underpasses on the HSR; and protection of water systems such as the Grand River and Thames River Watershed (Blandford-Blenheim, 2017).

Indigenous communities are a key stakeholder in HSR. Indigenous peoples maintain collective rights to land and resources. They possess a deep cultural and spiritual relationship with the natural land. Infrastructure projects, such as HSR, also support major resource development projects, in which Indigenous communities are poised to have a significant role (UN Department of Public Information, 2002). Ongoing community engagement throughout the HSR process has been emphasized by Indigenous communities in the TWC (MTO, 2016).

Rural communities represent an additional stakeholder. Prime agricultural lands that support local farmers could be impacted by HSR (MTO, 2016; OMAFRA, 2017; OMAFRA, 2020). The Ontario Federation of Agriculture notes that rural communities and farmers are concerned HSR may divide them from the remaining province, as grade crossings create more boundaries (Fraser, 2018).

Despite the benefits, government attitudes, economic climate, and external interference can influence the investment and public support for HSR (Chang et al., 2019). An additional challenge specific to HSR in the TWC is the current number of freight and commuter passenger operators that share infrastructure (MTO, 2016). Outside of feasibility studies, current research has not extensively studied optimal route selection for HSR in the TWC (Katz-Rosene, 2014; MTO, 2016). Our research will contribute to developing knowledge in this area and can be used to evaluate corridors in other regions as well.

THE IMPORTANCE OF GIS APPLICATIONS

It has been proven that geographic information system (GIS) applications are effective decision-making tools for transportation planning, as they provide opportunities to analyze data to reveal relationships, patterns, and trends as a project progresses (Tat & Tao, 2013). Rail design involves many socioeconomic and environmental variables that require detailed analysis (De Luca et al., 2012). GIS is beneficial to this research as the implementation of an HSR line in the TWC is inherently a spatial problem. For instance, De Luca et al. (2012) utilized a multi-criteria decision-making method to evaluate the economic feasibility, as well as the environmental and social impacts of a new HSR in the Berlin-Palermo corridor (De Luca et al., 2012).

As identified by Tat & Tao (2013), GIS applications are also helpful for improving stakeholder and community member understanding, while allowing for public input in the decision-making process. GIS analysts can analyze information gathered through public participation and make informed decisions as the project progresses (Tat & Tao, 2013). Likewise, public participation in the selection process for HSR stations in Southern Ontario identified that Chatham and Guelph are crucial locations, in conjunction to the previously identified Union Station, Malton, Kitchener, London and Windsor, as stops along the proposed line (MTO 2016). Figure 3 shows how the information gathered from the public was spatially analyzed using GIS tools, to generate a conceptual map of the proposed HSR route and distinguish the two phases in the MTO's final report (MTO, 2016).

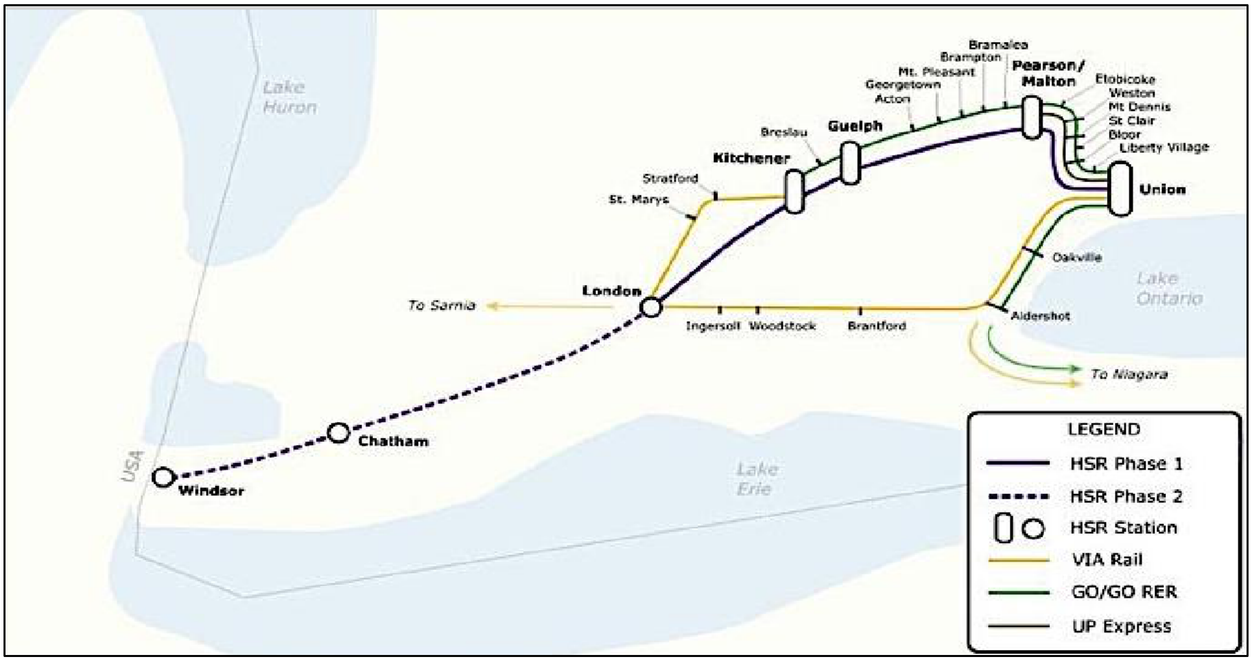


Figure 3. *Map of the proposed HSR route and phases in the TWC (MTO, 2016).*

PURPOSE OF RESEARCH

The purpose of this research is to identify the optimal location for Phase 2 of the HSR in the London-Windsor region of the TWC, using an MCE to ensure minimal socioeconomic and environmental impacts of the new rail line.

RESEARCH OBJECTIVES

1. Identify the socioeconomic and environmental variables that influence the development of an optimal HSR route.

2. Design a GIS analysis model using the MCE method by preparing the constraints, criteria, and assigning criteria weights to aggregated data.
3. Apply the MCE model to determine the optimal route for an HSR system.
4. Evaluate the strengths and limitations of the MCE model and suggest recommendations for future HSR transportation planning.

