Generation and Evaluation of Optimal Routes for a New Bridge: The case of Istanbul

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by

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Abstract

There are numerous evaluation methodologies being employed to compare, assess and evaluate transport project alternatives. This thesis proposes a methodological framework that is able to generate route alternatives, define criteria for evaluating the route alternatives and finally carry out the evaluation to determine the most preferred route. It is case tested in Istanbul where five alternative locations have been defined over the Bosporus Strait as potential sites to build a new third bridge to address the ongoing issues of traffic congestion. The technique used for generation and evaluation of alternatives is done on geographical information science (GIS) platform. Working on GIS allows decision making and evaluation of alternatives to be done spatially. In addition to these techniques, stakeholders' preference and opinion were gauged through open interviews and discussions as well as formally in terms of assigning weight to evaluation criteria.

This proposed methodology is developed to be generic hence it can be used in any similar type of project evaluation at a different location or setting.

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1. Introduction

1.1. Background

The transportation sector in many countries often constitutes the largest public sector investment (Sinha & Labi, 2007). The economic status and global competitiveness of a country or a region are greatly influenced by the quality and quantity of its transportation infrastructure as such facilities provide means of mobility and accessibility for people, goods and services. With the global increase in personal travel demand and commercial growth, transport agencies and providers are also striving to keep their infrastructure in acceptable condition and to offer desirable levels of service (Sinha & Labi, 2007). Alongside these efforts, the evaluation and monitoring of expected impact alternative decisions are increasingly becoming important. Such impacts involve economics, social, ecological and technical aspects.

Transportation projects may be described as multicriteria decision problems because of their multifaceted conflicting objectives. These may include construction cost, user cost, environmental impacts and physical factors such as slope and soil stability. A transport project entails the evaluation of a discrete set of alternatives with respect to these conflicting objectives (Giuliano, 1985). Under these circumstances optimal solutions do not exist. However the outcome of an evaluation should be able to identify the best compromise alternative which is closest to achieving the stated objectives. Selecting a transportation project involves a complex decision making process where relevant criteria and urgency of choices are taken into account (Medda & Nijkamp, 2003). It is necessary that all relevant criteria are considered including long term and short term impacts, beneficial effects and adverse consequences as well as accounting for spatial and temporal boundaries when assessing transport project alternatives. Criteria are determined based on geographical area which is most likely to be affected by each project and ideally should be defined by relevant stakeholders. Apart from the economic, social and ecological themes, a transport system theme is also fundamental to capture criteria such as ease of traffic congestion, traffic density, potential infrastructure capacity and reduction in travel time.

There are numerous forms of assessment methods that have been developed and employed to assess the possible impacts of proposed policies, programmes and projects (Medda & Nijkamp, 2003). Evaluation of transport project and plans have been carried out in the past using a variety of methodologies. Multi Criteria Analysis, Cost Benefit Analysis (CBA), Environmental Impact Assessment (EIA), Analytical Hierarchy process, Risk Assessment, simulation and mathematical modelling are some examples of these methodologies. These different methodologies may encompass a wide range of disciplines such as economic, social, environmental, quality of life, equality and apply different tools of measurement like analytical tools, modelling and participatory methods (de Ridder, Turnpenny, Nilsson, & von Raggamby, 2007; Hinkel, 2009). However they frequently seek to answer the same question and often have overlapping areas of concern. They use a variation of checklists, matrices, networks and overlay methods and in all cases one of the key objectives is the inclusion of environment quality and impacts in the planning and decision making (Tsamboulas & Mikroudis, 2000).

Most, if not all, of the major cities in the world are faced with transportation problems that they are trying to solve. With a population exceeding 12million, Istanbul, the biggest metropolitan city of Turkey has been facing problems of traffic congestion for many years. The Istanbul Metropolitan Municipality has tried to address this congestion problem by investing in the improvement of public transport services to reduce motorized traffic (Istanbul Metropolitan Municipality & Japan International Corporation Agency, 2008). The specific goals include:

1. improving and expanding public transport services therefore reducing dependence on private vehicles
2. improving and developing the road networks to cope with the growing vehicular traffic in the short term and anticipate future spatial expansion in the long term.
3. using existing roads efficiently by strengthening traffic regulations and traffic demand management

Alternative transport projects that have been proposed to address this problem include building a third road bridge, constructing an underwater railway tunnel and improving the current sea transport system.

This research intends to focus on only one of these projects namely the third bridge project which has five alternative locations that have been defined for the construction of the new bridge. A spatial multicriteria decision making methodology is proposed for selecting the most preferred alternative among the set of alternative bridge locations.

1.2. The Decision Problem

Transport projects have great impacts on the society as a whole, the economy and the environment. Assessing transport choices and alternatives is crucial as investments in infrastructure are large and have repercussions throughout the society (Hildén, Furman, & Kaljonen, 2004). The Turkish government through the Ministry of transportation has proposed to build a third bridge connecting the Bosporus strait convinced that this will address the severe traffic congestions of Istanbul.

This decision has been heavily criticized by transportation and city planners as well as non-governmental organizations (D Toraman, Demirel, & Musaogly, 2008). A local transport expert stated that having a third bridge itself will create extra traffic and would not relieve the pressure on the two existing bridges therefore preferring a no build alternative (Gercek, 2009). Additionally Gercek asserts that it is not possible to build ones way out of congestion and attempts to do so will only lead to never ending cycle of land speculation, lobbying by construction firms and political patronage. Moreover critics have voiced their concerns over the destruction of natural resources like forests and water sheds and the financial costs involved (Gercek, 2009).

Nevertheless the government is going ahead with its plans to construct a new bridge and an impact study by the Ministry of Transport has defined 5 alternative locations for constructions. Hence it is important that these alternative bridge locations are evaluated and the best alternative is one that will both serve to satisfy transport demand as well as taking into account the stakeholders interests, the current land use and ecologically protected areas of Istanbul. To evaluate these alternatives there is a need to develop a methodological framework for decision analysis that will offer a simple and effective way of selecting the most preferred alternative.

The proposed methodology will evaluate the 5 alternative bridge locations based on optimal routes generated for each alternative. Therefore in deciding which is the most preferred location to build the bridge, the spatial characteristics of the route that is generated for each bridge alternative is taken into consideration and the total route impact is evaluated and compared. It should be noted that the alternative bridge is also defined as part of the route.

The proposed method has the ability to deal with multiple and conflicting objectives, consider the most relevant criteria, gauge the importance of a group decision making process and identify the most preferred alternative. This framework will be illustrated through its application on a real world decision making problem involving the selection of a preferred alternative location for the construction of a new bridge in Istanbul, Turkey.

The framework consists four major phases: route generation, traffic assignment, SMCE and assigning suitability values to the five alternatives. The route generation phase encompass defining the most preferred route for each bridge alternative based on technical criteria. The second phase includes forecasting the congestion levels of these generated routes. The third phase entails the process of spatial multi criteria evaluation where composite maps are prepared for the five alternatives based on user defined criteria. The final phase evaluates the five alternative routes by extracting suitability values from the composite maps produced in the third phase.

1.3. Main Objectives and Research Questions

The main objective of this research is to formulate a methodological approach to generate and evaluate optimal routes for 5 defined alternative locations for constructing a 3rd bridge connecting the Bosporus strait with the intention to define the most preferred location to build the bridge.

- *Sub objective 1*

Methodological Approach

1. What methods have been previously used to generate and evaluate transport project alternatives?
2. Who are the stakeholders involved in these projects?
3. What criteria and themes do these stakeholders consider important in the evaluation process?

- *Sub objective 3*

Travel Demand Modelling

1. How to simulate traffic assignment for the year 2023?
2. What is the performance of each route after traffic assignment?
3. What is the preferred route after traffic assignment and on what basis is it preferred?

- *Sub objective 4*

Evaluation of alternatives

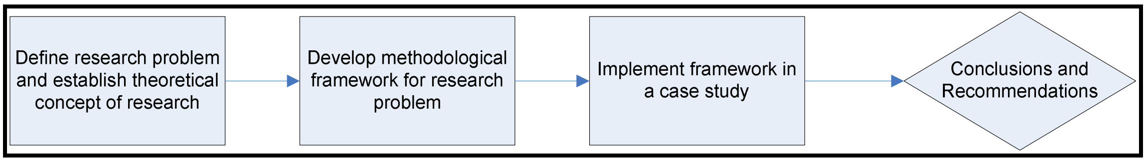
1. What criteria are considered important by the stakeholders in evaluating the alternatives?

2. How are weights determined and assigned to the different criteria and themes?
3. How to assess the alternatives based on the user defined criteria?
4. What is the preferred route after evaluation of the 5 routes?

1.4. Research Overview

The research is carried out in three main phases – defining the research problem and establishing the theoretical aspects of the problem, developing a methodological framework to answer the problem then implementing the developed framework in a real life problem.

Figure 1 Overview of research



1.5. Thesis Structure

Chapter 1 introduces the thesis research with a brief background on the transportation sector and the need for evaluating proposed transportation projects. The research problem, objectives and an overview of the research is presented.

Chapter 2 presents the literature review and looks into the different methodologies being used in previous researches and internationally for evaluating transport projects as well as explaining the concept of spatial multi criteria analysis which is the approach used to evaluate the alternative routes.

Chapter 3 describes the study area, discussing the physical and relevant characters and discusses the need for the new bridge.

Chapter 4 describe the research methodology in detail looking into the four main phases of generation of alternative routes, transport modelling, preparation of suitability maps using SMCE and finally the evaluation of the alternatives by assigning the suitability values to the five alternative routes.

Chapter 5 illustrates the results of the four main phases – generation phase, traffic assignment, evaluation and suitability values assignment phase and discusses them

Chapter 7 presents the conclusions and recommendations.

2. Literature Review

2.1. Introduction

Decision making is more complex than ever before. Transport projects require governments, municipalities and transport planners to justify the impact of their actions. There are several factors contributing to the complexity of decision problems (Keeney, 1982). First of all is that a decision usually has multiple objectives. Factors such as minimizing environmental impacts, maximizing economic benefits, maximizing positive social impacts and minimizing health and safety hazards have to be achieved simultaneously. The difficulty of identifying good alternatives is also another factor contributing to the complexity of decision problems. The desirability of an alternative is affected by many factors hence the need for careful analysis to identify a single alternative that seeks to achieve the problem objectives. The long time horizons of a project requires that implications of alternatives to be considered in the decision making process. Decisions affect many different groups of people which also contribute to the complexity of decision problems.

Transportation planning had always been dominated by engineering views in the past. Recently social science views have been influential in the discussion of transport behaviour and infrastructure as transport policies face conflicting views between economic gain and environmental constraints (Nijkamp & Blaas, 1994). Accordingly transportation planning cannot be done in isolation from other fields of planning and policy making such as economic, environment, social and technological policy. It is multidimensional activity that focuses on various and often conflicting interests with the main goal of conflict resolution.

Planning and decision making processes involves a sequence of logical steps beginning with identifying objectives, designing alternatives, impact assessment and finally the choice of the best alternative (Hildén, et al., 2004). Planning and decision making are the two main phases of this process. Communicative approaches can be integrated into this process when the relevant stakeholders take part in the planning and assessment.

The following sections will discuss a few approaches of generating routes, the different approaches to evaluation of route alternatives by different countries and will also discuss multicriteria evaluation, spatial multi criteria evaluation (SMCE) and its components.

2.2. Generation of routing alternatives

Generating alternative routes is a critical and component of transportation planning. Frequently alternative solutions are dictated by the political process or institutional constraints (Miller & Shaw, 2001). A GIS allows selection and evaluation of alternative routes using buffer, overlay, interpolation, and visualization techniques for summarizing and communicating attributes

The generation of alternative routings is done in the early stages of planning process and ideally should consider the values of all interest groups and stakeholders. Generally the generation of route alternatives in transport planning encompass the definition of one or few alternatives that are proposed by proponents. These alternative routes are then subjected to EIA (Environmental Impact Assessment) or SEA (Strategic Environmental Assessment) if and when required. However this approach is usually biased towards the proponents interests and moreover the alternatives are not devised in a spatial manner (Keshkamat, Looijen, & Zuidgeest, 2009).

Determining the best route through an area is one of the oldest spatial problems (Berry, 2004). Routing usually involves the selection of path through a transport network and can be solved effectively using GIS and Remote Sensing technologies. Previous researches have already seen the application of GIS for routing projects like pipeline routing project (Nonis, Varghese, & Suresh, 2007), transmission line routing (Berry, 2004) and transport route planning (Keshkamat, et al., 2009).

An approach to generating route alternatives is to solve the problem as a surface shortest path problem (Miller & Shaw, 2001). This approach solves for a minimum cost path through a surface representing geographic space and is alternatively known as the Least Cost Path procedure. This problem can be solved using polygons, regular square grid and triangulated irregular network (TIN) surface models. There are two different strategies to generate routes based on this approach. Firstly is to generate solutions based only on cost and then use multicriteria decision models to compare the solutions based on their attributes. Another strategy to generating solutions is to incorporate attributes using suitability mapping with proper scale to generate a cost for each location, that is, a higher score implies lower suitability.

The application of the Least Cost Path procedure for identifying optimal routes based on user-defined criteria has been used extensively in GIS applications (Berry, 2004). The different applications, whether it is locating highways, pipelines or electric transmission lines follows the same procedure of 1) developing a discrete cost surface indicating relative preference at each location, 2) generating an accumulated cost surface from a starting location to all other locations and 3) deriving the optimal route from an end point as the path of least resistance guided by the accumulated cost surface (Berry, 2004).

Yildirim et al employed ArcGIS Spatial Analysis module to find the best route for a new gas-pipeline using both GIS and raster based analysis for developing the least cost path (Yildrim, Nisanci, & reis, 2006). Nonis et al developed a GIS based approach for pipeline routing by utilizing relative ranking and weights by considering factors that are likely to affect the potential routes (Nonis, et al., 2007). The procedure involves selecting factors that will affect the pipeline route. These factors define the rules which the routes should abide by then maps are derived from these factors which are then used to generate suitability maps and identify the optimal route using the least cost path procedure as defined by Berry.

Keshkamat et al designed a spatial multi criteria network analysis method for generating route alternatives (Keshkamat, et al., 2009). This approach takes into account environmental concerns, transport efficiency, safety issues, socio-economic demands, technical and financial feasibility as well as integrating stakeholder involvement. The designed method has three major components, that of identifying data and criteria, weighting assignment module and the geospatial processing module where spatial multi criteria analysis (SMCA) and Network Analysis are carried out.

The criteria identified in the first component reflect stakeholders concerns as well as the weighting assignment. In the SMCA, suitability maps are prepared based on the defined criteria and their weightings. Thereafter the raster extraction algorithm of Beyer is used to extract the suitability value of the raster cell to the road vector layer. This means that each road link has been assigned a value, therefore making it possible for the generation of a least cost path.

It can be concurred from the above approaches that the generation of routes on a GIS platform generally involve the generation of suitability maps based on defined/user-defined criteria followed by identifying an optimal route using a least cost path procedure.

2.3. Evaluation of routing alternatives

The evaluation of transport projects was relatively simple in the past. The process entailed the study of whether the particular project would be able to repay its investment costs through the combination of its benefits in saving travel time, operating expenses and reductions in accidents (Litman & To, 2009). However this approach is heavily criticized for not considering other impacts such as the transportation facilities cost, traffic demand, equity and other alternatives or options.

The earliest scientific attempt for transport project evaluation was carried out in France in the mid 19th century (Nakamura, 2000). The materialization of railway systems caused people to question the necessity and priority of other transport projects such as canals and roads. French civil engineers then tried to estimate the benefits of transport facilities and compute consumer surplus

In the 1960s the US Department of Defence developed a system that aimed to evaluate the effects of military and other public expenditure. The 1970s saw the popularity of Cost Benefit Analysis (CBA) being applied to all World Bank projects and other international development aid organizations. During and after the 1980s the prominent European countries started adopting cost effective analysis for the evaluation of transport projects.

At present there are similarities as well as differences between countries with regards to scope and method of evaluation. The methodological approaches used by the United Kingdom, United States, Japan and developing countries are discussed briefly below.

2.3.1. UK Approach

A review of evaluation methodologies for transport projects in the United Kingdom revealed that emphasis used to be channelled towards direct user benefits hence the key elements of evaluation entail economic factors (Vickerman, 2000). The standard assessment procedure for roads had been the COBA procedure which is essentially a cost-benefit procedure that places importance on factors that can be measured or monetized. The said procedure relies on transport modelling that assesses changes in traffic patterns that result from a project and measures benefits by time saving in travelling and reduction in accidents (Vickerman, 2000). Therefore the COBA procedure is biased towards projects that will cause major savings in travel time and decline in accident costs. COBA does not capture factors such as environmental costs and benefits as well as economic impacts on the surrounding regions.

Due to the narrow scope of the COBA procedure, the UK government proposed an integrated transport system and in parallel a planning system that supports it. The objective of this approach known as

NATA (New Approach to Appraisal) is to develop a transparent and flexible framework for evaluating and prioritising road transport projects. The NATA approach captures all elements of COBA and additional factors such as:

- environmental impact (noise, local air quality, landscape, biodiversity, heritage, water)
- safety
- economy (journey time reliability, scheme costs, regeneration, access to public transport)
- accessibility (community severance, pedestrians and others)
- integration

These criterions both had quantitative elements which are measurable and qualitative elements whish are evaluated on a seven point scale for negative to positive effects (Vickerman, 2000).

2.3.2. US Approach

The benefit-cost (BC) framework dominates evaluation methods in the United States(Lee, 2000). Similar to the UK's NATA approach the BC framework depends on transport demand forecast to generate information such as induced demand, consumer surplus and savings in travel time (Lee, 2000). Criterion such as value of time, traffic safety, environmental impacts, efficiency, regional economic impacts and equity are also considered.

The approach essentially contains three main processes:

1. Alternative phase

In this first phase the base alternative, project alternative and supporting actions are taken into account. The base alternative is also known as the do nothing alternative which represents the utilization of current capital resources with no further investment to the proposed project. Project alternatives or investment options are generally classified according to the amount of investment – from low capital alternatives to high capital alternatives. The project that is chosen from the alternatives will then have a set of supporting actions to ensure that the investment generates the maximum benefit.

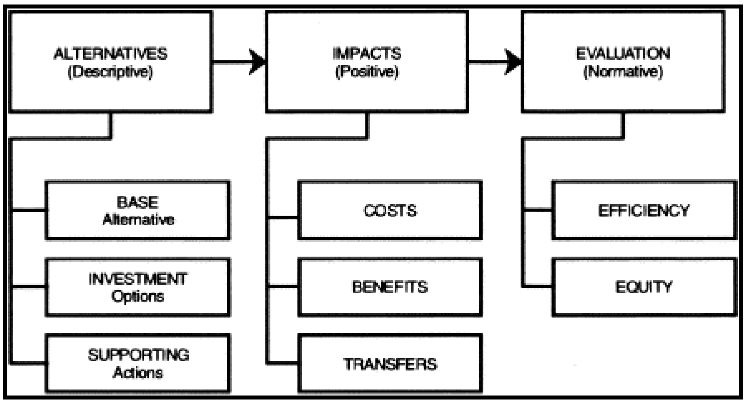
2. Impacts phase

Impacts of a project are classified into costs, benefits and transfers. Costs of a project typically consists of capital, maintenance and operations costs. Benefits include both positive and negative spillovers derived from building the project. According to Lee a large number of impacts are basically transfers which individuals may gain or lose and does not affect the society as a whole (Lee, 2000). Transfers maybe in terms of finance such as user fees or taxes, or job opportunities created from construction work.

3. Evaluation phase

The final phase brings together information on alternatives and impacts and evaluates whether a project is feasible or not.

Fig 2 Components of benefit-cost analysis



Source: (Lee, 2000)

Lee also discussed other evaluation methods that are mainly classified as scoring and weighting methods, process oriented techniques and measures of effectiveness (Lee, 2000). Scoring and weighting methods include multi objective or multi criteria programming, cost effectiveness and sufficiency ratings. Process oriented techniques such as focus groups are increasingly replacing the Delphi method. Measures of Effectiveness (Moeinaddini, Khorasani, Danehkar, Darvishsefat, & zienalyan) places importance on the performance of each alternative and how well it serves its proposed objectives. The fundamental requirement for the evaluation of effectiveness is that it should be comparable among all alternatives.

2.3.3. Japan Approach

The evaluation system and approaches for transport projects in Japan have one thing in common and that is to evaluate the "social significance of projects from the viewpoint of efficiency and equity by applying a sort of multi criterion analysis.." (Morisugi, 2000). The Cost-Benefit Analysis is adopted as the method to evaluate social efficiency.

The Japanese government adopted the Cost-Benefit Analysis as the standard formal procedure for evaluating transport projects. This approach includes the conventional CBA which places a lot of emphasis on economic efficiency and user's benefits and does not consider social equity and environmental factors (Morisugi, 2000). To supplement this narrow scope a Multi Criteria Analysis is employed to cover factors such as regional economic impacts, local and global environmental impacts. The current evaluation system is used to not only evaluate newly proposed projects but also to re-evaluate projects that are or have been delayed.

2.3.4. Developing Countries Approach

In developing countries the World Bank employs an evaluation method known as the engineering-economic approach for evaluating non-emergency road investments (Talvitie, 2000). This approach seeks to achieve a road system that is functional and that the technical standards will minimize the road transport costs to the society in general. The transport costs considered in this approach are:

1. Construction
2. Rehabilitation and periodic maintenance
3. Routine maintenance and system operation costs

4. Road user costs (vehicle operating costs, accident and time costs)
5. External costs to society (pollution and other identified benefits)

The data input need for the engineering-economic analysis include travel demand, facility performance and operating costs, value of time, traffic safety and facility costs (Talvitie, 2000). The lack of socioeconomic data and travel data in developing countries more than often makes it difficult to develop travel demand models. In these cases travel volumes are forecasted using the GNP anticipated growth.

Inputs from facility performance and vehicle operating costs are generated from the World Bank's own elaborate model that predicts the deterioration or improvement in road conditions based on cumulative axle loads or maintenance services performed by the road administration.

Savings in travel time is recognized as an important benefit, however in developing countries this only accounts for a small fraction of the total benefits.

Facility costs such as the cost of maintenance, rehabilitation and construction are usually based on information collected locally, mainly from the road administration.

2.4. Multicriteria Assessment

Multicriteria analysis and/or evaluation is also commonly known as Multicriteria Decision Analysis (Proctor & Drechsler, 2003). Multicriteria Analysis (MCA) may be defined as a "decision aid and a mathematical tool allowing the comparison of different alternative scenarios according to many criteria, often conflicting, in order to guide the decision maker towards a judicious choice" Roy in (Chakhar & Martel, 2003). MCA attempts to simplify complex decision-making tasks that are most likely to involve numerous stakeholders, several alternatives and possible outcomes and criteria that are sometimes difficult to quantify. Proctor and Dreschler state that MCA is an effective procedure that identifies tradeoffs in a decision making process with the main goal of achieving the most preferred alternative (Proctor & Drechsler, 2003).

The fundamental characteristic of an MCE is that it starts from a number of explicitly formulated criteria (Voogd, 1983). Hence the objective is to find solutions to decision problems by evaluating the alternatives by means of the performance characteristics of the formulated criteria (Jankowski, Andrienko, & Andrienko, 2001)

The use of MCE in research has been used in transportation investment planning (Giuliano, 1985), evaluation rail transit networks (Gerçek, Karpak, & K l nçaslan, 2004), environmental decision making (Kiker, Bridges, Varghese, Seager, & Linkov, 2005), least cost path analysis for an all-weather road (Atkinson, Deadman, Dudycha, & Traynor, 2005) and housing site selection (Al-Shalabi, Mansor, Ahmed, & Shiriff, 2006).

MCE uses both qualitative and quantitative information and combines the information of several criteria to formulate a single composite index of evaluation (Effat & Hegazy, 2000). A criterion maybe a factor that provides suitability of a phenomenon in continuous measure or maybe a constraint that limits the alternatives that are being considered (Effat & Hegazy, 2000).

2.5. Spatial Multi Criteria Evaluation (SMCE)

According to estimations 80 % of the data that are used by decision makes and managers are related to geography (Malczewski, 1999). Decision problems that use and involve geographical data are known as spatial decision problems. There has been a growing use of Geographic Information System (GIS) in many applications including transport planning and urban land use planning.

Spatial Multicriteria analysis goes a step further than the conventional multicriteria analysis whereby the analysis is applied in a spatial context. Therefore decision makers, objectives, alternatives and criteria have a spatial dimension. SMCE essentially integrates multi criteria evaluation methods and spatial analysis. Spatial decision problems normally entail a large set of alternative and multiple conflicting evaluation criteria (Malczewski, 2006). These alternatives are typically evaluated by decision makers, managers, stakeholders and interest group who have different preferences with respect to the importance of evaluation criteria.

SMCE requires data on the geographic locations of criterion values and alternatives and the decision analysis process encompass combining and transforming geographical data into a decision (Sharifi & Retsios, 2004). Analysis involves procedures such as using geographic data, decision makers and/or stakeholders' preferences and the manipulation of data and preferences according to specified decision rules.

SMCE allows the assessment of multiple criteria and alternatives to aid the understanding of their impacts, advantages and disadvantages. In this case the alternatives have specific geographic locations and their characteristics or performance is represented by a separate map, commonly known as criterion maps.

Numerous researches have employed SMCE to evaluate projects. In Istanbul, a framework was developed to assess four alternative routings for a proposed third bridge (Dogukan Toraman, Demirel, & Musaoglu, 2005). The location of the third bridge had been predetermined then SMCE combined with remote sensing and photogrammetric were used to assess four alternative routings based on five main evaluation criteria – social, environmental, economic, topography and network competence.
A study conducted in Klang Valley, Malaysia also applied SMCE to develop and evaluate an integrated plan for public transport and land use development (Sharifi, Boerboom, & Shamshudin, 2004). The ILWIS-SMCE module was used to design and evaluate an alternative rail network which when combines with other transportation systems will meet the socio economic and environmental requirements of the people of Klang valley. The study selected the value focused approach after considering its "objectives, decision making paradigms and approaches, procedural rationality

Another study in Malaysia saw the application of SMCE as a planning tool for strategic rail network planning and transit zone identifications (Sharifi, et al., 2004). The study employs ILWIS- SMCE module to evaluate three strategic alternative light rail networks and design alternative solutions for transit zone locations in the Klang Valley.

2.5.1. Evaluation Criteria

SMCE decision making requires the arrangement of objectives and identification of attributes that will be useful in indicating the degree to which these objectives are achieved (Malczewski, 1999). The objectives define the direction a decision maker is aiming for hence it is a statement of a desired state of a geographical area under consideration. An attribute is used to measure the performance of the objective and indicates the directions of improvement for the objective. Therefore objectives and their underlying attributes form a structure of evaluation criteria for a decision problem.

According to Malczewski evaluation criteria is a broad term that refers to both the concept of objectives and attributes (Malczewski, 1999). It can be defined as "*parameters used to evaluate the contribution of a project to meet the required objective*" (Nolberto, 2004). Criterion will give a measurement of how well an alternative has achieved its objective and maybe spatial if it needs information on locations to measure the effect of the alternative (Sharifi, 2008)

Generally defining a set of evaluation criteria is done with respect to the decision problem. However the selection process is not simple and depends on many factors such as the type of alternatives, the geographical areas that are likely to be affected by the alternatives, stakeholders preference and data availability. According to Malczewski there are two tendencies when it comes to defining a set of evaluation criteria. Firstly the number of evaluation criteria is defined such that the decision model fits the problem situation as close as possible. This typically leads to complicated situation where there are numerous number of criterions to be dealt with. Secondly the number of criteria defining the decision problem is small leading to oversimplification. Accordingly a balanced approach is needed to identify all possible evaluation criteria.

Attributes should be comprehensive, measurable, complete, operational, decomposable, non redundant and minimal (Malczewski, 1999). To be comprehensive a set of attributes should clearly indicate as to how it's associated with the objectives. A measurable attribute is capable of assigning a number to the attribute of each alternative and has the ability to assess the preferences of the decision makers at various levels. A complete set of attribute covers all relevant aspects of the decision problem and is able to adequately represent the multicriteria nature of the problem. A set of attributes is operational if it can be used meaningfully in the decision making process. A set of attributes that is decomposable is able to disaggregate decision problem into smaller dimensions. A set of non redundant attributes is not accounted for more than once. Finally a set of attributes is minimal when it is not possible to define a smaller set of attributes representing the same decision problem.

The techniques of selecting criteria include examining relevant literature and this can be in the form of relevant researches and case studies or government documents. Another technique suggested by MacCrimmon in Malczewski is analytical studies. He stated that system modelling can be used as an analytical method to identify a set of evaluation criteria for multicriteria decision making (Malczewski, 1999). A survey of opinions is also another technique for selecting evaluation criteria. In this approach, those who will be affected by the decision or a group of experts are asked to identify criteria that should be included in the analysis.

2.5.2. Standardization

Because of the different scales on which the criterion are measured, SMCE requires that the values contained in the various criterion maps are transformed to comparable units (Moeinaddini, et al., 2010). There are a number of approaches that can be used to make criterion maps comparable and this depends on the classification of criterion maps on the basis of the type of information available (Malczewski, 1999). The classification is based on the difference between deterministic decisions and decision under uncertainty, accordingly criterion maps can be standardized as deterministic, probabilistic or fuzzy.

A deterministic map assigns a single value to each object (point, line, polygon or pixel) on a map layer. Linear scale transformation and value/utility function approaches are two examples of deterministic method. The probability method is based on probability theory which states that the outcome of an observation is dependent upon chance and cannot be predicted precisely. The fuzzy membership function manipulates arithmetic and algebraic operations on fuzzy numbers to acquire crisp numbers (Malczewski, 1999). This "fuzzy" concept evaluates suitability by scaling values to a common range where suitable and unsuitable areas are continuous measures (Effat & Hegazy, 2000).

For ILWIS-SMCE analysis the values and classes of criterion maps are transformed to a common scale which is called utility. Utility is defined as "the measure of appreciation of decision maker with respect to a particular criterion and relates its value/worth which measures in a scale of 0 to 1" (Ifeanyi, Adoh, & Alabi, 2010). An output standardization with the value of 0 means that the input value is perceived to have low utility while an output standardization of 1 is perceived to have high utility.

In ILWIS-SMCE the standardization procedure are different for factors and constraints. In standardizing factors (benefits and costs) the output values range between 0 and 1. The module offers the following linear standardization functions – Maximum, Interval and Goal. The "Maximum" approach standardizes the input values by dividing them by the maximum value of the map. The "Interval" approach standardizes the input values with a linear function that uses the minimum value and the maximum value of the input map. The "Goal" approach standardizes the input values with a linear function that requires a specified minimum and maximum value.

Standardizing constraints will result in either a pixel obtaining a value 0 (not performing) or value 1 (performing). The five possible approaches to standardizing constraints are – Unequal to zero method, Minimum method, Maximum method, Inside method and Outside method.

The standardization of input maps for SMCE is a fundamental procedure as it allows various input maps with different meanings and scales to be transformed to the same unit of measurement. Only when input maps have equivalent measurement basis then weighting can be applied.

2.5.3. Criterion Weights

Objectives and attributes do not always have the same value to the decision maker therefore different priorities are given to the different attributes measuring the objective (Sharifi, 2008). The information about the relative importance of evaluation criteria is achieved by assigning weight to each criterion. The assigning of weight gauges the stakeholders preferences in the decision making process.

The weight is therefore defined as the “value assigned to an evaluation criteria that indicates its importance relative to other criteria under consideration” (Malczewski, 1999). Accordingly the larger the weight the more important is the criterion on the overall utility (Malczewski, 1999).

There are numerous techniques that exist to assign weights to the different criteria. Malczewski discussed four of these techniques and theses are 1) ranking methods, 2) rating methods, 3) pairwise comparison method and 4) trade off analysis method. The ranking method is the simplest way of assessing the importance of weights whereby the criterions considered are ranked in order of preference by the decision maker. This method is often criticized of its simplicity and its inability to deal with a larger number of criteria. Additionally it also lacks a theoretical foundation.

The rating methods require that decision makers assign weights based on a predetermined scale, for instance a scale of 1 – 10. The point allocation approach and ratio estimation approach are two examples of rating methods. Rating methods are usually criticized for lack of formal theoretical foundations and the difficulty to justify the meaning of the weights assigned to the criteria.

The pairwise comparison method was developed in the context of analytic hierarchy process. The method entails creating a ratio matrix and by taking the pairwise comparisons as the input it computes relative weights as output. The advantage of pairwise comparison is that it allows only two criteria to be considered at a time. However this can become cumbersome when there are many criteria. Pairwise comparison is also criticized for not taking scales into account when criteria are measured.

The trade off analysis method uses direct assessments of trade offs that decision makers are willing to make between pairs of alternatives. The approach requires decision makers to compare two alternatives with respect to two criteria at a time and assess which is the preferred alternative. From this one can deduce how much weight the decision maker has given to the different criteria.

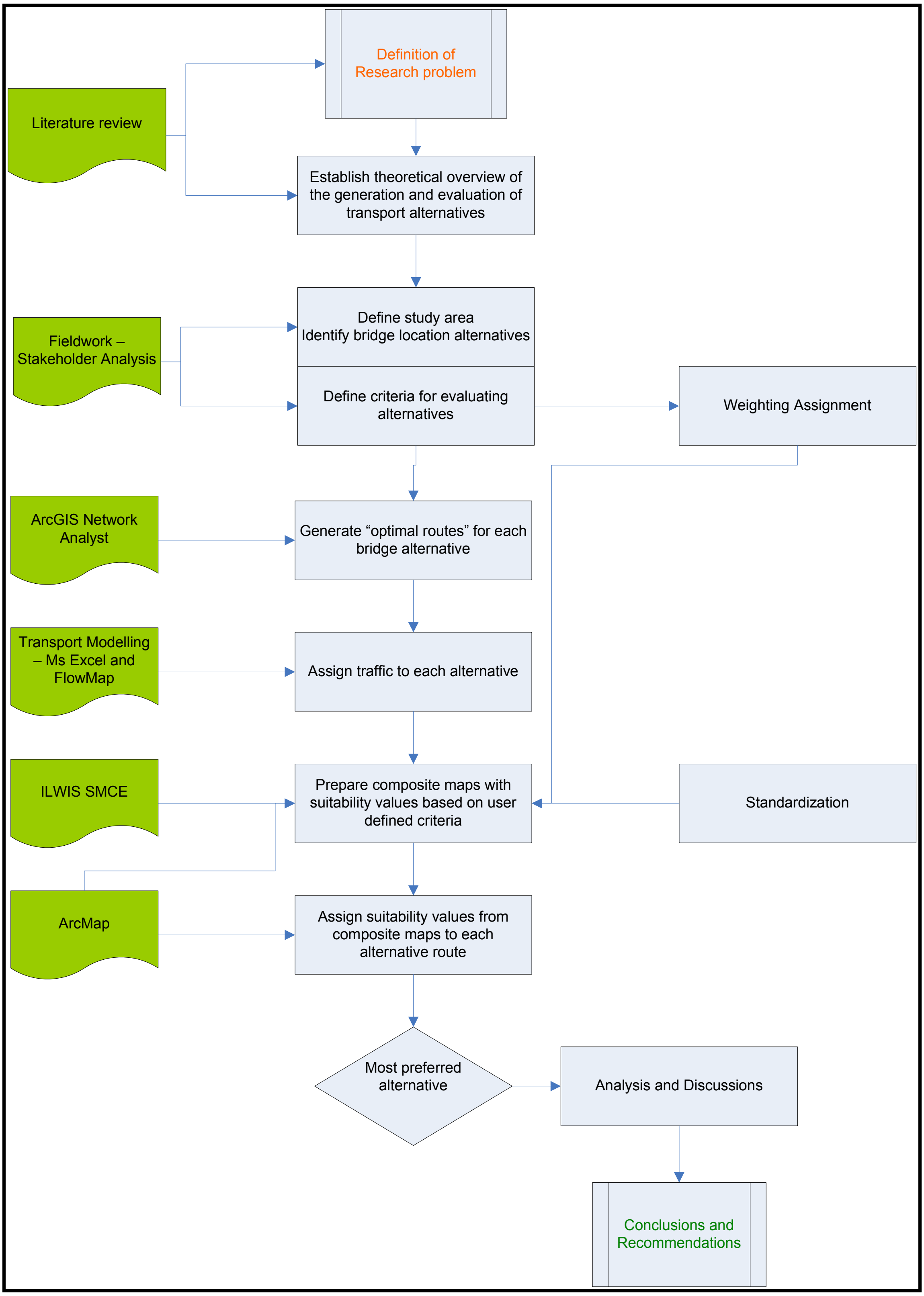
2.6. Conceptual Framework

The conceptual framework presents the overall procedure of the research. The development of research problem, research objectives and research questions were largely aided by reviewing literature on evaluation of proposed transport projects internationally and also on the case study area, which is Istanbul. The methodological approach to the generation and evaluation of the routes for the proposed third bridge have also been defined based on similar transport alternatives evaluation researches and a well as studies on Istanbul.

Stakeholder analysis was carried out during fieldwork and collection of secondary data which was mainly in GIS format. Based on these data, analysis was conducted on GIS platform to generate and evaluate alternative, consequently identifying the most preferred alternative.

The first phase which entails the generation of routes for the five alternatives was carried out on GIS platform. The second phase which involves transport demand modelling was done on Microsoft Excel and Flowmap. The third phase was one on ILWIS-SMCE and the final evaluation phase was carried out on ArcMap.

Figure 3 Conceptual Framework



3. Study Area Description

3.1. Istanbul

Istanbul has a long and fascinating history having been the capital of the Roman Empire, the Byzantine Empire, the Latin Empire and the Ottoman Empire (Rothengatter, 2005). Settled more than 6000 years ago, it is the centre of culture and has undergone several significant cultural changes and also changed its name accordingly, from Byzantium, to Constantinopolis, to Istanbul (Rothengatter, 2005). The city is the heart of modernization of Turkey although the capital was moved to Ankara after the First World War.

Fig 4 Istanbul

The city is a cultural and economic crossroad of Europe and Asia. Being the largest metropolitan city of Turkey and one of the largest in Europe, it is located on the Bosporus Strait and the only city in the world embracing two continents with Europe on one side and Asia on the other. It has a population of approximately 12.6 million people as of 2007. The average annual population growth rate from the year 2000 to 2007 stood at 3.30%. Urbanisation has spread onto both sides of the city and its form is basically shaped by its historical spatial patterns and newly developed industry and service sectors. The city is a huge metropolis connecting continents, cultures, religions and home to more than 12million people. It is the largest business and cultural centre of the region and the most important city of Turkey providing developed financial, commercial, industrial, cultural and educational services than all other cities in the country (Gercek & Demir, 2008). Between 1990 and 2004, Istanbul produced almost 23 per cent of Turkey's total annual GDP. However, Istanbul's shares in GDP by sector and international trade indicate its greater importance in the national economy, especially financial, professional and international trade, which enjoy shares of more than 40 %, followed by commercial shares of 35.5 % (Istanbul Metropolitan Municipality & Japan International Corporation Agency, 2008).

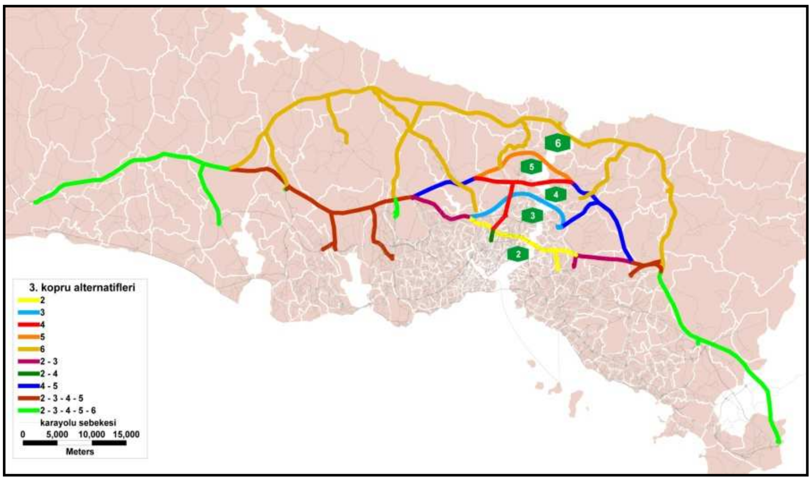
The city of Istanbul is also important because of its strategic geographical location making it a trade hub between Europe to the west and Asia to the east. It is characterised by rolling terrain and divided by the Bosphorus strait linking the Marmara Sea with the Black Sea. Its urban form extends onto the two sides of European and Anatolian. Resembling many European cities, Istanbul has expanded rapidly in recent years and its urban form influenced by its history, topography, and demography and socio economic structure. The population of Istanbul increased dramatically in the 1970s due to migration of people from the Anatolian side to the European side seeking employment opportunities in the new industrial areas that were being constructed on the outskirts of the city. Consequently the city experienced a growth of housing development, taking over outlying villages.