STUDY AREA

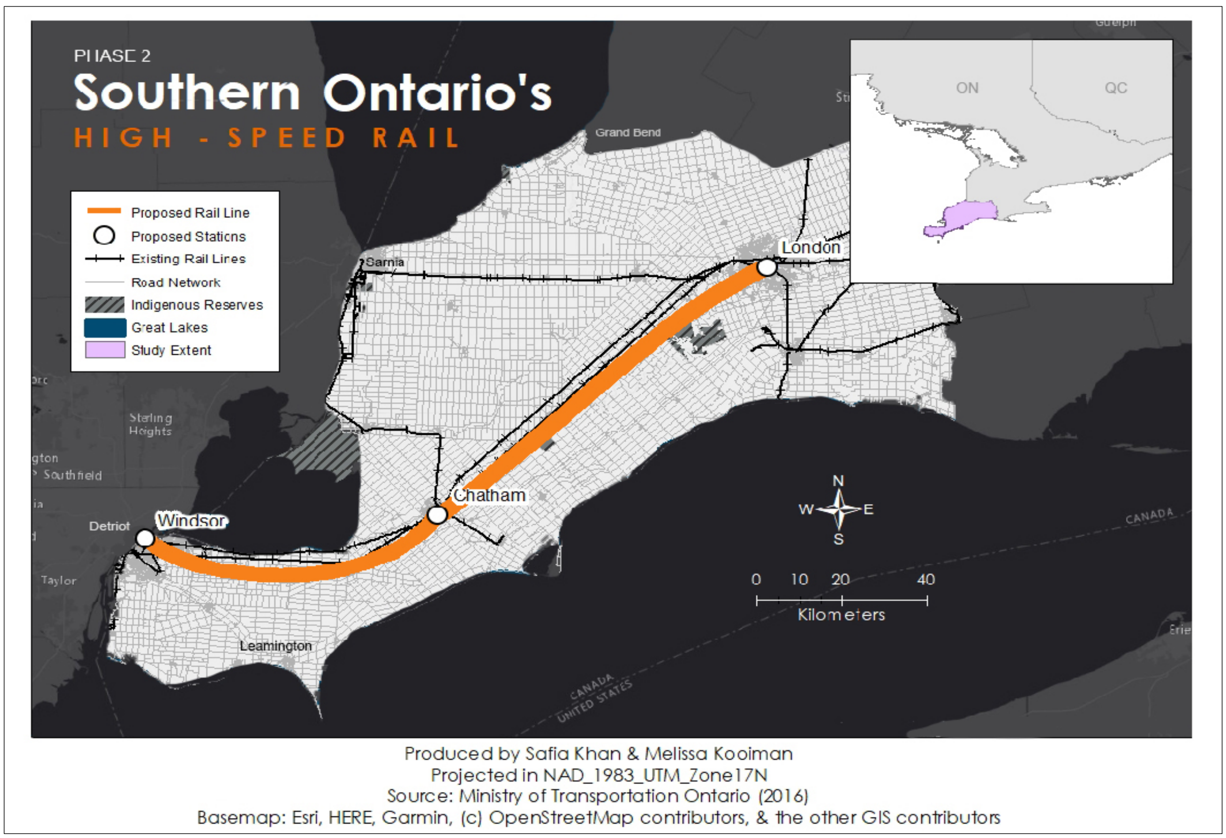


Figure 4. *Map of the selected study area found in Phase 2 of the TWC.*

The study area is the London-Windsor region of the TWC. This is the location of Phase 2, the proposed new-build HSR track (MTO, 2016). Figure 4 illustrates the study area and its existing road and rail infrastructure and built-up areas.

The London-Windsor region is found in the south-western portion of the TWC. It includes the larger counties of Middlesex, Elgin, Lambton, Chatham-Kent, and Essex. Windsor, in particular, is a primary port of entry from the United States to Canada (Wallenfeldt, 2020). The western region of Ontario is home to an estimated 2.8 million Ontarians and features a mix of rural, small urban, and large urban areas (Canadian Index of Wellbeing & University of Waterloo, 2018). It contains Canada's Industrial Heartland (SOMA, 2020) and many manufacturing, agriculture, and food-processing industries (Eisen & Emes, 2016).

The proposed HSR project, including Phase 1 and 2, stretches the TWC and a large portion of Southern Ontario. It has 7 stations located in Toronto, Malton, Guelph, Kitchener, London, Chatham, and Windsor. Understanding the entire HSR route supports an analysis of Phase 1, the proposed retrofitted region between Toronto-London, which will need to be considered for the completion of this project. The TWC is inhabited by over 7 million people (MTO, 2016). It provides approximately 3.4 million jobs and more than 50% of Ontario's GDP (MTO, 2016). Many of these jobs often require movement across the TWC region. The area also includes the province's Innovation SuperCorridor, which features start-ups, research institutions and leading manufacturing and agricultural hubs (MTO, 2016).

In addition to the social and economic landscapes in the TWC, significant environmental features are present, including the Niagara Escarpment and the

Greenbelt. There are at least 10 Indigenous reserves and territories that pass through the TWC, including the Mississaugas of the New Credit, Six Nations of the Grand River, and Aamjiwnaang (MTO, 2016). The acknowledgement of these territories in the proposed construction zone necessary to address stakeholder engagement and avoid disruption of lands.

The study area of London-Windsor, Ontario, allows for the optimal route configuration of Phase 2 of the proposed HSR. The land-use types and existing infrastructure in this area are considered throughout the data collection and research process (MTO, 2016). They are key in determining the siting of Phase 2, as route planning near or through these lands can have detrimental socioeconomic and environmental impacts (MTO, 2016).

RESEARCH APPROACH

The research approach follows the four research objectives. It identifies the socioeconomic and environmental variables that influence HSR planning to develop and apply a GIS-based MCE for the optimal route of Phase 2.

OBJECTIVE 1

Identify the socioeconomic and environmental variables that influence the development of an optimal HSR route.

To discuss the many variables associated with HSR development, we classify them as socioeconomic and environmental constraints and criteria. Socioeconomic and environmental constraints outline where HSR development is unsuitable, while criteria identify the varying suitability of land. Figure 5 summarizes the constraints and criteria that are considered in our research.

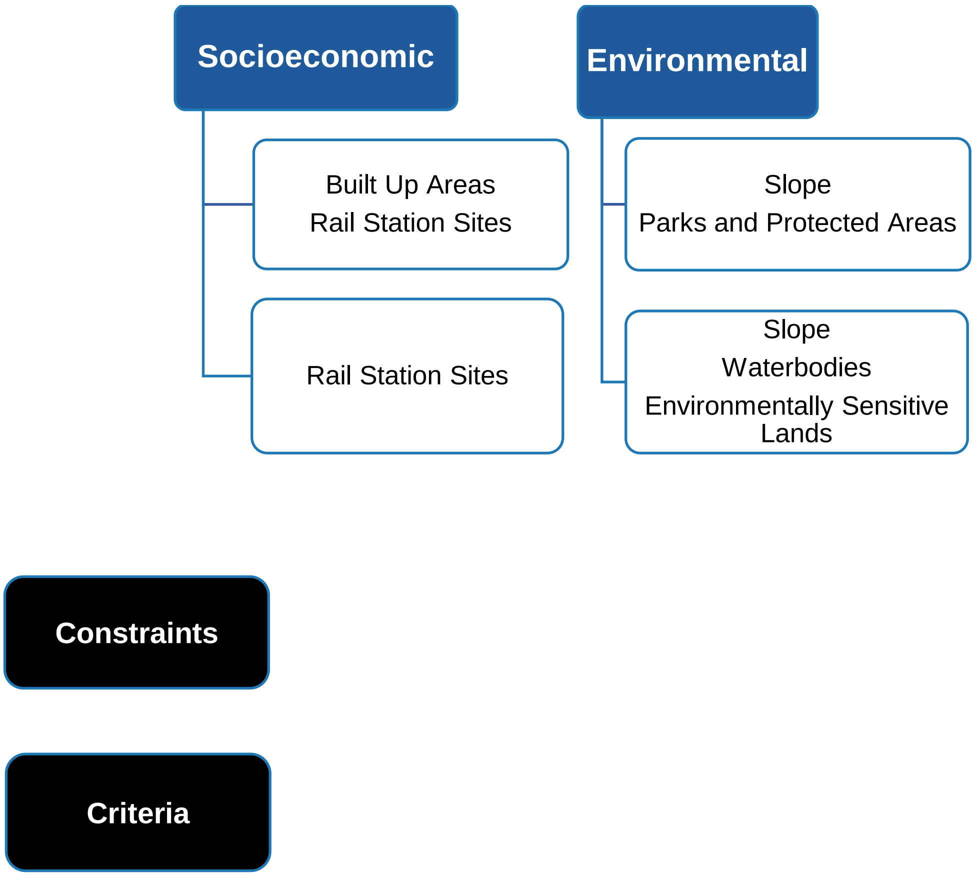


Figure 5. *Overview of the socioeconomic and environmental constraints and criteria.*

SOCIOECONOMIC FACTORS

Socioeconomic factors consider the potential impacts on society and the influence of social facilities and infrastructure as they relate to HSR development. In our research, socioeconomic constraints and criteria center on built-up areas and the existing passenger rail station sites in the London-Windsor region.

SOCIOECONOMIC CONSTRAINTS

- **Built-Up Areas**

  Built-up areas include man-made landcover features across rural and urban areas, such as buildings. The HSR must not intersect existing built-up up infrastructure in the area from London to Windsor.

- **Rail Station Sites**

  As identified through public participation in the MTO selection process, the HSR must connect to the existing passenger rail stations within the study area. This includes stations in London, Chatham, and Windsor (MTO, 2016).

SOCIOECONOMIC CRITERIA

- **Rail Station Sites**

  For criteria purposes, the HSR is also most suitable near existing rail stations in London, Chatham, and Windsor.

ENVIRONMENTAL FACTORS

Environmental factors consider the geographical aspects that influence suitability and potential negative ecological impacts. Environmental constraints include the slope and parks and protected areas. Criteria focus on a gradual slope, proximity to waterbodies, and environmentally sensitive lands.

ENVIRONMENTAL CONSTRAINTS

- **Slope**

The connectivity between locations along an HSR can be severely limited by complex topography (Martin & Greenwood, 2013). HSR requires flat curve radii and relatively shallow gradients (Martin & Greenwood, 2013). Based on HSR alignment and geometry, it is not suitable to build on slopes above 3.50% (Parsons Brinckerhoff, 2009).

- **Parks and Protected Areas**

  The HSR cannot intersect parks and protected areas from London to Windsor. Parks include provincial regulated parks and federally protected areas (e.g. national parks, national marine conservation areas, and national wildlife areas). This criterion also includes Indigenous reserves. This is in acknowledgement of the significance of avoiding these lands and including Indigenous communities in the decision-making process for HSR in the TWC (UN Department of Public Information, 2002).

ENVIRONMENTAL CRITERIA

- **Slope**

  A moderate to lower slope is more economically sustainable, operationally safe, and supportive of HSR transportation infrastructure (Kumar, Panchal, Ashish, & Singh, 2017). A higher slope would involve more cutting operations (Farooq, Xie, Stoilova, & Ahmad, 2019). Table 2 depicts acceptable grades for HSR as prescribed by the California High-Speed Rail Authority. Based on HSR alignment design standards, gentler and gradual slopes below the 3.50% constraint are more suitable (Parsons Brinckerhoff, 2009).

Grade	Description
Desirable Grades	As low as reasonably practical, with a limit of 1.25%
Exceptional Grades	Above 1.25% and shall be as low as practical up to 3.50%

Table 2. Slope grades for HSR alignment and design.