Population density in Istanbul has increased from 1,067 inhabitants per km2 in 1985 to 2,333 inhabitants per km2 in 2007. In densely populated areas, densities are as high as 44,205 inhabitants per km2. Istanbul is also facing a substantial increase of car ownership in recent years as a result of population increase and economic growth. The number of registered vehicles dramatically increased from 200,000 in 1980 to 1.7 million in 2007 and of all registered vehicles in Turkey, 26.4% are registered in Istanbul. The transport system is not able to keep up with the rapid urban growth and change hence the existing bridges face severe traffic congestion (Karsak & Ahiska, 2005; Ulengin, 1994).

As a result of increasing population, growth in use of private automobiles and the insufficient road network capacity the existing infrastructure crossing has exceeded its capacity. There are several ongoing projects including the Marmaray Tunnel project that has been proposed to address this problem of traffic congestion. Plans are currently underway to construct a 3rd road bridge to connect the Bosporus Strait linking the European and Asian regions of Istanbul. This proposal seeks to address the heavy travel demand hence relieving the existing transport corridors of their highly congested conditions and provide additional capacity to address the extensive growth in the area. According to a report by OECD the main obstacle to improving the transportation system is the "highly fragmented decision-making process characterised by a large number of actors, operating both formally and informally" (Organisation for Economic Co-operation and Development, 2008).

The proposed location of a third bridge to connect the two sides of İstanbul has stirred up considerable debate. Supporters state that a third bridge is critical to address traffic problems in the city, while others say that it is not necessary expressing concerns about environmental consequences on the city's forest and water resources. There has been 5 alternative locations proposed by the Ministry of Transportatio to build the new bridge, the first alternative situated in between the two existing bridges and the other four are spread out to the north of the Fatih Sultan Mehmet Bridge.

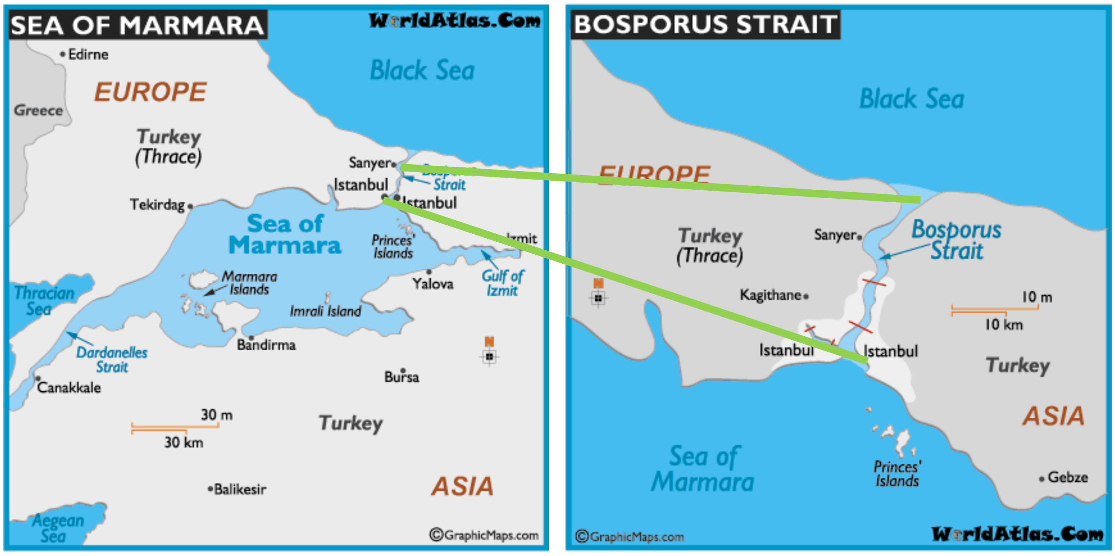
Fig 5 Map showing the 5 alternative locations of the proposed third bridge



3.2. Bosporus

The Bosporus has always been an important trade route for ships from Mediterranean Sea and the Black Sea. It is 32km long and has a maximum width of 3.7km at the northern entrance and a minimum width of 700m. The depth of Bosporus changes from 36 to 124m in midstream. The two existing bridges that connect the Asian and European continents were opened in 1973 and 1988. The shores of Bosporus features as the city's favoured location for settlements and its trademark being the yali – a Turkish mansion constructed on the waterside.

Fig 6 Bosporus Strait



Currently transportation over the strait is provided by two road bridges and ferry lines. Bosporus Bridge was opened in 1973, has 6 lanes and is 1074meters long. The second bridge, Fatih Sultan Mehmet was opened in 1988 connecting the Trans European Motorway, has eight lanes and 1092 metres long. Bicycles and pedestrians are not allowed on both bridges. The opening of these two bridges had great impacts on Istanbul in terms of population distribution and providing a vital link for commercial, education, employment and recreation purposes between the Asian and European sides. Even thought the Trans European Motorway serves the intercity transportation, it is also heavily used for the daily intracity trips crossing the Bosporus. The increasing number of trips between the Europe and Asian side is due to the distribution of employment and population among the two sides of the city. A household travel survey conducted in 2006 showed that there are approximately 21 million daily trips made in the metropolitan area and 10% of these trips are made between the two continents (Celik, 2009). Of this continent crossing traffic, 300,000 trips are made by ferries while 1,000,000 trips use the bridges. These trips not only cause congestion on the two bridges but also for intra-continent traffic.

3.3. Transport Planning in Istanbul

Henry Prost, a French architect prepared the first land use plan of Istanbul in 1973. The plan had propositions to decentralize the historic peninsula to the outskirts of the old city wall (Gercek & Demir, 2008). The industrial area which was initially located on the shores of Golden Horn because of the proximity to sea transport began to decentralize and continued to expand to the outskirt of the city until the 1970s. Migrants began moving in settling between the industrial areas and the city walls. Housing development also took place rapidly within this period to cope with the rising immigrants who are part of the labour force. Consequently the Istanbul Metropolitan Municipality (IMM) was not able to keep up with rapid process resulting in the land use plans always being behind the developments (Gercek & Demir, 2008).

At the national level the administrative duties in the transportation sectors are looked after by the Ministry of Transport. This includes duties such as formulating policies, planning, budgeting and regulatory activities. The Ministry also works with the EU in agendas such as the physical integration of infrastructure, vehicles, environmental standards, improvement of border crossing and policies affecting trade (Gercek & Demir, 2008).

At the metropolitan scale, IMM covers a number of organizations that are responsible for transportation division of planning, land use, traffic regulation and the other different modes of transport such as the rail transit system, bus and maritime transportation. The Department of Transportation is the official department under the IMM that is directly responsible for transportation at the metropolitan scale. Developing plans and projects, making decisions on strategic issues relating to transport, integrating programs and projects are some of the duties carried out by the department. The department is further divided into 6 directorates:

1. Transportation Planning
2. Transportation Coordination
3. Public Transportation Services
4. Rail Systems
5. Traffic
6. Road Maintenance and Repair

According to Gercek and Demir (2008) there is a lack of coordination among the state and municipal agencies. The local municipalities are responsible for local needs such as small scale planning while the IMM is in charge of the large scale master plan and also builds and operates the transportation infrastructure.

3.4. The need for a Third bridge

The idea of building a third bridge over the Bosporus had been proposed since 1997 and supposedly situated between Vanikoy and Amavutkoy. The Ministry of Transport together with the Ministry of Reconstruction and Resettlement vouched quite strongly for this project in 1999 despite heavy opposition from the IMM. In February 2003 the government announced the suspension of the third bridge project stating that that the project should be considered only if the Istanbul Municipality was involved (Elicin).

At the present time the mayor of Istanbul Metropolitan Municipality, Kadir Topas has confirmed that the Bosporus project is the most important predicament of the Istanbul Transport Planning (Istanbul Metropolitan Municipality, 2009). He stated that the Ministry of Transportation has come up with the 3rd bridge project offer for Istanbul and gave assurance that the project will go through suitability analysis and land usage analysis by the Istanbul Metropolitan Planning (IMP). Furthermore the mayor stated that the route of the third bridge will not affect valuable areas such as forests agricultural areas and water basins (Istanbul Metropolitan Municipality, 2009).

The Bosporus crossing is essential for the transport system of Istanbul; however statistics reveal that only 10 % of all trips are made between the two sides. The proposed third bridge proves to be attractive for local and foreign investors because of its huge investment budget. The bridge is envisaged to have three lanes in each direction with the Light Rail Transit running in the middle. The total cost of the bridge and the additional necessary links is estimated to be 1.5 US billion dollars (Alpkokin & Hayashi, 2003).

Like other fast growing mega cities Istanbul is facing a rapid increase of motor vehicles as well as population and economic growth. Car ownership has increased from 43 cars per 1000 inhabitants in 1980 to 134 cars per 1000 inhabitants in 2000 (Gercek & Demir, 2008). Nevertheless car ownership is still low in Istanbul as compared to other metropolitan cities of the developed countries. The average travel time for motorised trips has been increasing incredibly over the years and the city is suffering from severe traffic congestion. With the rapid growth and changing urban structure the public transportation system has not been able to keep up with it. The total trips made by public transport has remained more or less the same in the last twenty years whereas the share of private car trips increased from 19.3 % to 26.3 % (Gercek & Demir, 2008)

Alpokin and Hayashi (2003) argue that the third highway bridge will encourage the car usage as new road links creates their own traffic. Just as Istanbul has experienced before with the two existing bridges the city will once again experience "paradox of bridges and also is doing now for the third, meaning that every new bridge is reaching to its capacity much earlier than expected and creating the demand for the next" (Alpkokin & Hayashi, 2003)

4. Methodology

This chapter presents an overview of the methodological employed in the generation and evaluation of optimal routes in Istanbul. The methodological framework was based and developed around similar studies that have been undertaken in evaluating proposed transport projects and generally entails the generation of alternatives, assignment of traffic to the alternatives and evaluation of the alternatives. The common elements identified in these studies are establishing evaluation criteria and developing indicators for alternatives, carrying out comparative evaluation on alternatives and identifying the recommended alternative.

The designed framework for evaluating alternatives is presented in Figure 7. The contribution of stakeholders' involvement, travel demand modelling and spatial multicriteria evaluation represents a larger part of the research and entails data acquisition, open interviews, analysis and evaluation. The framework offers a method for generating and evaluating proposed transport projects by combining geographic information system practices and travel demand modelling with spatial analysis to ensure the integration of generating alternatives and evaluation in a spatial context. Although the framework does not claim to be holistic nevertheless it demonstrates a flexible and generic method of analysis of transport projects that can be applied in any study area.

The technicalities of the research were carried out in four main phases, namely:

1. Route generation
2. Travel demand modelling
3. SMCE
4. Assignment of suitability values to the five alternative routes.

The first phase involves the generation of routes for each bridge alternative based on the combination of the least travel time and shortest physical distance of the road links. The output of this phase is two separate routes for each alternative bridge, one on the European and another on the Asian side of Istanbul. These two separate routes are then connected to the bridge alternative to define it as the route alternative.

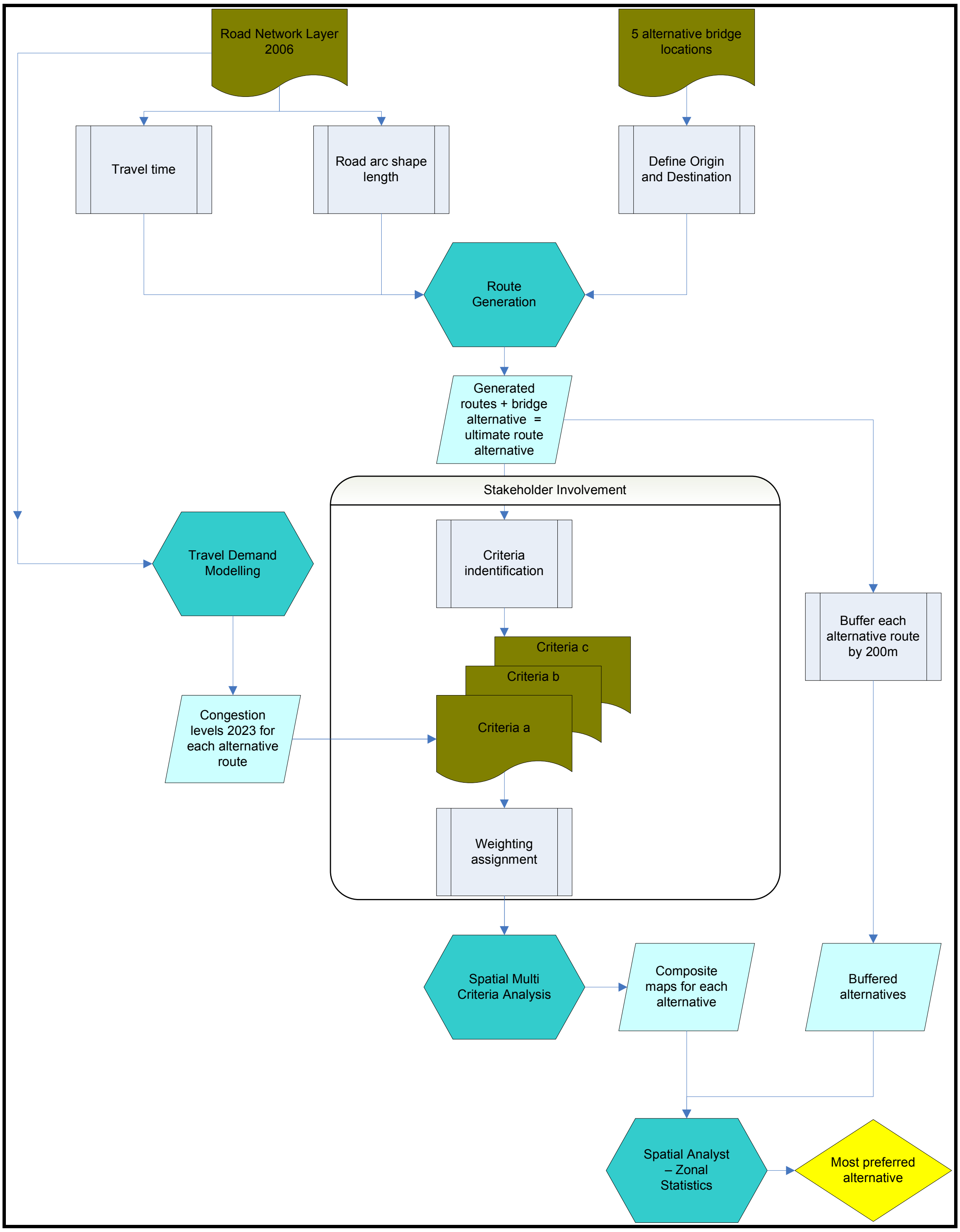
Phase 2 entails the forecasting of travel demand for the year 2023 where trips are assigned to the existing road network in addition to each alternative bridge which is essentially the new link in the network. This phase was carried out using the traditional 4 step model.

Spatial Multi Criteria Evaluation is performed in phase three whereby each alternative route is evaluated based on traffic assignment performed in phase two in addition to the user defined criteria. The output of phase 3 is 5 composite maps, one o each alternative, which has suitability values from 1 to 0.

The fourth and final phase brings together the output of phase 1 and 3. At this stage the suitability values are assigned to the 5 alternative routes which have been buffered in order to capture the spatial characteristics of the 5 different routes.

The figure below summarises the methodological approach:

Figure 7 Methodological Approach



4.1. Fieldwork – Istanbul

Data collection during fieldwork at Istanbul largely involved secondary data although primary data collection also played an essential part. Secondary data that were collected mainly constituted of GIS data needed to carry out the analysis. Additionally the transport master plan of Istanbul and other relevant reports on Istanbul and images were also acquired.

Primary data collection was carried out in the form of holding open interviews and discussions with local transport experts at the local university (ITU) and urban planners and transport experts at IMP. The open interviews were held to gauge the stakeholders' perception of the proposed third bridge project and to identify criteria that are relevant to evaluate the five alternative routes and bridge locations.

Stakeholders were also engaged in the course of assigning weights to the criteria used to evaluate the different alternatives after fieldwork. This was done through online correspondence whereby the relevant questionnaires were sent to stakeholders via email. They assigned weights to the evaluation criteria and sent back their weightings.

4.2. Network Analysis

A network analysis is commonly used for applications such as transportation and in utility networks. It has the capability to model the transportation of people and resources such as water and electricity. In this phase of analysis, Network Analyst was employed to generate the best routes for the five different alternative locations of the proposed third bridge.

ArcGIS Network Analyst is an extension on ArcGIS Desktop that aids in conducting network based spatial analysis. Network Analyst offers the option of providing travel directions, looking for closest facilities, creating service areas and origin-destination cost matrices.

In this first phase of analysis the Network Analyst function is used to generate the best route through the network on the basis of least travel cost. The best route could be the shortest physical distance, it could be least expensive, least amount of time or a combination of these (Chen, Rinks, & Tang, 2001). In this case the best route is defined as one with the combination of minimum travel time and shortest path from the origin to the destination. Therefore the time it takes to pass through a link and the distance of each link is an indicator for a cost. The underling assumption behind this choice is that the two practical constraints of daily travelling are the actual distance itself and the time it takes to travel that distance. Additionally current route planners incorporate both physical distances and mean travel time when computing optimal routes between two points on a road network (Ambrose, Bukovsky, Sedlak, & Goeden, 2009).

Travel time is one the most important factors that affects the attractiveness of different routes hence it influences the choice of route for commuters to a great extent. Arguably travel time is the most relevant estimate of distance as they are usually complimentary. However traffic density varies due to unpredictability of rush hour traffic congestion hence travel times along these routes vary within a day. The density of traffic during peak hours maybe a factor limiting the distance that could be reasonably travelled because it extends the time taken to travel the distance. Therefore the shortest route may not always be the one with the least travel time for a longer route may have a shorter travel time because of lighter traffic flows.

In view of this, travel time and physical distance are taken as two separate criteria. Independently a route with the shortest physical distance does not necessarily mean it has the least travel time. Consequently the mean travel time is incorporated in this assessment criterion to capture the combination of having the shortest path as well as having the minimum travel time in the route.

Table 1 Assessment criteria for route generation

Guiding principles	**Objectives**	**Criteria**	**Explanation**
Maximize transport efficiency	Reduction in travel time	The assigned travel time with congestion	The shorter the travel time is the better for the route.
Maximize transport efficiency	To avoid where possible routes with longer physical distance	The physical distance of each road link	The shorter the physical distance of the route the better

4.2.1. Data and Data Preparation

The data needed to generate the routes for the five alternative location of the 3rd bridge include vector data and a jpeg format image identifying the 5 alternative locations. The vector data entails the road network shapefile of 2006 which was acquired from IMP. Attributes of this road network include the shape length of each link, road types which are either a highway, sea/rail network or walk which denotes pavement that is explicitly for walking, hourly and daily capacity of each road link and travel time.

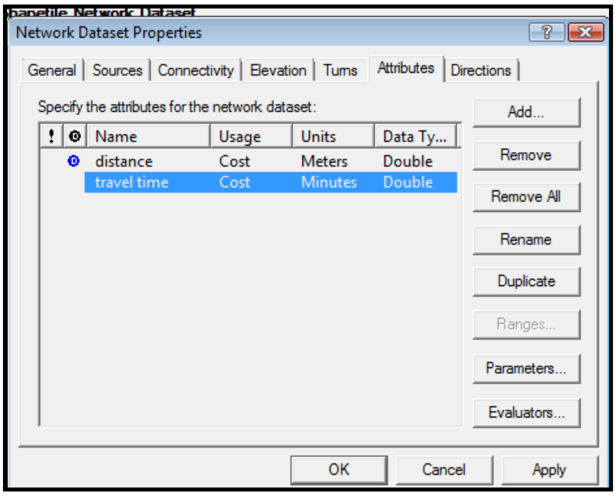
To prepare the data for network analysis it is necessary to extract only the highways road type from the road network layer. The sea/rail and walk road type were removed as vehicles do not use them. This was done using selection by attribute on ArcMap.