Note. Adapted from *Parsons Brinckerhoff, 2009*.

- **Proximity to Waterbodies**

  It is more suitable to build further in proximity to waterbodies, including lakes, rivers, and streams. High water levels near HSR are not preferred as they can result in construction issues and inundation (Panchal & Debbarma, 2010).

- **Proximity to Environmentally Sensitive Lands**

  Environmentally sensitive lands, including wetlands, should be avoided where possible to limit the adverse impacts on ecosystems, biodiversity and local communities (Clauzel, 2017; Ravazzoli et al., 2017).

OBJECTIVE 2

Design a GIS analysis model using the MCE method by preparing the constraints, criteria, and assigning criteria weights to aggregated data.

An MCE is performed using the socioeconomic and environmental constraints and factors outlined in Objective 1. Through a comprehensive literature review on the benefits of GIS tools, MCE was determined as the most appropriate method to achieve the intended goal of building an HSR. Similar studies have used MCE for HSR planning purposes. A study conducted by Rosenberg & Esnard (2008) in Florida determined the most suitable placement of a railway station using Weighted Linear Combination, which is typically incorporated into the MCE method as an initial step and its larger process (Rosenberg & Esnard, 2008). Likewise, Farooq et al. (2019) used GIS and remote sensing techniques to conduct an MCE analysis of an HSR in Xiongan, Beijing. Satellite datasets were used to gain insight on settlement percentage, slope, elevation, and vegetation, and the feasibility of routes (Farooq et al., 2019). Spatial analysis of the study area is crucial in determining the optimal HSR route as construction and route planning may be limited by the region's geography (Tat & Tao, 2013).

Figure 6 shows a flowchart of the high-level methodologies used for data cleaning and the MCE layer generation. Early stages involved dissolving a municipalities extent layer for the study area, projecting to the appropriate coordinate system of NAD 1983 UTM Zone 17N, and clipping all desired vector and raster layers to be used as intermediate, criteria, and constraint data. Table 3 demonstrates how factors in the MCE are weighted using a 9-point rating scale and pairwise comparison. Tables 4-6 illustrate how this method was applied to our study.

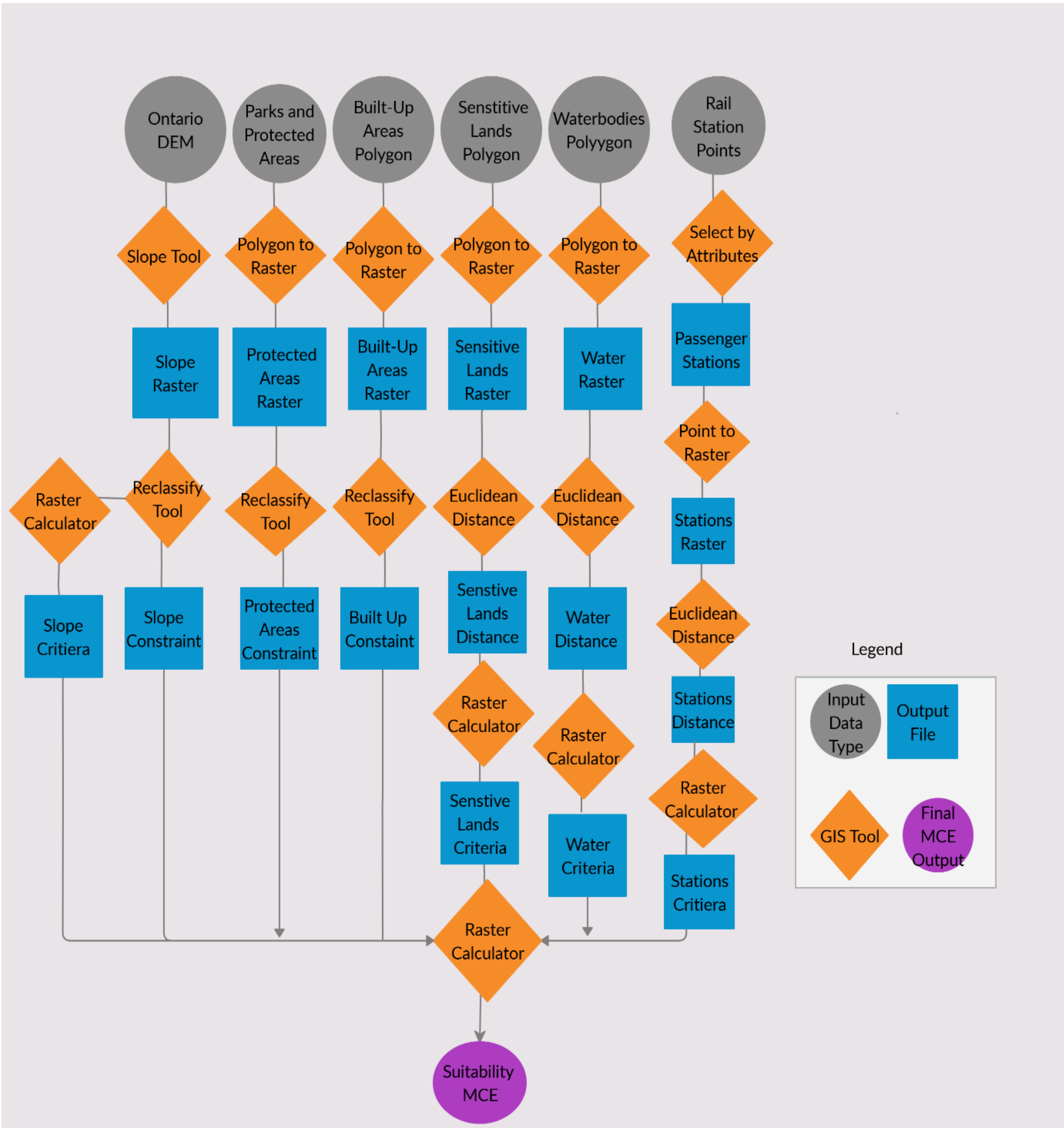


Figure 6. *Flowchart depicting the procedures used to develop the intermediate, criteria, and constraint layers for the MCE model.*

Table 3. A modified version of the 9-point rating scale.