For the location of the 5 alternatives the jpeg image was georeferenced and then digitized on the road network layer.

4.2.2. Building the Network dataset and defining Network Attributes

In ArcCatalog the road network layer is then used to build the network dataset using the Network Analysis extension. The attributes necessary for this network include the travel time and shape length and this is taken into account when building the road network. Travel time and shape length are defined as a cost. The newly built network is then displayed in ArcMap again for the actual generation of routes.

Figure 8 Building Network Dataset



4.2.3. Solving the best route for each alternative locate

To begin with the analysis, the proposed locations of the five bridges are identified on the basis of the image acquired from the Ministry of Transportation through the Istanbul Metropolitan Municipality (refer to Figure 5). This image illustrates the proposed sites that have been identified by the Ministry of Transportation as potential locations to build the third bridge.

In view of the fact that Istanbul lies on 2 different continents, generating a route for the bridge will require two independent separate routes, essentially one on the eastern side of the bridge and the other on the west. In network analyst translates to the fact that there are also two fixed origins – one in the east and the second in the west.

Basically the origins are located on the Trans European Motorway based on the extent of the road network layer that is used for analysis. Consequently the origins are positioned on the most eastern and western part of the TEM. The TEM is part of the Trans European Networks (TENs) that connects the two most important metropolitan centres of Turkey, Ankara and Istanbul to Europe. The route is regulated as a national and international freight transportation motorway and it hosts many important industrial plants, universities making it one of the most heavily used corridors. In addition to this the TEM is also used for intracity trips crossing the Bosporus where 10% of the total daily trips are made through the two existing bridges by bus and cars. A previous study done on the third Istanbul Bosporus crossing identified three types of interrelations that should be evaluated and analyzed and these are:

- International transit transportation between Europe and Middle East countries
- Intercity transportation between Anatolian and European cities of Turkey
- Intracity transportation within Istanbul (Caliskan, 2006).

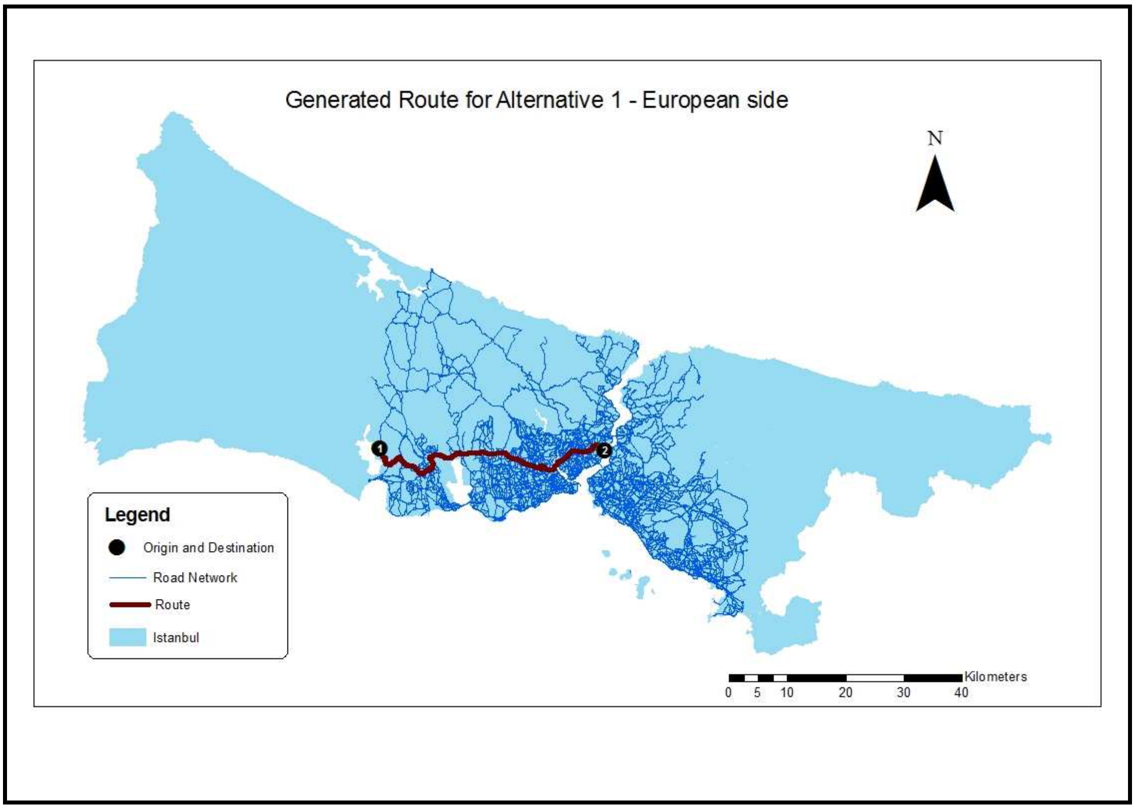
Hence the underlying reason for selecting the TEM as the fixed origins is because it is utilized by intracity and intercity trips as well as national and international trips.

The Destinations are defined by the possible location of the foot of the bridge on both the eastern and western side as illustrated in the image acquired from IMP.

There are five types of network analysis layers: 1) route analysis layer, 2) closest facility layer, 3) service area layer, 4) Origin Destination cost matrix layer and 5) vehicle routing problem layer. The relevant analysis for this phase is the route analysis layer. The route analysis layer can find the best route from one point to another. The Origins and Destinations are specified interactively by placing points on the screen and using the “Solve Network” button to find the route. The preferred route in this case is specified as one that has the least travel time combined with the shortest distance.

Finding the preferred route is done twice for each alternative, that is, on the east and then on the west. The diagram below illustrates the preferred route for bridge alternative 1 on the western side. Note that the Origin (1) is fixed and only the Destinations will change according to the location of the bridge. This same process is applied for the other 4 alternatives.

Figure 9 Illustration of the route generated for Alternative 1 on the European side



4.3. Traffic Assignment

Traffic assignment involves the selection of routes between origins and destinations within a transportation network. In the traditional 4 step transport model, traffic assignment is essentially the fourth step, following trip generation, trip distribution and modal split. This procedure involves predicting routes that vehicles would take and assigning them to the different links of the road network (Zuidgeest & Maarseveen, 2007). The result of traffic assignment is an estimate of the total number of trips that will use each link in the road network. When compared with the capacity of these different links, information such as congestion levels can be forecasted.

4.3.1. Data

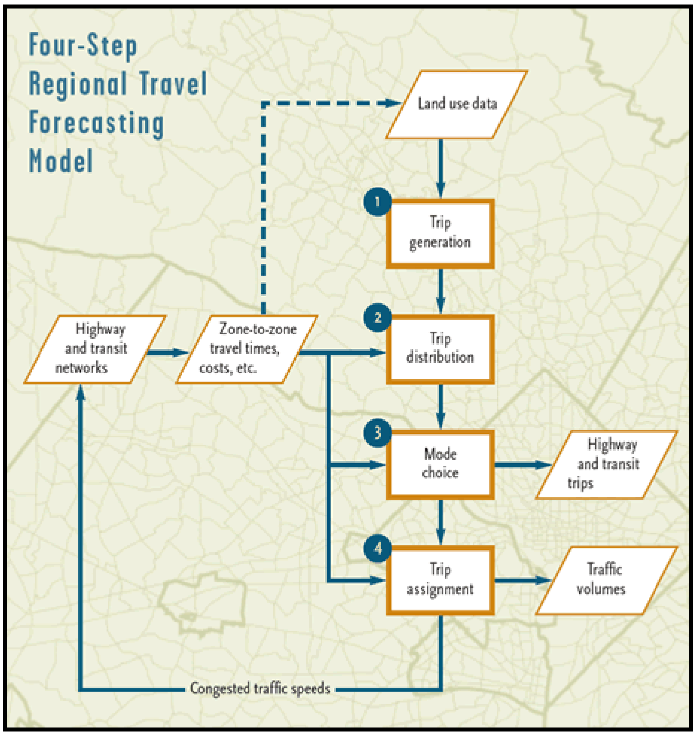
Data used in this phase of the research include ArcMap shapefiles which are ultimately imported into Flowmap for analysis. The shapefiles include the TAZ layer, the road network layer – in this case there are five separate layers, each one containing the existing road network and an alternative bridge. Other fundamental data include an excel file which contains socio economic data of each of the TAZ such as population, student and employment numbers, car ownership, household size and income.

The Transportation Master Plan for 2008 contained relevant information and parameters that are adapted and used in travel demand modelling on Microsoft Excel and Flowmap. The Istanbul Master Plan for Transportation was carried out by the Istanbul Metropolitan Municipality and the Japan International Corporation Agency in 2008. This report entailed the Trip Generation figures of 2005 which is essentially the Trip Productions and Attractions. There were also forecasted figures for the year 2023. However these were aggregated figures and depict trip production and attractions for the 33 districts of Istanbul for 2005 and 2023. This study however uses TAZ as the unit of study and Istanbul has 451 TAZs. The parameters for the calculation of the trip productions and attractions are given in this report and this is used for the calculation of the Trip Generation for the TAZs in 2005 and 2023.

4.3.2. The 4-Step Model

The classic four step transport model applies independent models for each travel demand component and works by feeding outputs from one model to the next one sequentially (Miller & Shaw, 2001). The four step approach is trip based and the first three steps are used to estimate the demand for travel. In the fourth and final step, the travel demand is equilibrated with the travel supply when trips are loaded onto the network.

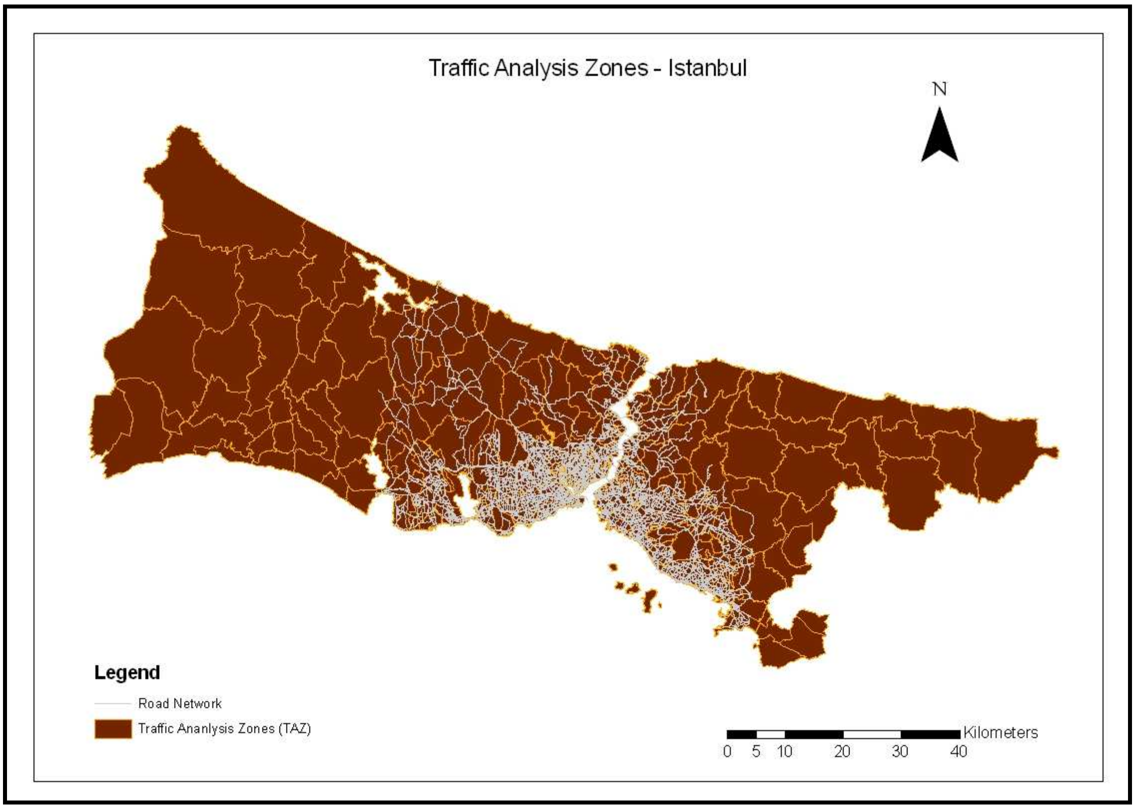
Figure 10 The Four Step Model



Source: (Metropolitan Washington Council of Governments, 2010).

The geographic unit of analysis in a four step model is the transport analysis zone (TAZ). Istanbul is divided into 451 TAZs. However the road network dataset employed only covers the inner city therefore only the 402 TAZs that intersect this road network were considered.

Figure 11 Istanbul Traffic Analysis Zones



4.3.2.1. Trip Generation

The first step of the model is to determine the number of daily trips that are made within Istanbul. This procedure is carried out by estimating the number of trips produced in and attracted to each transport analysis zone. These estimates are carried out using:

1. land use and socio economic data
2. parameters and assumptions about the number of trips typically made by each type of household and to each destination

The table below shows the list of variables that are used in the trip production and attraction models (Istanbul Metropolitan Municipality & Japan International Corporation Agency, 2008). There are four different trip purposes defined by the Master Plan and these are:

1. Home Based Work (HBW trips)
2. Home Based School (HBS trips)
3. Home Based Other (HBO trips)
4. Non Home Based (NHB trips)

Table 1 Variable List in Production and Attraction Model

Trip Purpose	Production	Attraction
HBW	Workers in Home	Employment in working place
HBS	Students in Home	Students in School Place
HBO	Population Average Income Workers in Home	Population Student in school Employment in working place
NHB	Students in school Employment in working place	Population Student in school Employment in working place
	Control total Population Students in home Number of Vehicles Average Income Employment in working place	

Source: (Istanbul Metropolitan Municipality & Japan International Corporation Agency, 2008).

For this analysis, socio economic data is available in the data acquired from fieldwork. The TAZ attribute table contained basic information such as TAZ identities, area of each TAZ and employment and student numbers. This table was then joined to the database file which contained socio economic data such as:

- Population per TAZ
- Number of workers in home per TAZ
- Number of employment in working place per TAZ
- Number of students in home per TAZ
- Number of students in school per TAZ
- Household size per TAZ
- Average Household income per TAZ
- Number of vehicles per TAZ

It can be seen that the variables listed in the table above (table 1) are available in the TAZ layer and the database file acquired from fieldwork. Drawing from the above variables, the trip production and attraction for HBW and HBS are computed using the models outlined in the Masterplan. The models are illustrated below:

- HBW Production = Net Trip Rate (1.94) * Working Ratio (0.88) * Number of Workers (Home place) by zone
- HBW Attraction = Net Trip Rate (1.94) * Working Ratio (0.88) * Number of Employment (Working place) by zone

- HBS Production = Net Trip rate (2.02) * Studying Ratio (0.87) * Number of Students (Home place) by zone
- HBS Attraction = Net Trip rate (2.02) * Studying Ratio (0.87) * Number of Students (School Place) by zone

Trip productions and attractions for HBO and NHB are estimated using linear regression model and the equation is shown below: (Istanbul Metropolitan Municipality & Japan International Corporation Agency, 2008).

- Gi = a + b1*Xi1 + b2*Xi2 + b3*Xi3 +....
- Aj = a + b1*Xi1 + b2*Xi2 + b3*Xi3 +....

Where;
Gi = Production trip from zone i
Aj = Attraction trip to zone j
Xin, Xjn = socio economic data in zone i and j
A, bn = model parameters

Again, using the variables acquired from the TAZ layer and table with socioeconomic data the trip productions and attractions for HBO and NHB are computed. The model parameters are adapted from the Masterplan and are shown in the table below.

Table 2 Parameter of Trip Production and Attraction Model

Trip Purpose	Gen/Att	Y = a + b1*X1 + b2*X2 + b3*X3 + b4*X4 + b5* x5						R squared
		a	b1	b2	b3	b4	b5	
HBO	Generation	-748,943	0.425737	1,163,230	0.558952			0.986
			Population	Average Income	Workers			
	Attraction	1,063,040	0.44342	0.290994	0.257524			0.849
			Population	Students at school	Employment			
NHB	Generation	511,731	0.089921	0.296634				0.718
			Students at school	Employment				
	Attraction	464,118	0.015623	0.03754	0.286727			0.641
			Population	Students at school	Employment			
	Control Total of Generation							
		-33,342	0.091362	-0.0225442	0.426405	0.100278	-0.00149	0.99
			Population	Students in home	Number of vehicles	Average Income	Employment	

The final result of this computation is the productions and attractions figures for 2005. However for the productions and attractions for 2023 is required for this research. To be able to compute the 2023 figures the trip increase ratio from 2005 to 2023 as is applied to the computed 2005 productions and attractions figures. As stated in the Master Plan the trip increase ratio is approximately 1.47, accordingly this ratio was applied to the computed 2005 productions and attractions to forecast the 2023 trip generation.

In light of this it is important to note that the third bridge is not included in the Istanbul metropolitan Municipality's strategic plan for the city (Gercek, 2009). Therefore the trip increase ratio as stated in the Masterplan does not incorporate trips that are likely to be generated by the inclusion of the third bridge. Accordingly the forecasted trip generation of 2023 does not incorporate the trips generated by the third bridge. However it can be assumed that with an additional third bridge, more trips will be produced and attracted to each zone in comparison to the trip increase ratio that has been used in the model.

4.3.2.2. Trip Distribution

The output of the trip generation modelling is the total number of trips originating and departing from each TAZ (Zuidgeest & Maarseveen, 2007). In trip distribution modelling the objective is to recombine trips "produced" and trips "attracted" into complete trips. The model is essentially a destination choice model whereby origins and destinations are matched to develop an Origin-Destination table, "the matrix that displays the number of trips going from each origin to each destination" (de Jong, 2007).

The process of modelling trip distribution works on the general assumption that time spent travelling (travel time or generalized cost) is perceived negatively and the further the destination the more unlikely anyone is going to take that trip. Accordingly trips produced in a given zone will be largely attracted to nearby zones, some will be attracted to moderately distant zones and very few will be attracted to very distant zones. This principle is described by the distance decay function whereby the interaction between two locations declines as the distance between them increases (de Jong, 2007). It is mathematically known as the gravity model and travel time is represented as impedance.

Flowmap is a software developed in the 1990 as a simple program to calculate and display the flow of goods and people on a map (de Jong, 2007). To this day Flowmap is also capable of computing flow patterns, network distance, accessibility analysis and gravity modelling. For gravity modelling, Flowmap uses different types of distance decay functions such as exponential, power and tanner function.

For this research the doubly constrained model was used whereby a distribution function is fitted into the trip productions and attractions (computed from the trip generation module). In this model the sum of the estimated number of trips from every origin must be equal to a preset number per origin. The sum of the estimated number of trips to every destination must be equal to a preset number per destination. Furthermore the number of trips from every origin to any destination is inversely related to the distance between origin and destination. The model works on three formulas:

1) $Tij = Ai.Bj.Oi.Dj\ f(Cij,\beta)$
2) $Ai = 1 / (\Sigma j\ Bj.Dj.f(Cij,\beta))$
3) $Bj = 1 / (\Sigma i\ Ai.Oi.f(Cij,\beta))$

$f(Cij,\beta) = \exp(-\beta.Cij)$

where:
Tij = the estimated number of trips between origin i and destination j
Ai = the balancing factor for origin i
Bj = the balancing factor for destination j
Oi = the constraint value for origin i
Dj = the constraint value for destination j
β = the distance decay parameter
Cij = the distance between origin i and destination j

Formula one computes the actual trips in the Origin Destination Matrix, the second formula equates the total number of trips from origins in the matrix to the set number and formula 3 equates the total number of trips to the destinations in the matrix to the set number. The balancing factors ensure that the sum of the estimated outflows per origin equals the known origin total and the sum of the estimated inflows per destination equals the known destination total.

To begin with the analysis the road network layers need to be converted from ArcMap shapefiles to BNA format then the BNA file is converted into flowmap file where topological information is added.

To run the doubly constrained model a distance table needs to be configured. A distance table is a file that stores the shortest distance between all possible combinations of origins and destinations i.e. the distance table connects each TAZ to the others using the road network. The impedance unit is defined as travel time in minutes. The origins and destinations between zones are represented by the centroids of each TAZ. Flowmap takes care of this by replacing these intrazonal distances with the intrazonal distance based on the surface area of each zone. A specific formula ($C_{ii} = 0.667 (\sqrt{(S_i/3.14)}$ then used to overwrite the initial distance table with intrazonal distance of area.

The gravity model is then actually performed by defining the origin constraint as the Production and Destination constraint as Attraction. The model parameters used 0.0003 as the beta value and a mean trip length of 14.68 minutes, which is observed in Istanbul (Celik, 2009). The result of this module is an interaction matrix in a database file typically called a flowfile in Flowmap.

4.3.2.3. Modal Split

Modal split describes the proportion of total trips into the various transportation modes. Mode choice models analyze and predict choices that individuals or groups of individuals make in selecting the transportation modes that are used for particular types of trips (Caliper Corporation, 2010). Accordingly the objective is to predict the share or absolute number of trips by mode.

Approximately 50% of all trips made in Istanbul are on foot, private car usage in is approximately 14% while public transit is around 36% (Celik, 2009). Of these public transit only 2.3% is rail transit and due to the short railway network system and 1% ferries due to poor integration of the transit system (Celik, 2009).

Flowmap does not have the functionality to perform a full modal split analysis. Therefore the analysis could only perform a conversion from trips to vehicle trips. The average occupancy rate for private vehicles in Istanbul is 1.57 and this was used as an assumption to compute vehicle trips (Gercek & Demir, 2008). Accordingly: Flows per TAZ / (1.57) gives the number of vehicle trips per TAZ.

At this point it is important to note that a full modal split analysis would have been ideal for this research. However Flowmap is limited in that it is only built for simple transport models and does not have the functionality to study multi modal transport networks. Therefore the results may be too simplistic given the fact that it only considers the average occupancy rate of private vehicles and not those of public transits. For that reason the number of vehicle trips that is computed in the model is almost certainly overstated.

4.3.2.4. Traffic Assignment

The assignment of vehicle trips to network is the fourth and final step of the four step model and is essentially the objective of the second phase of the research. Traffic assignment models aim to determine the number of trips on different links of the road network given the travel demand between different pairs of zones. The models try to describe the modal split phase of the transport demand analysis. There are different models of traffic assignment, and they differ in their assumption for the variation in link travel times with the link volume. Three of the models are listed below:

1) All or nothing assignment model
2) Incremental assignment model
3) User-equilibrium model.

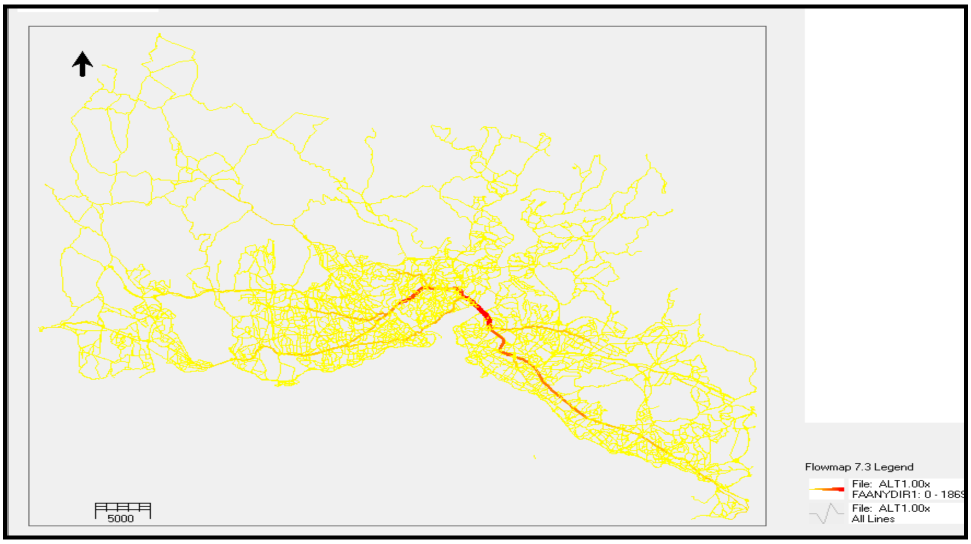
Flowmap utilises the all or nothing assignment (AON) model which assumes that all the traffic between a particular origin and destination will take the shortest path regardless of travel time. Therefore it is assumed that travel times on links do not vary with link flows and all trip makers have knowledge of the travel time on the links. Based on these assumptions of the travel times, a trip maker will choose a path or route that minimizes his/her travel time.

Performing the traffic flow assignment entails assigning the trips computed in the modal split module to the network and using trip length as the impedance. The results is stored as a database file.

The results of traffic assignment from this model are unrealistic in that only one path between every Origin-Destination pair is utilized even if there is another path with the same travel cost. Another limitation to the results of this assignment is that it ignores the fact that link travel time is a function of the link volume therefore traffic on links is assigned without consideration of whether or not there is adequate capacity or heavy congestion.

Results from traffic assignment provides for the calculation of Volume over Capacity ratios, the proxy for congestion. Figure 10 illustrates the daily flows of traffic in Istanbul on each road segment, which is essentially the volume of traffic. The results of the traffic assignment were exported back to Arcmap for proper display.

Figure 12 Traffic Assignment



It is imperative to mention at this point that a screenline analysis would have been most practical in this part of the research. A screenline analysis on each of the bridge alternative could have given an indication of the difference between trip assignment results with that actual traffic count on the alternative bridges. In addition to being a useful tool to calculate traffic flows that cross a scrrenline, a screenline analysis is also useful for the calibration of trip assignment models (Caliper Corporation, 2010).

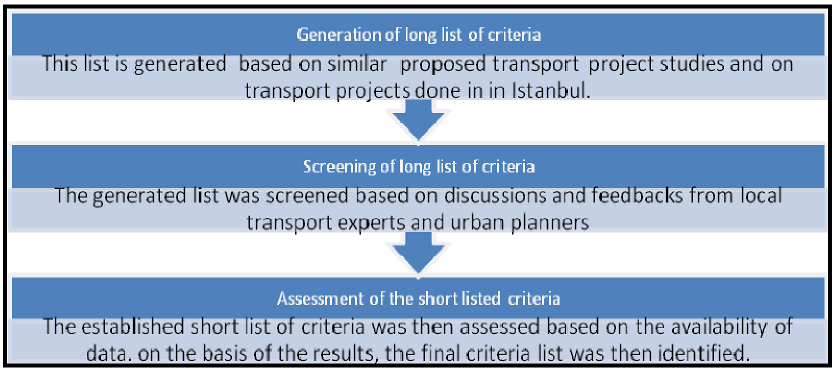
4.4. Spatial Multi Criteria Analysis

ILWIS-SMCE is used for this phase of the research to produce composite maps for each alternative. All data preparations for this phase were performed in ArcMap and ILWIS.

4.4.1. Criteria for evaluating the alternative route

The method used to identify the relevant criteria for evaluating the alternatives includes the generation of a long list of criteria, screening, assessment and finally identifying the most relevant ones. Figure 6 illustrates a schematic overview of this methodology. Each of these steps is then further explained in the following section.

Figure 13 Method for Criteria Identification



Step 1

The process of selecting the criteria is designed to compare and assess each of the 5 alternative routes and locations of bridges and they must answer the overall objective of the research. The first step involved identifying a long list of criteria from literature specifically those that are defined in similar transport projects and on previous studies that has been done in Istanbul.

The four main recurring themes in previous studies include social, environment, ecological and network competence. A paper by Ulengin identified various variables for the selection of the most suitable alternative for a water crossing infrastructure in Bosporus and these are: operations and maintenance costs, impact on ecosystem, impact on historical texture, contribution to social development, possibility of realizing the technical requirements, suitability to transportation masterplan, passenger traffic demand and overall contribution to general transportation system.

A multicriteria decision making approach to evaluate possible alternative routes for a predefined location for a third bridge in Istanbul listed social, environment, economic, topography and network competence as the main assessment criteria. Under the criteria "social", land use and populations density are selected as indicators, for the criteria "environment", air pollution, geological maps, earthquake risk maps were selected. Land value and consumption of energy were indicators for the "economic" criteria. For "topography", slope and aspect were used as indicators and for "network competence", accessibility was chosen as the main indicator.

In a study of three alternative rail transit network proposals in Istanbul, the projects were evaluated based on financial, economic, system planning, policy and environmental impacts criteria. The study employed Analytic Hierarchy Process (AHP) to organize perceptions, experiences, knowledge and judgements into a hierarchical framework with a goal, scenarios, criteria and alternatives of choice.

The list below presents the summary of criteria:

Social
• Land use and population • Contribution to social development
Environmental
• Environmental impacts • Impact on historical texture • Air pollution • Geology • Slope and aspect
Economic
• Operations and maintenance cost • Land value • Consumption of energy
Network Competence
• Accessibility • Suitability to transportation masterplan • Passenger traffic demand • Contribution to general transportation system

Step 2

Thereafter the next step involved discussing and getting feedbacks on this preliminary list with a group of stakeholders which comprised of two transport experts from Istanbul Technical University and two urban planners from IMP. In response to the preliminary list the team of experts state that the list of criteria was numerous and that it should be kept to a minimum for the study to be feasible and meaningful. Additionally three major guiding principles emerged after discussions and the following three guiding principles were formed to screen the preliminary list.

1. Maximize transportation services
2. Maximize accessibility to population and employment area
3. Minimizing impacts to the natural environment and historical sites

These guiding principles were then employed to screen the preliminary list of criteria. Under the first guiding principle, passenger traffic demand and the overall contribution of the bridge to overall performance of the transportation system were identified by the experts as important from the preliminary list.

The second guiding principle which is to maximize accessibility saw the selection of land use and population as the main criteria. In this case employment density potential economic development areas was said to represent a larger part of urban landuse as this defines the areas where people are employed.

The third guiding principle saw the selection of ecological areas and historical areas as the two important criteria. Air pollution was seen as important but due to data unavailability this criteria was dropped.

One of the most important criteria in the preliminary list is the operations and maintenance cost and land value. This was also highlighted by the expert team, however there was no data available as a proxy for this and personally the researcher felt that since the alternatives are similar, meaning they are not exclusive transport infrastructures but are all bridge infrastructures, the operation and maintenance cost for each alternative bridge should be more or less the same.

Step 3
According to Yoon and Hwang (1995) in (Atkinson, et al., 2005) the number of criteria used in any project may vary but generally 7-12 is regarded as the maximum. The final list is then derived by identifying criteria that can be generated from the available data. Ideally the criteria should be complete and exhaustive in such a way that it will cover aspects of the decision making problem to make the analysis complete. Although there are many criteria that may influence the assessment and evaluation of the most preferred route and location to construct the bridge, this methodology only considers criteria for which spatial data were collected or readily available.

Compensatory criteria for this methodology are called factors and they are spatial benefits and spatial costs. The criteria tree brings together all the objectives, criteria and their weights in a standardized manner and evaluates them. The criteria are classified into three major guiding principles defined in Step 2. Each guiding principle is viewed as a broad set of objectives which is broken down into objectives and criteria; accompanying these criteria are spatial data inputs that would accomplish them. Table 3 outlines these guiding principles, objectives and criteria.

Table 3 Evaluation Criteria for assessing route and bridge location

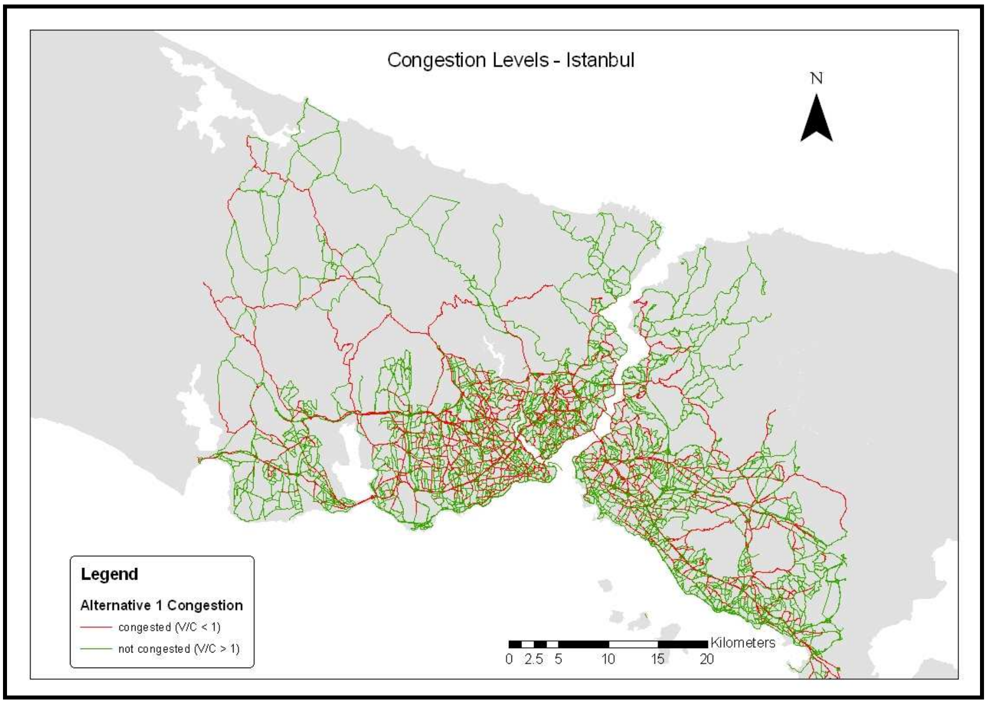
Guiding principle	**Objective**	**Criteria**	**Explanation**
Maximise Transport Efficiency	Increase mobility	Ability of the alternative to contribute to the improvement of the road capacity	This criterion is measured by the forecasted congestion levels of 2023. Congestion levels are measured with a volume to capacity

			(V/C) index and give a ratio of traffic volume over rated capacity.
	To increase network connectivity	Ability of each alternative to connect to the existing road network	This criterion is measured by the overall network connectivity of the road network with the introduction of a new link (bridge alternative)
Maximize accessibility to population and employment centres	To maximize the access provided for major population centres	Ability of each alternative to serve the maximum number of residents	This criterion is measured by the density of people living within a traffic analysis zone.
	To maximize the access provided for major employment centres	Ability of each alternative to serve the maximum number of working population	This criterion is measured by the density of people working in a traffic analysis zone.
	To maximize the access provided for generators of economic activity	Ability of each alternative to serve potential areas for economic development	This criterion is measured by the proximity of economic development to each alternative route. The closer the economic area is to the route the better it is.
Minimize impacts to the natural environment and historical sites	To avoid where possible or minimize encroachment on, or loss of ecological function	Disturbance of ecologically protected areas	This criterion is measured by the proximity of ecologically protected areas to each alternative route. The further the ecologically areas is to the route the better it is.
	To avoid where possible or minimize encroachment on archaeological and historical sites	Disturbance of archaeological/historical sites	This criterion is measured by the proximity of each archaeological/historical to each alternative. The further the sites are from the route the better it is.

4.4.1.1. Improvement to the road capacity

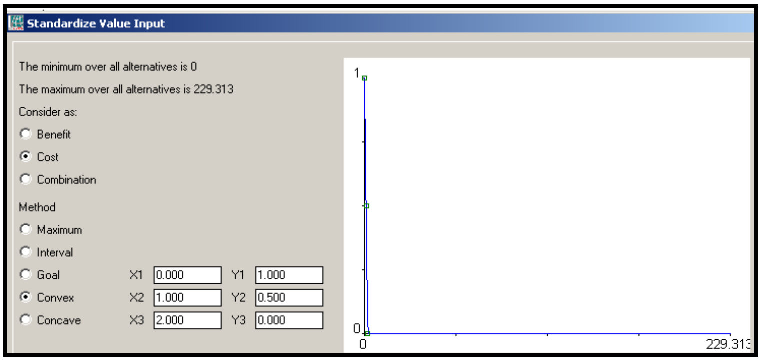
Forecasted congestion levels on the road network capture indicators such as the capacity to meet future travel demand and the amount of time spent travelling. Evaluation of congestion levels is carried out based on the performance of the existing road network together with each route/bridge alternative. A lower congestion level on an alternative relative to the others makes it more favourable. Traffic flow assignments for each alternative were forecasted for the year 2023 using the classic 4-step model on Microsoft Excel and Flowmap.

The travel demand modelling phase is used to simulate traffic flow assignment for the five alternative routes. The results of the traffic flow assignment are exported to ArcMap where the flows are compared with the existing road capacity to compute the congestion levels of 2023. The output of this is a road vector layer with congestion levels as attributes.



The preparation of data for the SMCE process requires importing the road vector layer into ILWIS as a shapefile format. The now segment map is then rasterized and its coordinate system and georeference is defined. Using the "IFUNDEF" function, the value 0 is assigned to undefined pixels on the raster while the road links maintain congestion levels as their attribute.

The standardize the input map, the convex standardization method was selected specifying input values (congestion values) less than 1 to be assigned a standardized value of 1, input values of 2 to be assigned a standardized value of .25 and defining the input value of 4 as the maximum value which is assigned a standardized value of 0. Input values of less than 1 are assigned a standardized value of 1 as it represents road links with no congestion – that is the volume of traffic flow is less than the capacity of the road link. The input value 2 is assigned a standardized value of .25 as this represents heavy congestion levels. Any input values with a value of more than 4 are assigned the standardized value 0 for this is perceived as severe congestion levels.



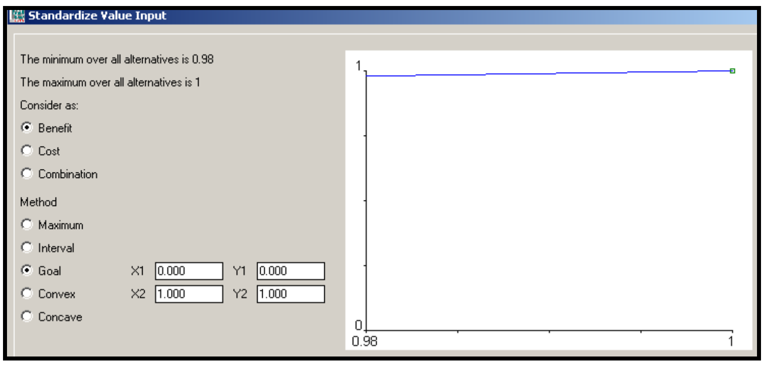
It should be noted that the output of the transport demand modelling gave extreme congestion levels as this was calculated based on the existing road capacity. Therefore the existing road network is saturated to a considerable extent showing that it is insufficient to cope with the future traffic demand.

4.4.1.2. Network Connectivity

Network connectivity is the physical relationship of the new link (Kiker, et al.) to the existing route system. This criterion focuses on the routes relation to the road network system as a whole and not specifically to any other individual route or group of routings. Network connectivity was measured on ArcGIS using ratio of links to the nodes. The values ranges from 0-1, meaning there are no connections between the nodes if the value is 0 and 1 represent the maximum number of connection.