1/9	**1/7**	**1/5**	**1/3**	**1**	**3**	**5**	**7**	**9**
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very strongly	Extremely
Less important				Equal				More important

Table 4. Pairwise comparison for research model criteria.

Factor	**Rail Stations**	**Environmentally Sensitive Lands**	**Waterbodies**	**Slope**
Rail Stations	1	3	1	5
Environmentally Sensitive Lands	1/3	1	1/3	3
Waterbodies	1	3	1	3
Slope	1/3	1/3	1/3	1
Sum	**2.66**	**7.33**	**2.66**	**12**

Table 5. Assignment of individual weights to criteria.

Factor	**Rail Stations**	**Environmentally Sensitive Lands**	**Waterbodies**	**Slope**
Rail Stations	1/2.66 **0.3759**	3/7.33 **0.4092**	1/2.66 **0.3759**	5/12 **0.4166**
Environmentally Sensitive Lands	(1/3)/2.66 **0.1253**	1/7.33 0.1364	(1/3)/2.66 **0.1253**	3/12 **0.25**
Waterbodies	1/2.66 **0.3759**	3/7.33 **0.4092**	1/2.66 **0.3759**	3/12 **0.25**
Slope	(1/3)/2.66 **0.1253**	(1/3)/7.33 **0.0454**	(1/3)/2.66 **0.1253**	1/12 **0.0833**
Sum	1	1	1	1

Table 6. Assignment of total weights to criteria.

Factor	**Rail Stations**	**Sensitive Lands**	**Waterbodies**	**Slope**	**Total Weights**
Rail Stations	1/2.66 **0.3759**	3/7.33 **0.4092**	1/2.66 **0.3759**	5/12 **0.4166**	(0.3759 + 0.4092 +0.3759 + 0.4166)/4 **0.3944**
Sensitive Lands	(1/3)/2.66 **0.1253**	1/7.33 **0.1364**	(1/3)/2.66 **0.1253**	3/12 **0.25**	(0.1253+0.1364 +0.1253+0.25)/4 **0.1592**
Waterbodies	1/2.66 **0.3759**	3/7.33 **0.4092**	1/2.66 **0.3759**	3/12 **0.25**	(0.3759+0.4092 +0.3759+0.25)/4 **0.3527**
Slope	(1/3)/2.66 **0.1253**	(1/3)/7.33 **0.0454**	(1/3)/2.66 **0.1253**	1/12 **0.0833**	(0.1253+0.0454 +0.1253+0.0833)/4 **0.0948**
Sum	1	1	1	1	1.0

OBJECTIVE 3

Apply the MCE model to determine the optimal route for an HSR system.

Environmental and socioeconomic data were tabulated, extracted and linked to their boundaries. To complete the MCE, the pairwise comparison is applied to conceptualize the importance of one criterion over another (Feizizadeh & Blaschke, 2013). Criteria are standardized on a scale from 0-100 using standardization equations, which can be broken down into two general expressions:

Standardization Equations

Equation 1. $100 *((X - X_{min}) / (X_{max} - X_{min}))$

Equation 2. $100 *(1- ((X - X_{min}) / (X_{max} - X_{min})))$

Where:

X_{min} = Minimum value for the criterion constraints

X_{max} = Maximum value for the criterion

The criteria and constraint layers are applied using the following formula:

MCE Algorithm

$$SUITABILITY = (Cn_1 Cn_2 ...) (W_1 Cr_1 + W_2 Cr_2 + ...)$$

Where:

Cn = Constraints

Cr = Criteria

W = Weight

OBJECTIVE 4

Evaluate the strengths and limitations of the MCE model and suggest recommendations for future HSR transportation planning.

STRENGTHS

Apitz (2012) found that using an MCE model allows users to analyze the complex relationships associated with different socioeconomic and environmental impacts (Apitz, 2012). Furthermore, the model provides information that can be used to improve our understanding of the trade-offs that need to be evaluated in decision-making processes that affect the environment and surrounding ecosystems (Apitz, 2012). In this research, MCE proves to be strong as the weighted overlay technique enables the analysis of multiple different factors, which contribute to the organization of important criteria, and constraint factors related to the optimal location of HSR development (Apitz, 2012).

LIMITATIONS

Carver (2007) found several limitations to overlay analysis, which included digital maps being difficult to comprehend when more than four or five factors are involved. The use of threshold values to map continuous variables, such as population density, on a nominal basis, inevitably leads to substantial losses of information as well (Carver, 2007). Such limitations are important to keep in mind, as the weighted overlay tool applies one of the most commonly used approaches for overlay analysis in ArcGIS to solve multi-criteria problems, such as site selection and suitability models (Carver, 2007).

RESEARCH FINDINGS

OBJECTIVE 1

Identify the socioeconomic and environmental variables that influence the development of an optimal HSR route.

OBJECTIVE 2

Design a GIS analysis model using the MCE method by preparing the constraints, criteria, and assigning criteria weights to aggregated data.

As shown in Figures 7-8, the following constraints and criteria were identified and analyzed to find the optimal route for Phase 2 of the proposed HSR in the TWC. The factors in the MCE were combined and weighted in the pairwise and factor weighting matrixes.