Alternatives	Nodes/Links	Connectivity
Alternative 1	214/217	.98
Alternative 2	165/166	.99
Alternative 3	185/186	.99
Alternative 4	195/195	1
Alternative 5	209/210	.99

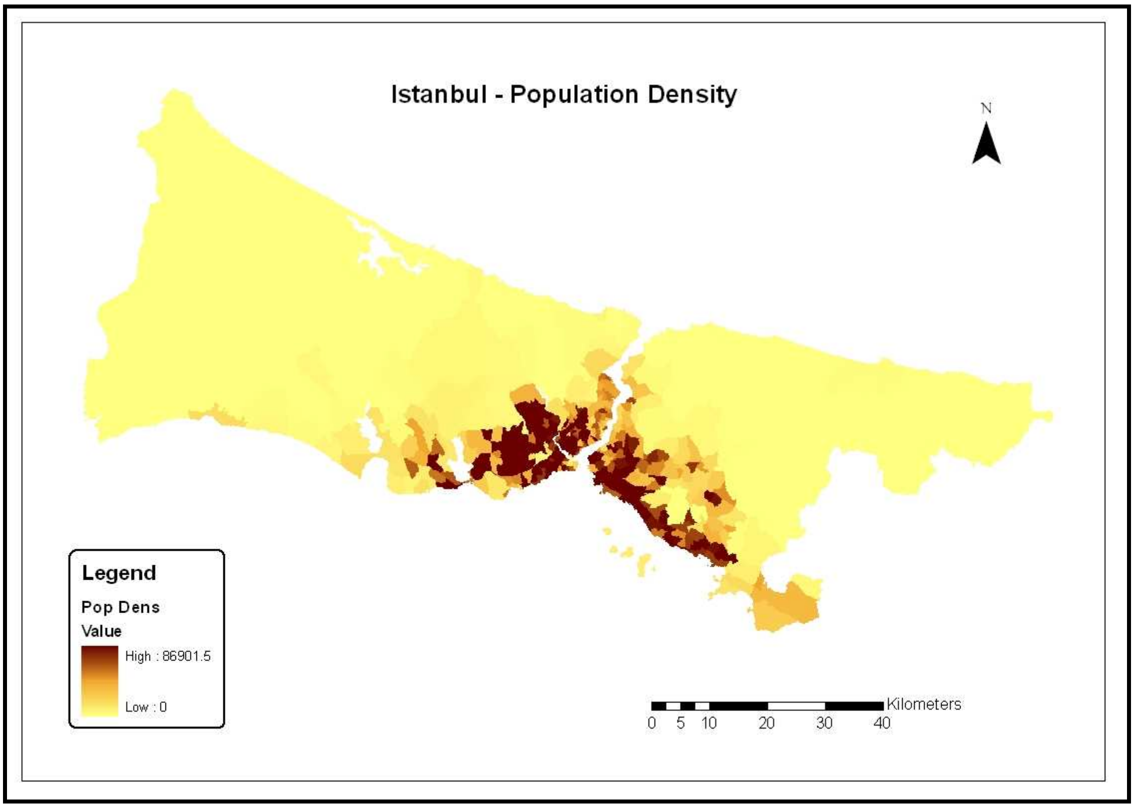
These figures are then used as non spatial input in SMCE. To standardize these values the goal standardization approach is selected by specifying the maximum input value of 1 as a standardized value of 1 and the minimum value input value of 0 as a standardized value of 0.



4.4.1.3. Population Density

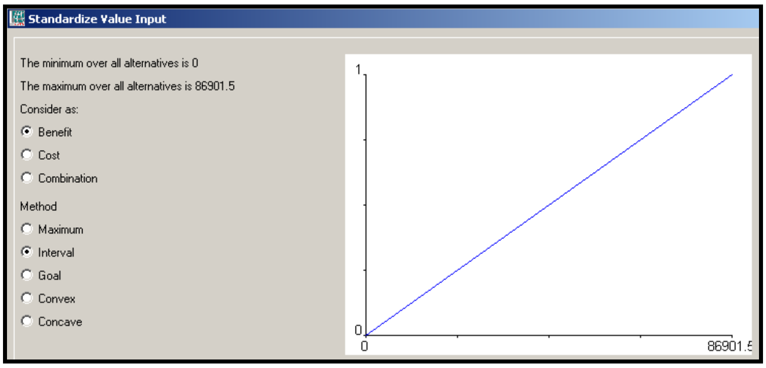
Population density is represented by the number of people residing per square kilometre in each Traffic Analysis Zone. This criterion was chosen as it is seen as the best representation of daily trips at the term of origin. Given that one of the fundamental purpose of the routes is to serve the residents of a particular area, this indicator reveals how many people live where. Therefore a route within close proximity of a highly populated area is favoured.

Figure 14 Istanbul Population



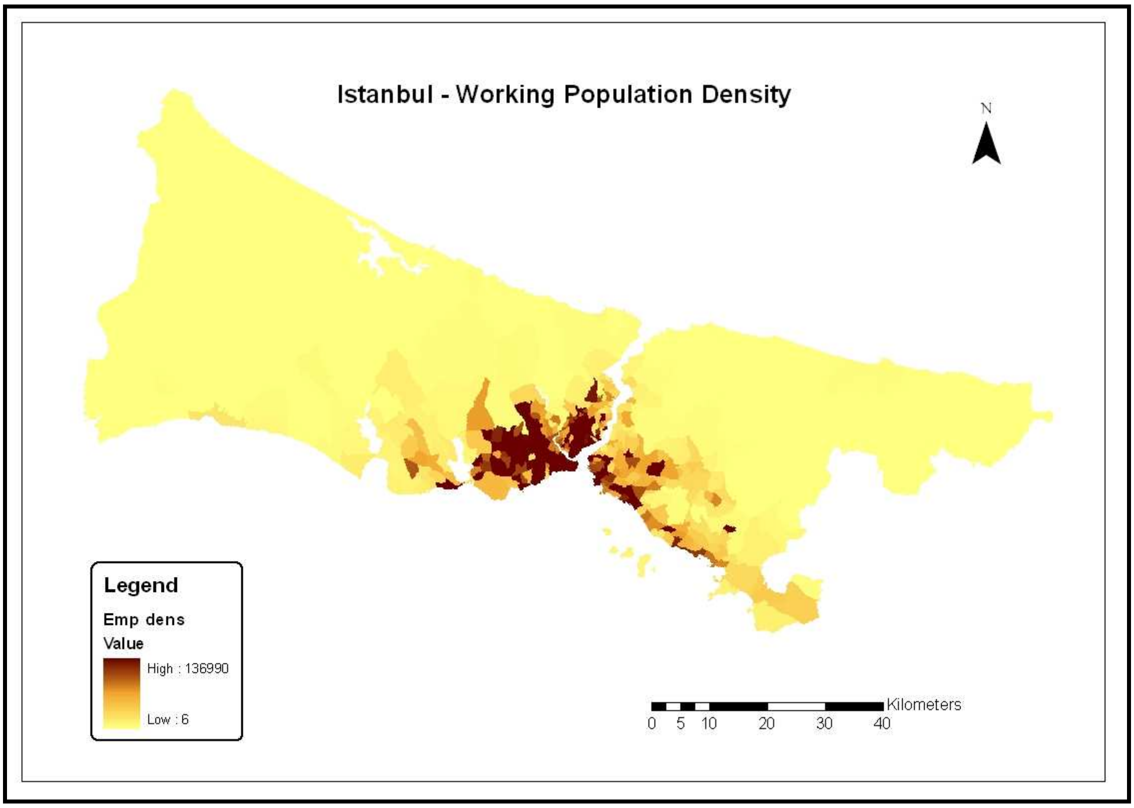
Population data is available in a database format file which is then joined to the TAZ shapefile layer in ArcMap to compute population density. To prepare the input map for SMCE, the population density layer is imported into ILWIS as a vector format. After defining its coordinate system and georeference it is then rasterized. Following the conversion to raster format the IFUNDEF function is then used to assign the value 0 to undefined pixels on the raster. The resulting raster is a continuous surface of pixels with population density per TAZ as its value.

The input map is a factor and a benefit, accordingly the interval standardization method was selected to standardize the input map. The output is that the minimum value in the input map is standardized to 0 and the maximum value of the input is standardized to 1. This standardization method allows cells that have a higher number of people to be assigned higher standardized values and cells that have lower pixel values are assigned a lower standardized value.



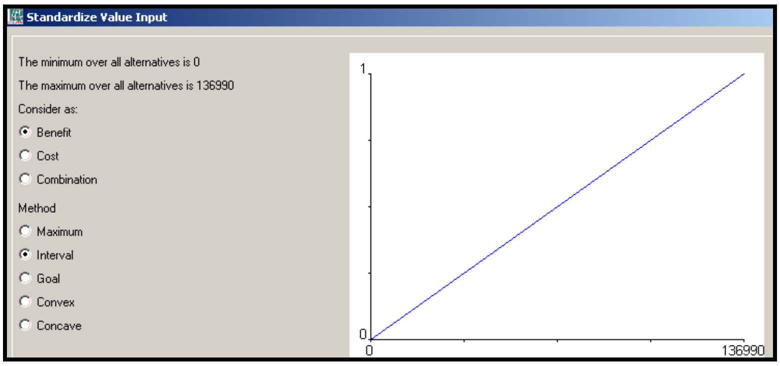
4.4.1.4. Working Population Density

Working population density represents the number of people working per square kilometre in each TAZ. Generally work trips account for a significant part of all vehicle trips. Employment numbers reveals how many people are working in a TAZ . A route running within a close proximity of an area with high employment density rate will improve commuter access to existing employment centres.



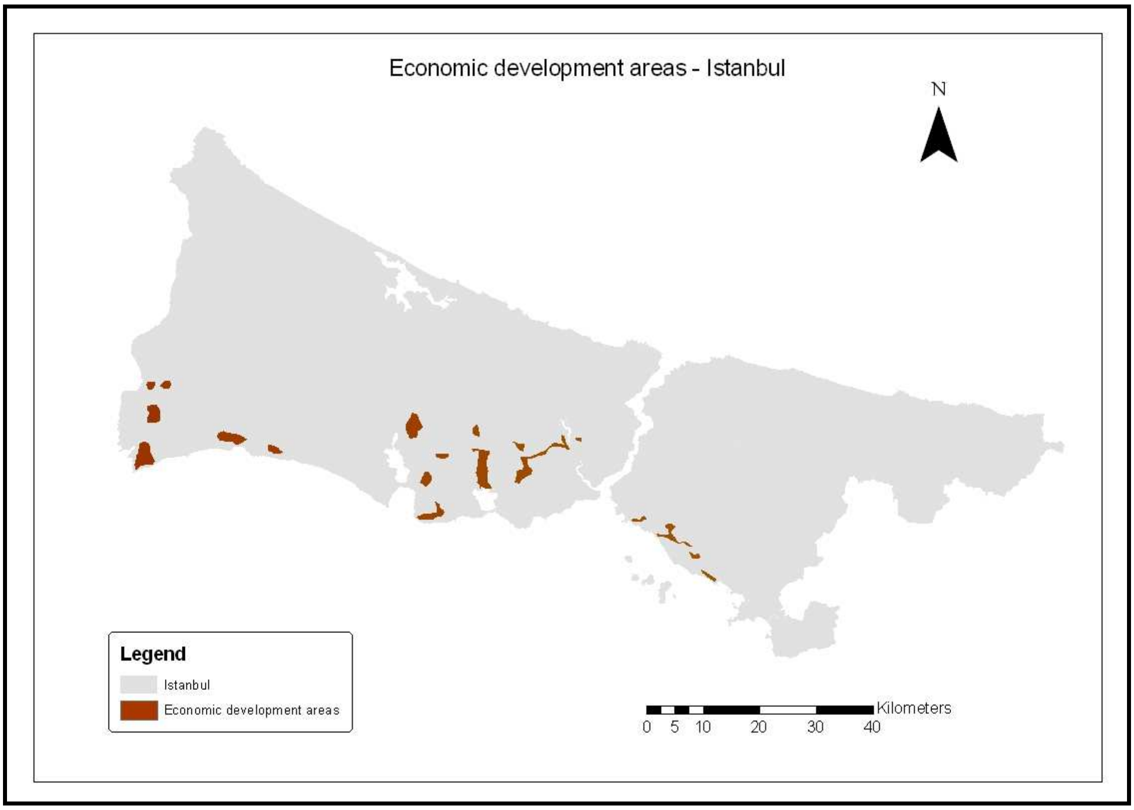
The main source of information for this criterion is taken from the TAZ shapefile. Employment data is an attribute of the TAZ which is used to compute working population density. To prepare the input map for SMCE, the working population density layer is imported into ILWIS as a vector format. After defining its coordinate system and georeferenced it is then rasterized. Following the conversion to raster format the IFUNDEF function is then used to assigning the value 0 to undefined pixels on the raster. The resulting raster is a continuous surface of pixels with working population density per TAZ as its value.

This is used as an input map for SMCE. Working population density is a factor and seen as a benefit, accordingly the interval standardization method was selected to standardize the input map. The output is that the minimum value in the input map is standardized to 0 and the maximum value of the input is standardized to 1. This standardization method allows cells that have a higher number of people to be assigned higher standardized values and cells that have lower pixel values are assigned a lower standardized value.



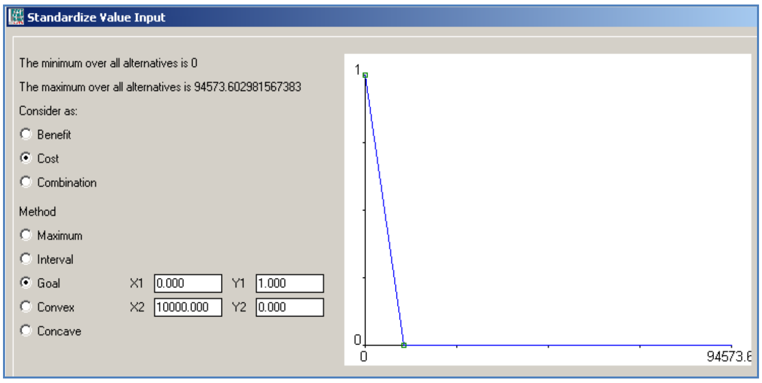
4.4.1.5. Proximity to potential areas for economic development

Potential areas of economic development represent areas that are earmarked for development of new central business districts according to the objectives of the Istanbul Master Plan of 2007 (Istanbul Metropolitan Municipality & Japan International Corporation Agency, 2008). These areas intend to enhance industrial economic transformation from secondary to tertiary. Information based service sector agglomerations, new urban centres, high tech industry and logistics centres are some of the services planned to be operated from these areas. Close proximity of alternative routes to these areas is important as this will enhance its marketability.



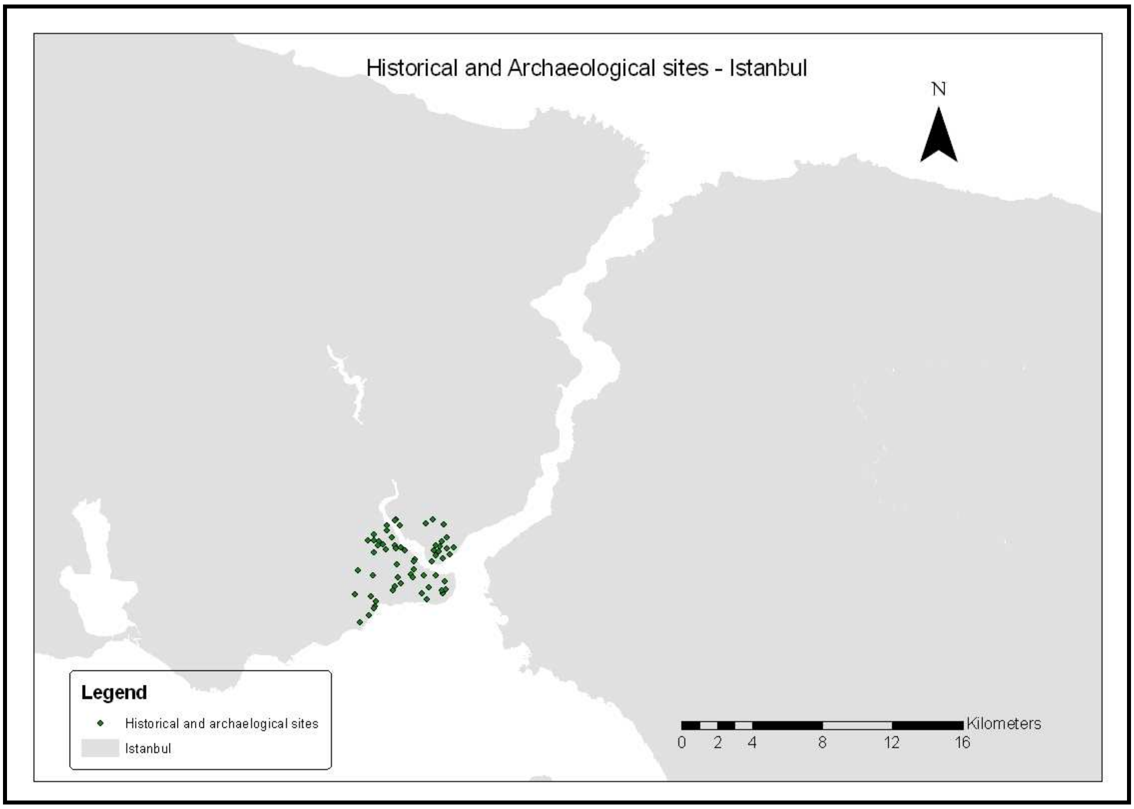
Data preparation for this criterion involves digitizing a jpeg image representing the potential areas of economic development in Istanbul. This resulting polygon map is imported into ILWIS as a shapefile format. This vector map is then assigned to the predefined coordinate sytem, rasterized then georeferenced. Following this conversion to raster, the distance calculation function is applied to the map whereby the operation calculates distance in metres from the pixels representing the economic areas to other undefined pixel representing the rest of the area in the raster map.

The resulting input map for SMCE is the distance map of areas of economic development and distance in this case is seen as a cost - the further the distance from the defined areas to the alternative route the higher the cost. The map is standardized using the goal method whereby the input values are standardized with a linear function that uses a specified minimum and maximum value. There is no mathematical definition for proximity in this criterion. The objective is for the highways to be as close as possible to economic development areas. Therefore a distance of 10000 metres is assumed to be the minimum distance people are willing to travel from a route to an economic area. Hence the minimum value is specified as 0 and maximum as 10000metres. The output of this standardization is that pixels that have values more that 10000metres are assigned a standardized value of 0. Pixel values within the 10000m range are assigned values from 0 to 1.

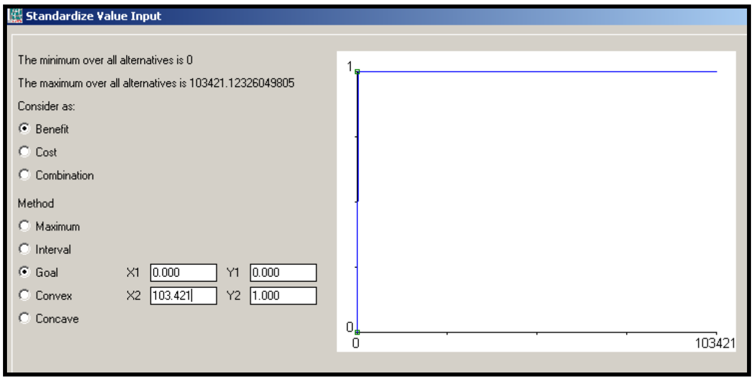


4.4.1.6. Proximity to archaeological areas and historical sites

Historic and archaeological properties, sites and buildings are resources that need to be protected and conserved hence it is preferred that a route be located as far as possible from these sites.



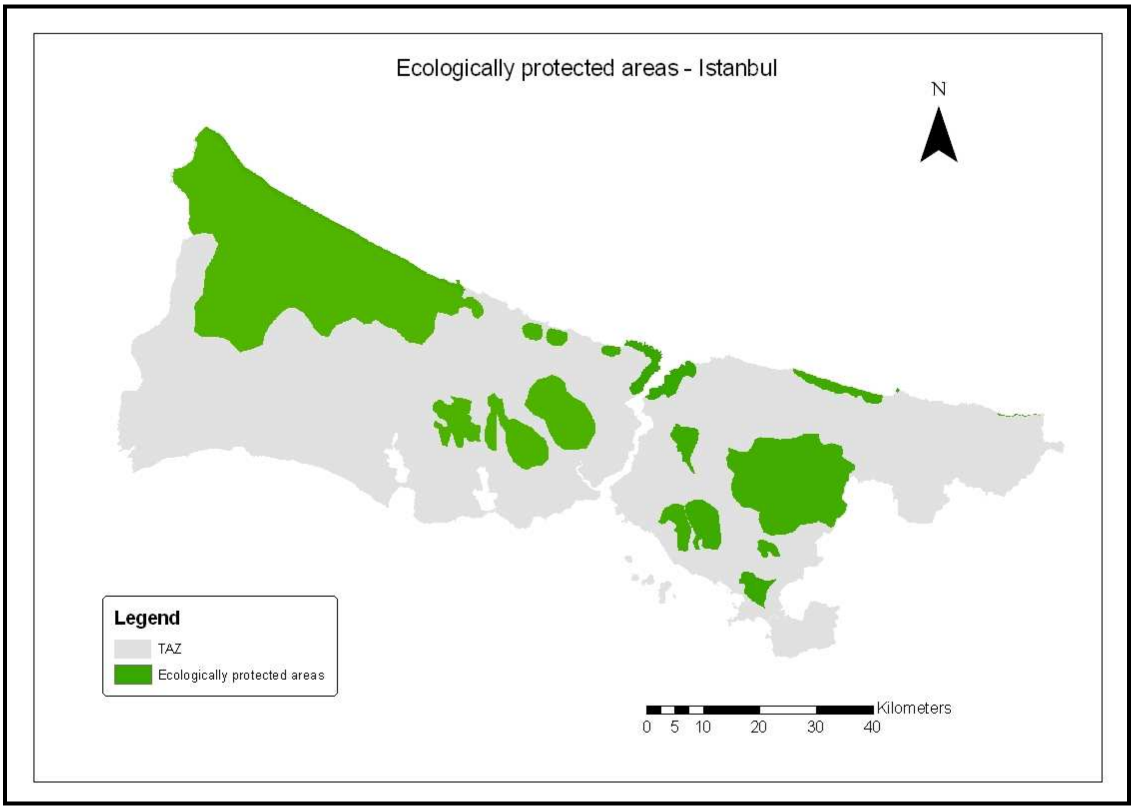
Data preparation for this criterion involves digitizing a jpeg image representing the historial and archaeological sites in Istanbul. The resulting point map is imported into ILWIS as a shapefile format. This point map is then assigned to the predefined coordinate sytem, rasterized then georeferenced. Following this conversion to raster, the distance calculation is applied to the map whereby the operation calculates distance in metres from the pixels representing the historical and archaeological sites to other undefined pixel representing the rest of the area in the raster map.



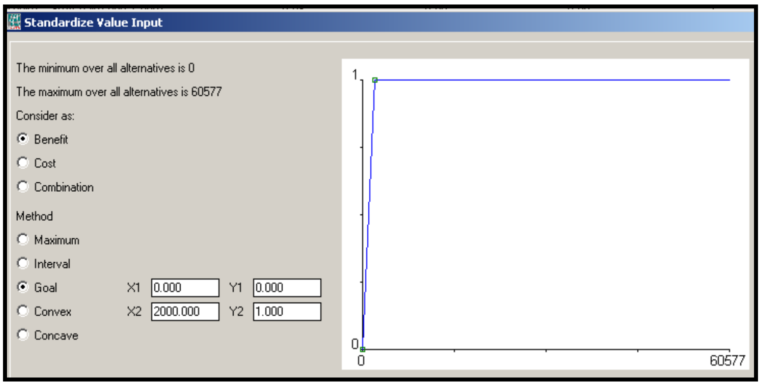
The resulting input map for SMCE is the distance map of archaeological and historical sites and distance in this case is seen as a benefit - the further the distance from the defined areas the better it is for the alternative route and the lower the cost. The input map is standardized using the goal method whereby the input values are standardized with a linear function that uses a specified minimum and maximum value. Since the input values represent the distance away from the archaeological and historical sites the minimum distance was specified as 0 and maximum distance as 100metres. The distance of 100metres is adapted from NEPA (National Environment Policy Act) standards whereby it states that highways from a distance of beyond 300 feet have a low probability of affecting historical sites.

4.4.1.7. Proximity to ecologically protected areas

Ecologically protected areas are areas defined by the municipality as natural areas that need to be conserved. These areas are mostly natural features like national parks, nature reserves, forests, water basins and wildlife. These protected areas are essentially for biodiversity conservation and alternative should be located as further away from these areas as possible.



The source of information for this criterion is a vector layer representing ecologically protected areas. The polygon map is imported into ILWIS as a shapefile format. This map is then assigned to the predefined coordinate sytem, rasterized then georeferenced. Following this conversion to raster, the distance calculation is applied to the map whereby the operation calculates distance in metres from the pixels representing the historical and archaeological sites to other undefined pixel representing the rest of the area in the raster map.



The resulting input map for SMCE is the distance map of ecologically protected areas and distance in this case is seen as a benefit - the further the distance from the defined areas the better it is for the alternative route and lower the cost. The input map is standardized using the goal method whereby the input values are standardized with a linear function that uses a specified minimum and maximum value. Since the input values represent the distance away from the ecological areas the minimum distance was specified as 0 and maximum distance as 2000meres. The distance of 2000 metres was selected because according to a study landscape fragmentation and biodiversity loss begins from a distance of up to 2km from a highway (Brotons & Herrando, 2001).

4.4.2. Weighting Assignment

The jury chosen for assigning weights in this research comprised of two local urban planners from IMP, a transport expert from ITU and a second transport expert from IMP. This choice was made because of their involvement in local transport development issues and also because of their local knowledge surrounding the issues of the proposed third bridge. This same group of stakeholders were also involved in defining the criteria for evaluating the alternatives. It would have been ideal to also involve members of the public and representatives from the state but this was not done due to time limitations.

The pairwise comparison method was used for the assignment of weights. This method was developed by Saaty in the early 1980s (Malczewski, 1999). The method entails the creation of pairwise matrix and computation of criteria weights. The scale that was used for pairwise comparison is illustrated in the table below. Pairwise comparison uses a scale of 1 to 9 to rate the relative preferences for two criteria and this is illustrated in the table below.

Table 4 Scale for Pairwise Comparison

Intensity of Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

Source: Saaty (1980) in (Malczewski, 1999)

The weightings may range from equal importance to a ranking of extreme importance, such as criterion A is extremely important than criterion B. These weights are expressed by the jury and to the seven criteria (Table 4). The results of their weighting did not reveal much variation. The individual matrix of pairwise comparisons by jury was then averaged out and the results are illustrated in Table 5.

Table 5 List of Criteria

Criterion	
A	Congestion levels
B	Network Connectivity
C	Population areas accessed

D	Employment areas accessed
E	Proximity to ecologically protected areas
F	Proximity to archaeological/historical sites
G	Potential areas of economic development accessed

Table 6 Pairwise Comparison of Evaluation Criteria

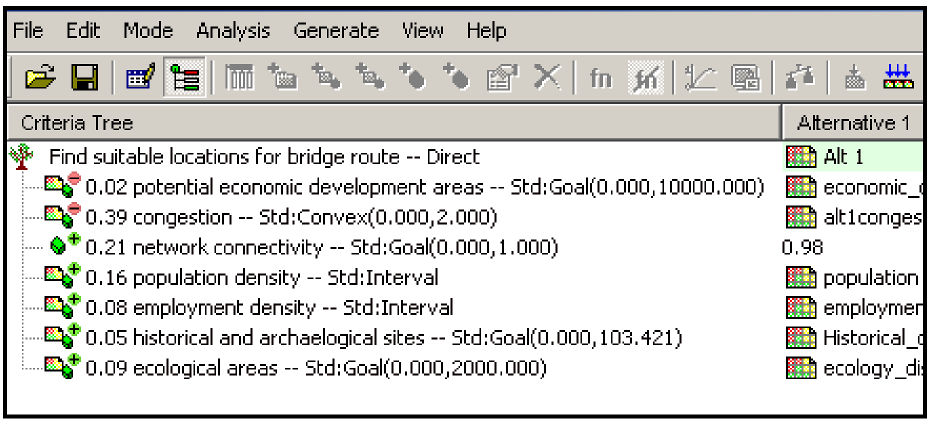
Criterion	A	B	C	D	E	F	G
A	1	6	6	7	4	5	7
B	1/6	1	6	5	3	4	7
C	1/6	1/6	1	4	5	5	6
D	1/7	1/5	1/4	1	2	3	4
E	1/4	1/3	1/5	1/2	1	3	6
F	1/5	1/4	1/5	1/3	1/3	1	4
G	1/7	1/7	1/6	1/4	1/6	1/4	1
	2.069	8.093	13.817	18.083	15.500	21.250	35.000

The table below presents the criterion weights that were computed from the above table.

Table 7 Determining the Relative Criterion Weights

Criterion	A	B	C	D	E	F	G	Sum	Weights
A	0.483	0.741	0.434	0.387	0.258	0.235	0.200	2.739	0.391346
B	0.081	0.124	0.434	0.276	0.194	0.188	0.200	1.497	0.213808
C	0.081	0.021	0.072	0.221	0.323	0.235	0.171	1.124	0.160575
D	0.069	0.025	0.018	0.055	0.129	0.141	0.114	0.552	0.078807
E	0.121	0.041	0.014	0.028	0.065	0.141	0.171	0.581	0.083038
F	0.097	0.031	0.014	0.018	0.022	0.047	0.114	0.343	0.049045
G	0.069	0.018	0.012	0.014	0.011	0.012	0.029	0.164	0.023382
	1.000	1.000	1.000	1.000	1.000	1.000	1.000		1.000

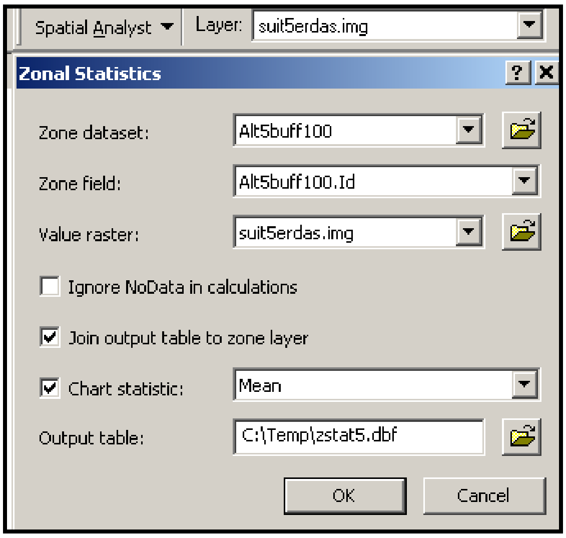
The figure below illustrates the criteria tree built into SMCE. The weights defined by the stakeholders are assigned to the different criteria using the direct method.



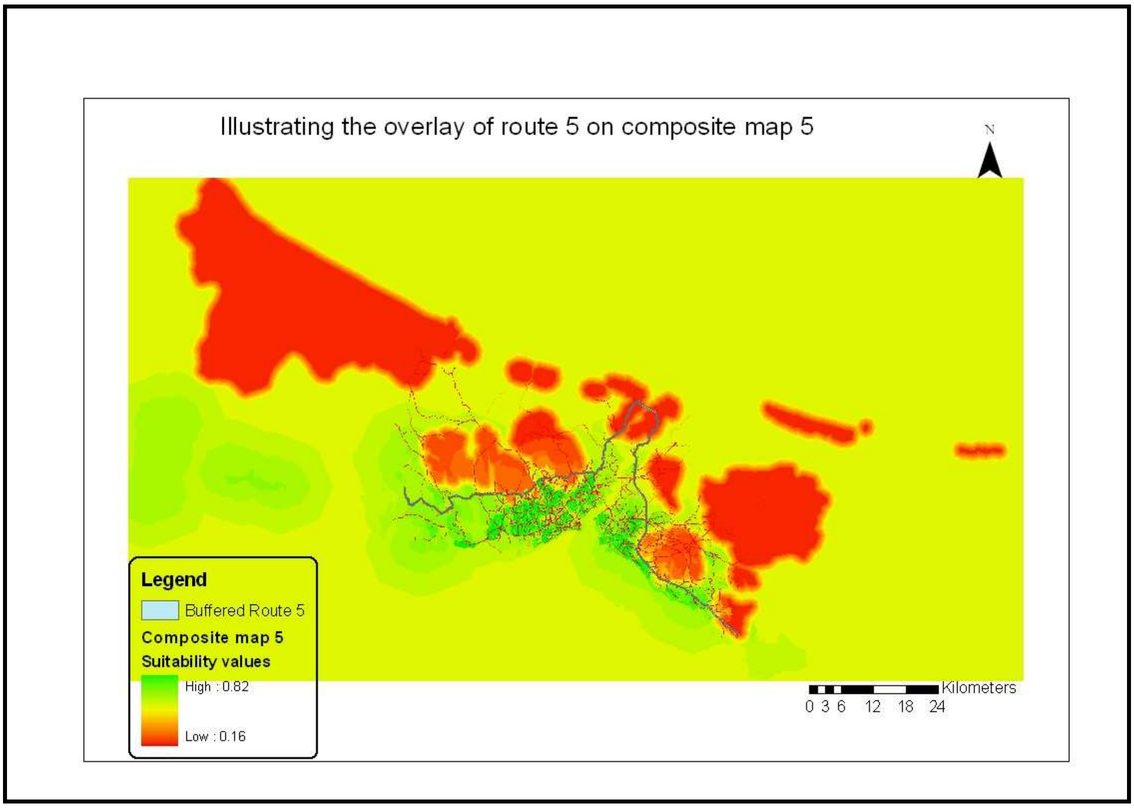
The outputs of this SMCE are five different composite maps which have different suitability values of 0 to 1.

4.4.3. Assigning suitability values to the routes

The procedure of assigning suitability values to the five alternative routes includes applying a buffer of 100metres to the different routes with the assumption that the area around each road link will capture the spatial characteristics of the road. The distance of 100 metres is selected with the reasoning that urban areas have a block sizes of around 100metres in length.



The Zonal Statistics function from ArcMaps Spatial Analyts has the capability of extracting and summarising raster values to a polygon layer. For this purpose the buffered routes were used to extract suitability values from the composite maps. The buffered routes are the main input in this procedure and the different composite maps are used as value raster maps. The figure below illustrates the composite map for alternative five along with the buffered route. Essentially the zonal statistics function summarizes the suitability values that are overlaid by the buffered route in a table format.



Illustrating the overlay of route 5 on composite map 5
N
Legend
Buffered Route 5
Composite map 5
Suitability values
High : 0.82
Low : 0.16
Kilometers
0 3 6 12 18 24

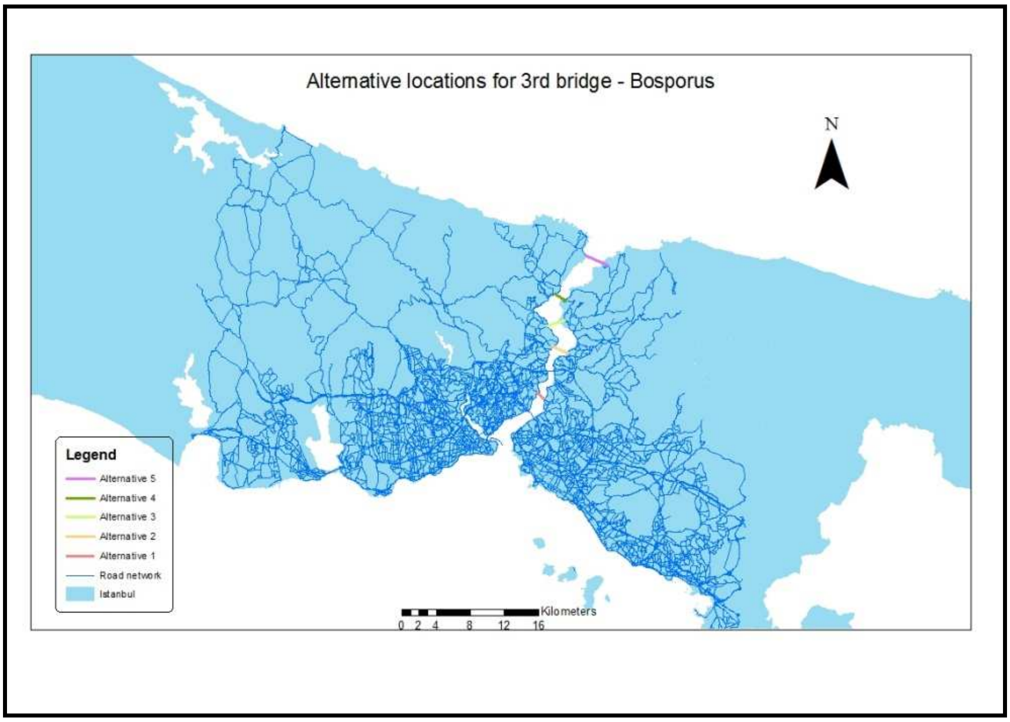
5. Results and Discussions

5.1. Network Analysis Results

5.1.1. Generated Routes

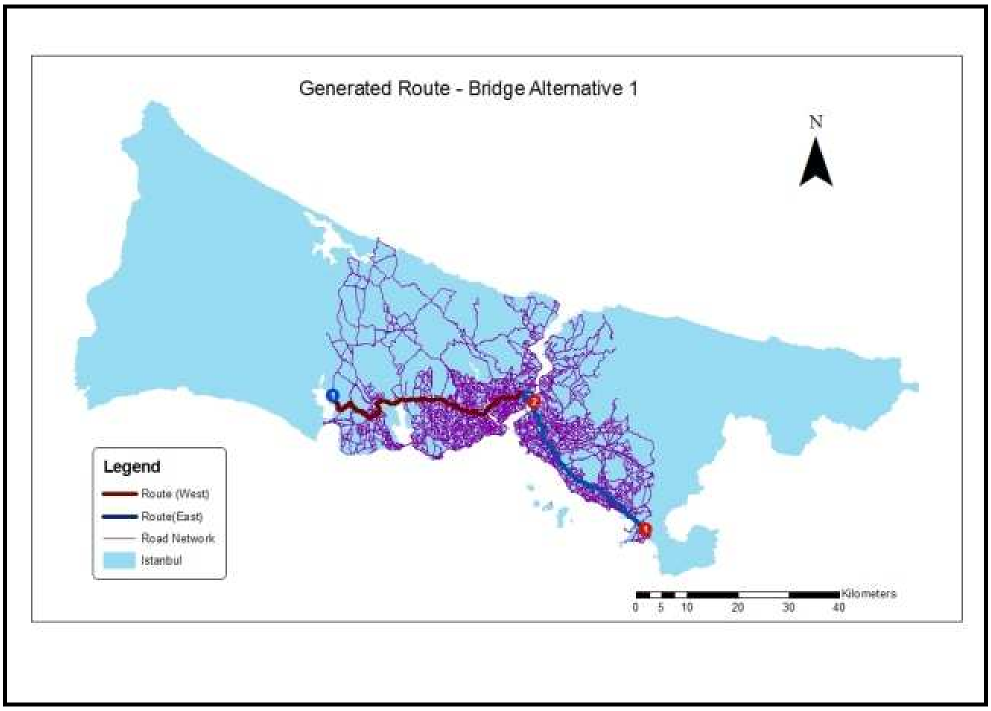
The map below shows the alternative locations of the proposed third bridge. These alternative locations are proposed by Turkey's Ministry of Transport. Alternative 1 is situated in between the two existing bridges and the other 4 alternatives are located to the north of the 2nd bridge. Based on these five alternative locations, routes were generated on the basis of travel time and physical distance.

Alternative locations for proposed third bridge

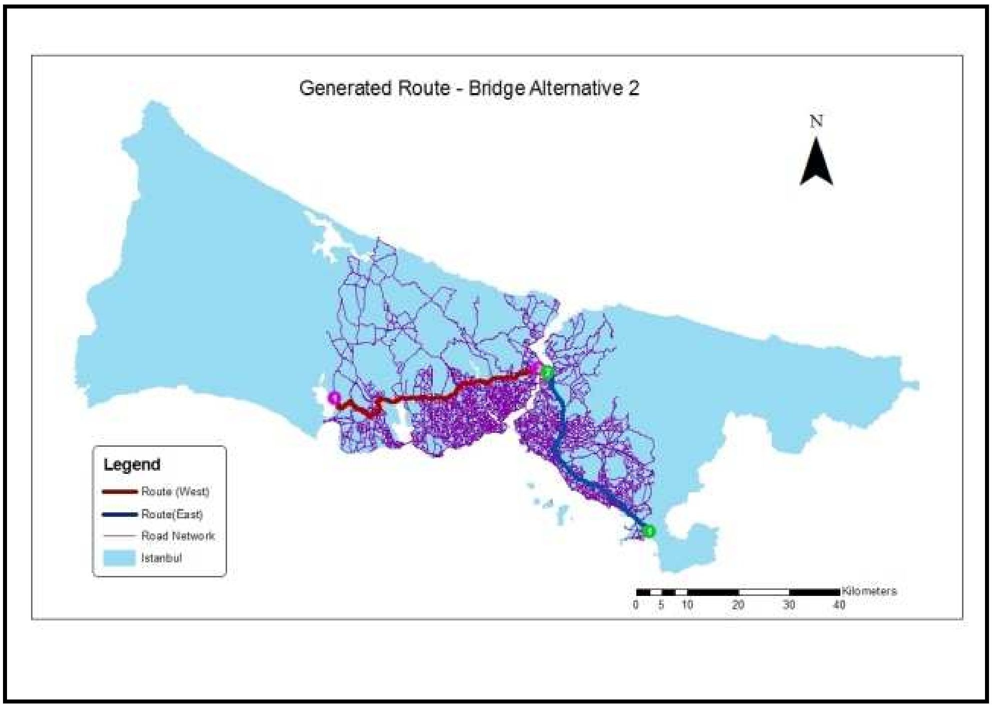


The five maps below show the routes generated for the five alternative locations of the third bridge. The origins are located on Trans European Motorway on the the far east and western side of the utilized road network extent. The destinations are the proposed location of the bridge. Optimal routes are defined by the physical distance of the route combined with the travel time on each link.