CONSTRAINTS

A. Rail Stations
B. Slope
C. Built-Up Areas
D. Parks and Protected Areas

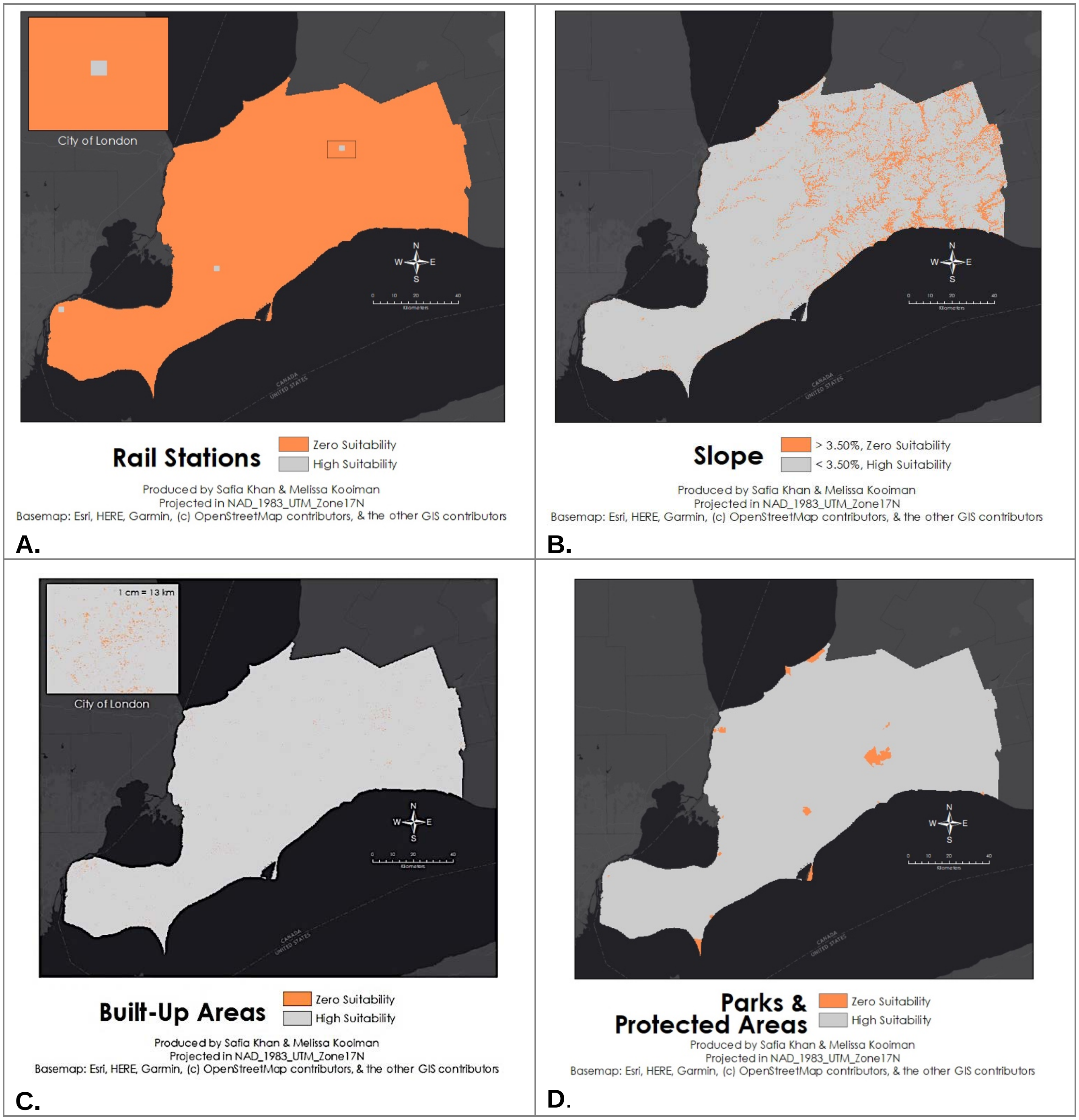
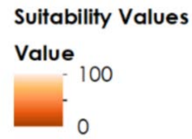


Figure 7. *Constraint rasters of existing rail station sites, slope, built-up areas and parks and protected areas.*



CRITERIA

- **A.** Rail Stations
- **B.** Slope
- **C.** Proximity to Waterbodies
- **D.** Proximity to Environmentally Sensitive Lands

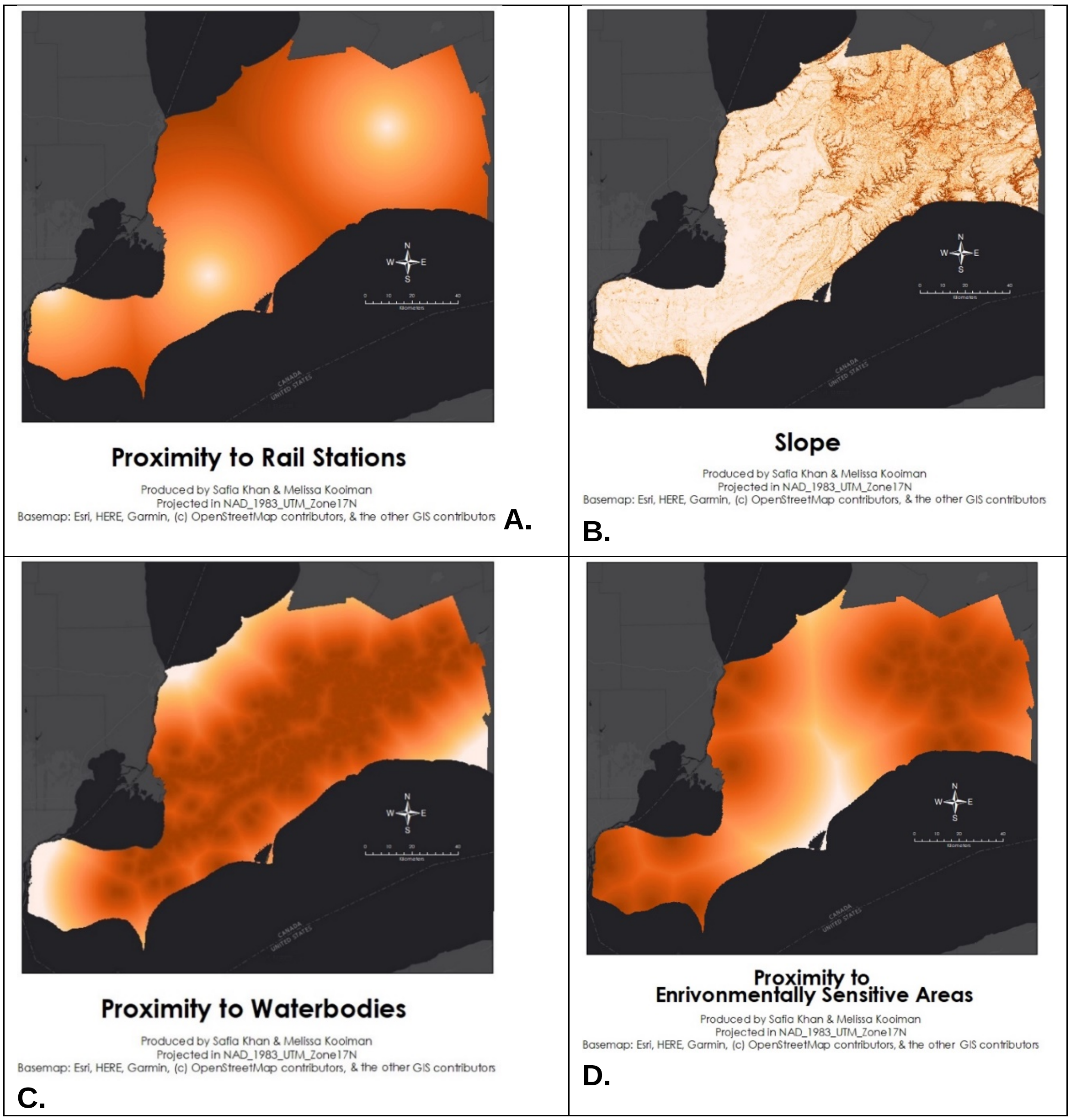


Figure 8. *Criteria rasters of existing rail station sites, slope, proximity to waterbodies, and environmentally sensitive areas.*

OBJECTIVE 3

Apply the MCE model to determine the optimal route for an HSR system.

Figure 9 illustrates the final suitability map of the modelling process that was applied through the application of the pairwise comparison, standardization, and MCE algorithm processing in the ArcGIS map algebra tools (Feizizadeh & Blaschke, 2013). It highlights areas of interest through suitability scores.

FINAL SUITABILITY

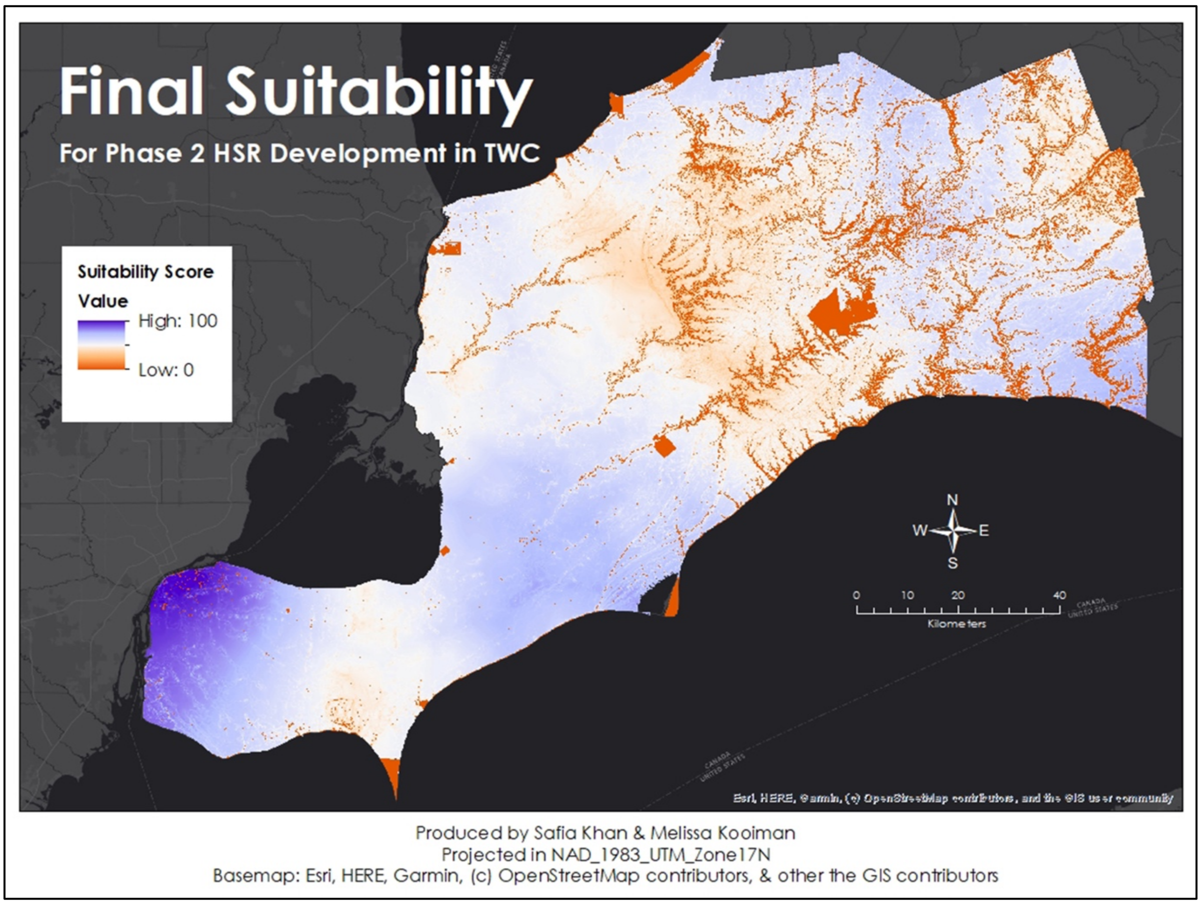


__Figure 9.__ Final suitability map and conceptualization of the optimal area for HSR development incorporating constraints and criteria in the MCE algorithm.

OBJECTIVE 4

Evaluate the strengths and limitations of the MCE model and suggest recommendations for future HSR transportation planning.

The MCE model intended to show areas for suitable development of HSR in the TWC based on the constraints and criteria. The strengths of the model are its ability to apply these various criteria to the study area into one suitability equation (Feizizadeh & Blaschke, 2013). This supports a precise output of considerations across more than one factor affecting suitability. It also proves valuable in identifying areas of interest for development, which can be beneficial in the decision-making process for the problem context (Feizizadeh & Blaschke, 2013). However, data for desired criteria, such as forests, remained limited and outdated. This limited the application of criteria to the model (Carver, 2007). Furthermore, existing factors within the model are limited by the available data. Although the model may effectively incorporate criteria and constraints, it may disregard important factors that influence suitability (Carver, 2007). At a more technical level, data on local or regional factors may be missing for the governments as well.

CONSIDERATIONS

Additional criteria and adjustments to weighting remain a consideration to our continuing research and MCE model.

- **Proximity to Existing Road Infrastructure**

HSR is not operational at level crossings as Transport Canada prohibits level crossings at speeds over 177 km/h on roads, highways, and farm crossings (OFA, 2020). Instead, HSR is often grade-separated, and bridges are constructed over roadways (AECOM et al., 2013). In some cases, the cost and feasibility of grade crossings may eliminate their use (Rozek & Harrison, 1988).

- **Proximity to Built-up Areas (Residential, Industrial, Commercial)**

HSR generates both airborne noise and ground-borne or regenerated noise (AECOM et al., 2013). Airborne noise occurs as trains move across the open landscape, while the latter is emitted through the ground from the passage of trains on the track form (AECOM et al., 2013). Table 4 shows the varying compliance offset distances in rural, transition, and urban areas, as outlined in an Australian HSR study (AECOM et al., 2013).

Table 7. Noise compliance offset distances for HSR in varying scenarios.

Scenario	Compliance Offset Distance
Rural Areas	230 m
Urban Areas	21 m

Note: Adapted from *AECOM et al., 2013*.

CONCLUSIONS

Upon completing the suitability analysis, the most suitable areas have been identified in our research findings to aid in the decision-making as to where Phase 2 of the new build track should be constructed for the HSR in the London-Windsor region of the TWC.

The MCE was successful in allowing for the weighting of criteria based on figures and thresholds obtained from multiple reputable sources and academic literature. Much of the academic literature focuses on the feasibility and operation of HSR around the world. There were more factors chosen in the initial stages of the project than those that were used in the final multi-criteria evaluation due to a gap in available data.

Despite a few limitations to running an MCE, the overall spatial analysis process was successful in informing where the construction of a new build track is prohibited and accepted for the least environmental and socioeconomic impacts. For the model to be more successful in the future, it would be beneficial to add more data to the model including existing rail lines, built-up areas for noise, and utility infrastructure. This would have allowed for a more detailed, accurate and refined suitability score that would aid in the project moving forward in the future.

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APPENDICES

APPENDIX A:

Table 8. Data sources.

Layer Name	Source	Year	Description
Municipalities	Municipal Boundary - Lower and Single Tier Ontario Ministry of Municipal Affairs and Housing https://geohub.lio.gov.on.ca/datasets/municipal-boundary-lower-and-single-tier	2020	A layer of lower and single-tier municipalities in Ontario used to generate study area extent.
Rail Stations	Ontario Railway Network (ORWN) Ontario Ministry of Natural Resources and Forestry https://geohub.lio.gov.on.ca/datasets/mnrf::ontario-railway-network-orwn	2020	The ORWN is a suite of 7 Data Classes that represents the Ontario Government's initiative to adapt the Federal Governments GEOBASE standard for the National Railway Network (NRWN) geospatial data. It includes railway stations located in London, Chatham, and Windsor.
Slope	Ontario Provincial Digital Elevation Model (DEM) (Version 3.0) Ontario Ministry of Natural Resources http://geo.scholarsportal.info/#r/details/_uri@=4215761220	2013	The Ontario Provincial DEM is designed to represent true ground elevation across the province.

Parks and Protected Areas	Provincial Park Regulated Ontario Ministry of Natural Resources and Forestry http://geo.scholarsportal.info/#r/details/_uri@=180702964&_add:true_nozoom:true Federal Protected Area Ontario Ministry of Natural Resources and Forestry https://geohub.lio.gov.on.ca/datasets/federal-protected-areas Indian Reserve Ontario Ministry of Natural Resources and Forestry http://geo1.scholarsportal.info/#r/details/_uri@=2956835007&_add:true_nozoom:true	2008 2018 2008	Indigenous lands merged with federal and provincial parks within Ontario.
Waterbodies	Ontario Hydro Network (OHN) – Waterbody Ontario Ministry of Natural Resources and Forestry https://geohub.lio.gov.on.ca/datasets/mnrf::ontario-hydro-network-ohn-waterbody	2020	This layer includes polygon features representing bodies of water like lakes, ponds, and rivers.

Environmentally Sensitive Lands	Wetlands (WER) DMTI Spatial Inc. http://geo.scholarsportal.info/#r/details/_uri@=4073993368	2014	This layer contains areas of wetlands across Canada. A wetland is a water-saturated area, intermittently or permanently water-covered, having cattails, rushes or grass-like vegetation (marsh) and/or shrub and tree-type vegetation (swamp).

APPENDIX B:

Table 9. Classification scheme for constraints and criteria.

	Classification	Standardization Scale
CONSTRAINT		
• Rail Stations	Rail Stations = 1 Other = 0	N/A
• Built-Up Areas	Built-Up Areas = 0 Other = 1	N/A
• Slope	Greater than 3.50 = 0 Lower than 3.50 = 1	N/A
• Parks and Protected Areas	Parks and Protected Areas = 0 Other = 1	N/A
CRITERIA		
• Rail Stations	Euclidean Distance	0 – 100
• Waterbodies	Euclidean Distance	100 – 0
• Environmentally Sensitive Lands	Euclidean Distance	100 – 0
• Slope	Percentage	100 – 0