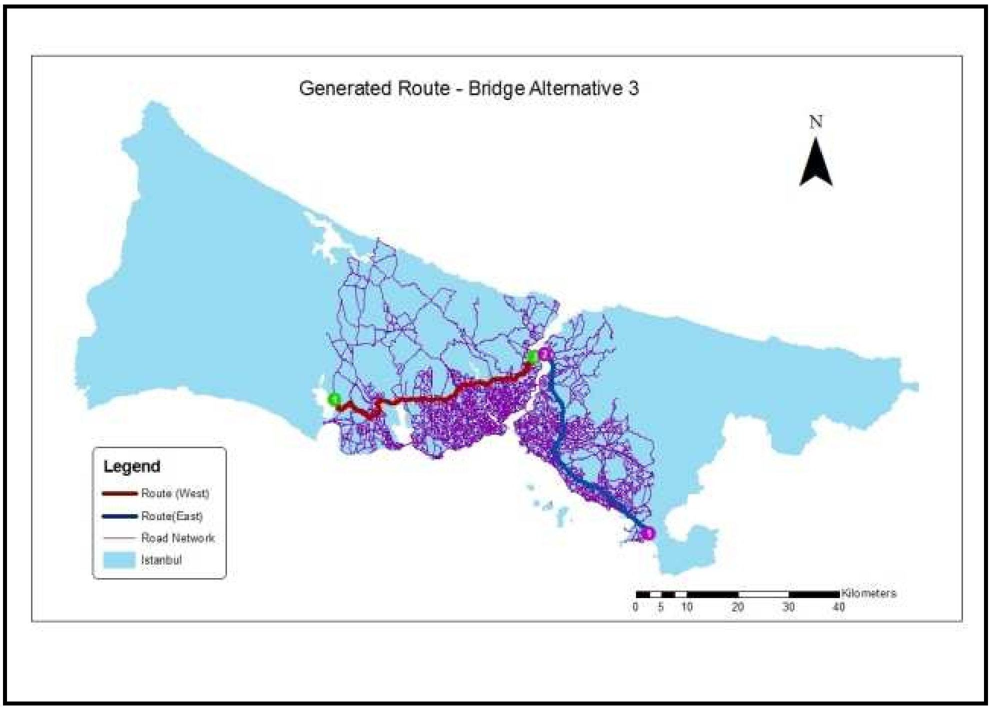
Alternative 1 has a route length of 90.37 kilometres and a total travel time of 118minutes. This appears to be the shortest route of all the alternatives and the second least travel time. This may be attributed to the fact that the route runs through the main central business district of Istanbul where congestion levels are high, accordingly the travel time is quite high.



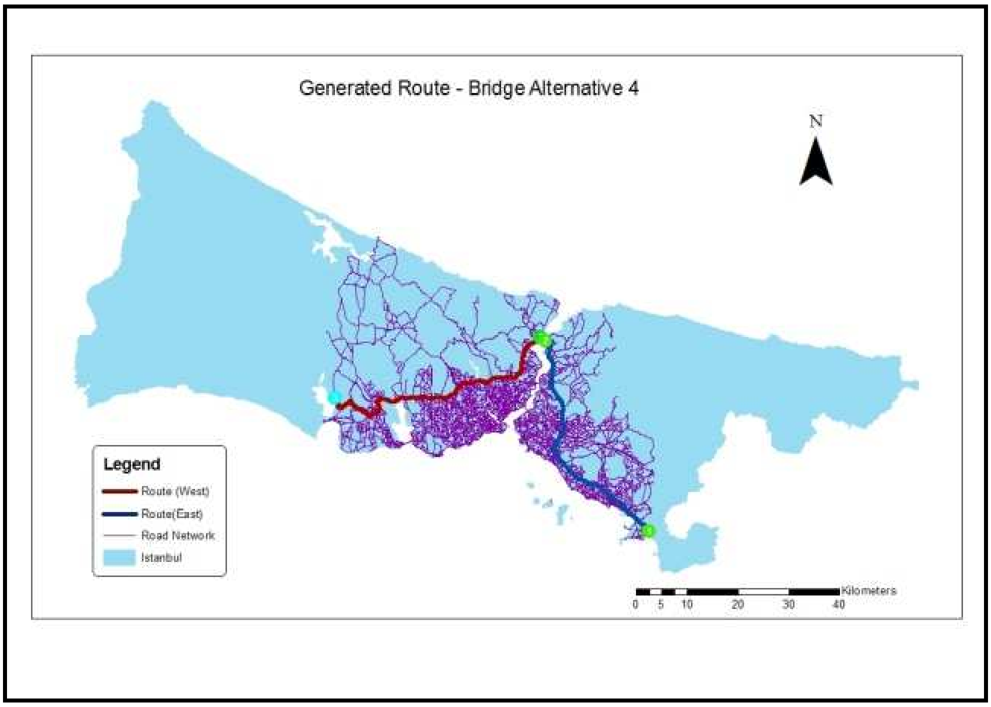
The second alternative route is basically similar to that of alternative 1 except for the fact that it branches off to the direction of the second alternative bridge on the last few kilometres. The route is 97.68km in length and has the least travel time of all the routes with a 115 minutes. This is attributed to the fact that as the route leaves the TEM after the 2nd exisitng bridge the road links become less congested as trip makers are using the TEM mostly for intercontinental trips.

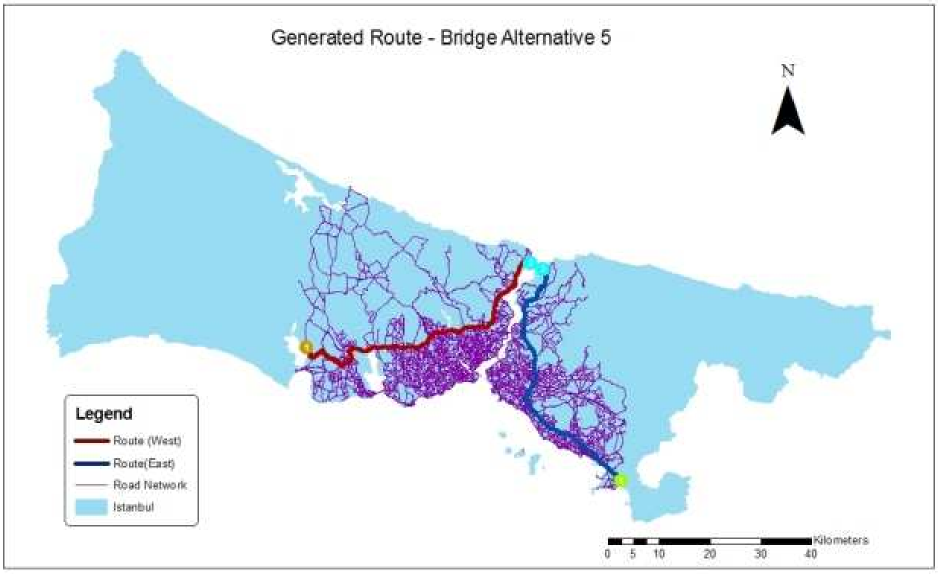


The route generated for alternative 3 becomes longer, with a length of 101.23 kilometres. The travel time stood at 119 minutes.



Alternative bridges 4 and 5 which are located right up north of the Bosporus strait logically proved to have the longest routes and accordingly the most travel time. Alternative 4 has route length of 106.710 kilometres and a total travel time of 134 minutes. Alternative 5 route has a length of 125.579 kilometres and a travel time of 154 minutes.





A common characteristic among these generated alternative routes is that the generated paths are mostly following the Trans European Motorway. The differences become apparent as the bridge locations are located more up north. The further north the location of the bridge the longer the route becomes. Travel time also increases with the length of the route however the travel time for Alternative 1 is longer than Alternative 2 even though the route length of Alternative 2 is longer than 1. This may be attributed to the heavy traffic density in the inner city where Alternative 1 lies. The table below summarises the characteristics of the five alternative routes that have generated.

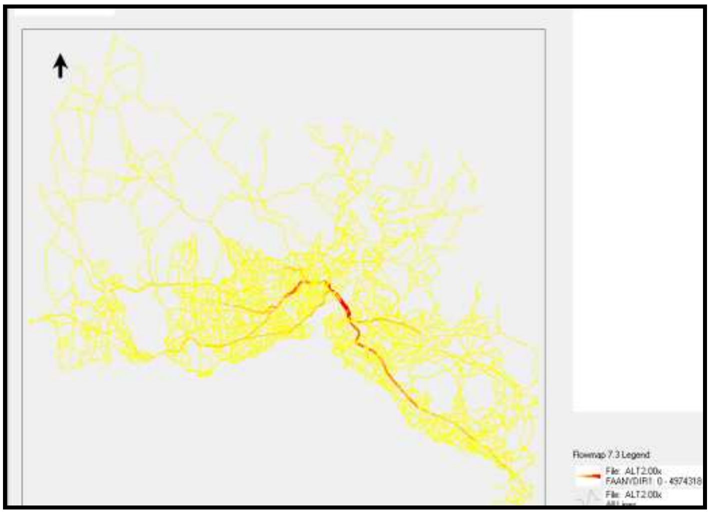
Table 8 Alternative Routes Length

Alternatives	*Route Length(km)*	*Travel Time (mns)*
Alternative 1	90.37	118
Alternative 2	97.68	115
Alternative 3	101.23	119
Alternative 4	106.710	134
Alternative 5	125.578	154

5.2. Traffic Assignment results

The figure below shows the results of the traffic flow assignment of Alternative 2 carried out on Flowmap. These flows represent 24hour flows in any direction. The yellow segments represent lower flows while the red segments illustrate higher levels of flow.

Traffic Flow Assignments (All or Nothing)



The 2023 trips were assigned onto the 2006 network to simulate traffic conditions with the addition of each alternative bridge.

The results of the five alternatives shown below are the result of an All or Nothing Assignment to simulate the 2023 traffic conditions. In these figures traffic volume on each road section is drawn by the colours yellow to brown which is proportional to the traffic volume – yellow representing low traffic volume and brown representing a high volume.

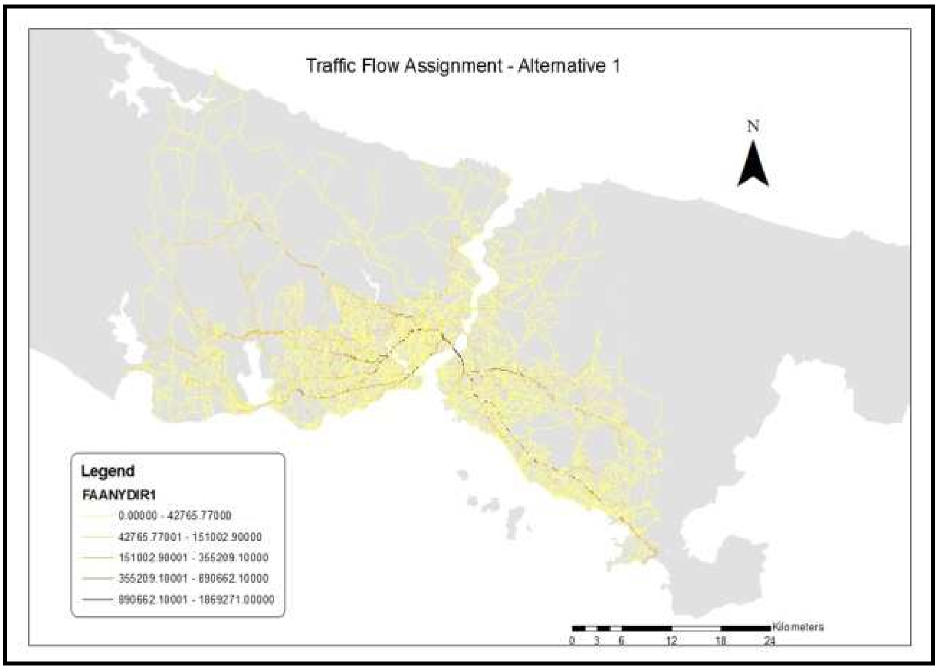
The results of traffic assignment from this model may have introduced errors due to the limitations of an AON assignment. An AON assignment is also referred to as the minimum path algorithm and is the simplest route choice assignment. The underlying assumptions for AON are that there are no congestion effects, all trip makers consider the same attributes for route choice and they perceive these route choices in the same way. Therefore the results that are presented below may be limited and unrealistic in that it does not consider congestion effects and the differences in travel times may have caused unrealistic travel paths. Accordingly traffic is only assigned to road links that has the minimum cost resulting in overloading the links. This type of assignment may be applicable in sparse and uncongested networks, however in Istanbul this is not the case so an alternative traffic assignment model that considers congestion levels would be ideal.

To compute congestion levels, the simulated daily flows of 2023 represent volume and the existing road capacity represents the capacity of each road segment. The proxy Volume/Capacity is then applied and values greater than 1 are essentially perceived to be congested segments. In the figures below each road link is drawn using either the colour yellow or brown. Yellow represents links that have a congestion level of less than 1 and brown represents all road links with a congestion level of that are greater than 1. Looking at traffic volume in all alternatives the volume capacity ratio exceeds

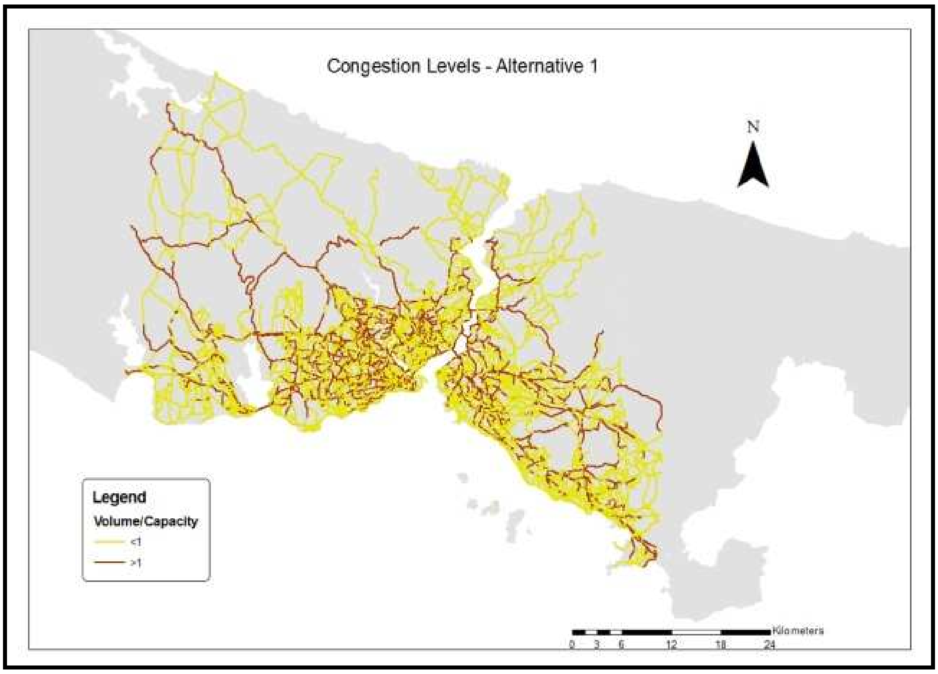
1.0 on a significant number of road links in 2023. This means that future traffic conditions will be catastrophic if no improvements are made to the existing road transport network.

Alternative 1

Traffic Flow Assignment 1

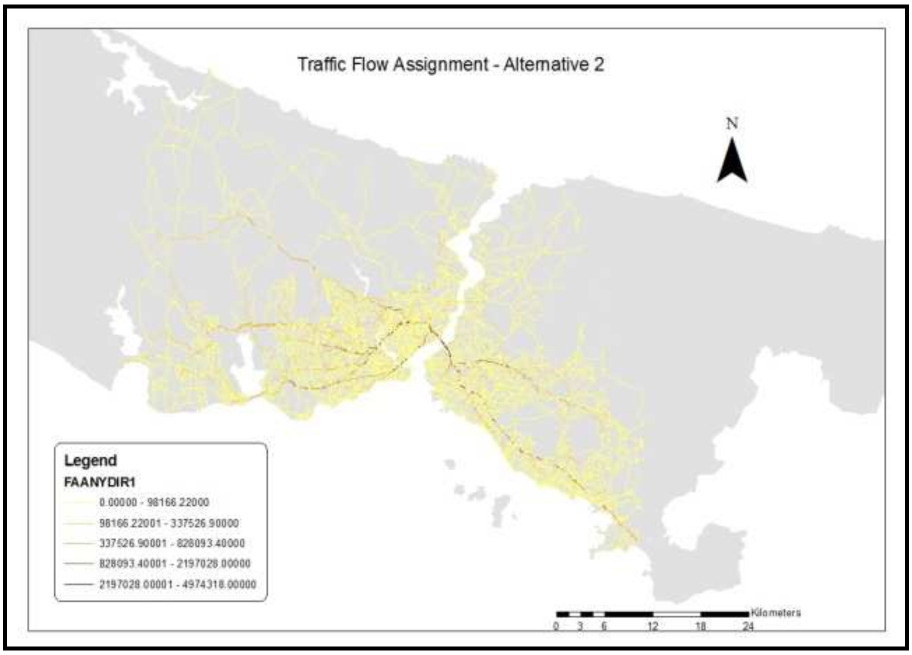


Congestion Levels 1

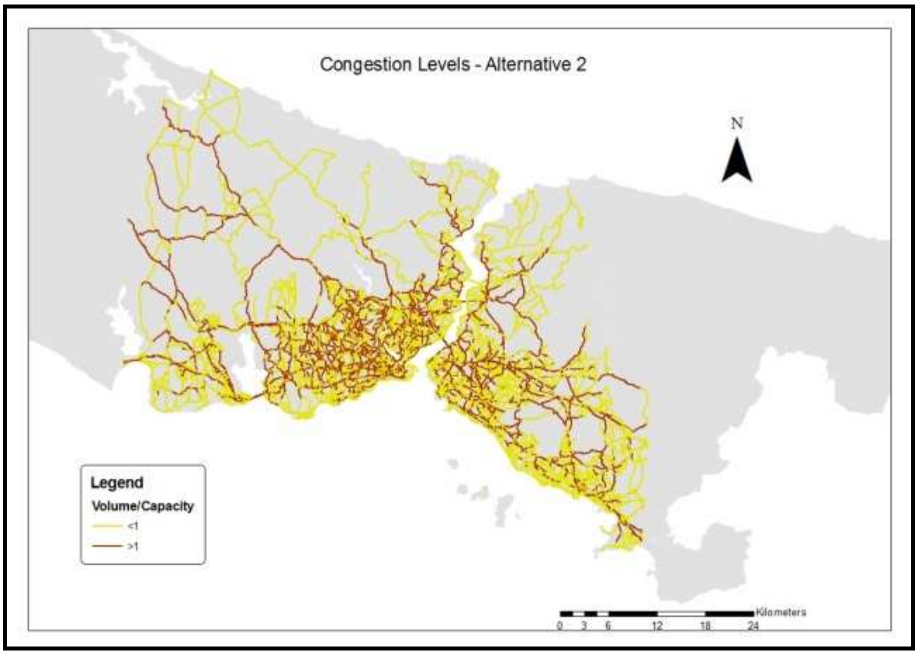


Alternative 2

Traffic Flow Assignment   2

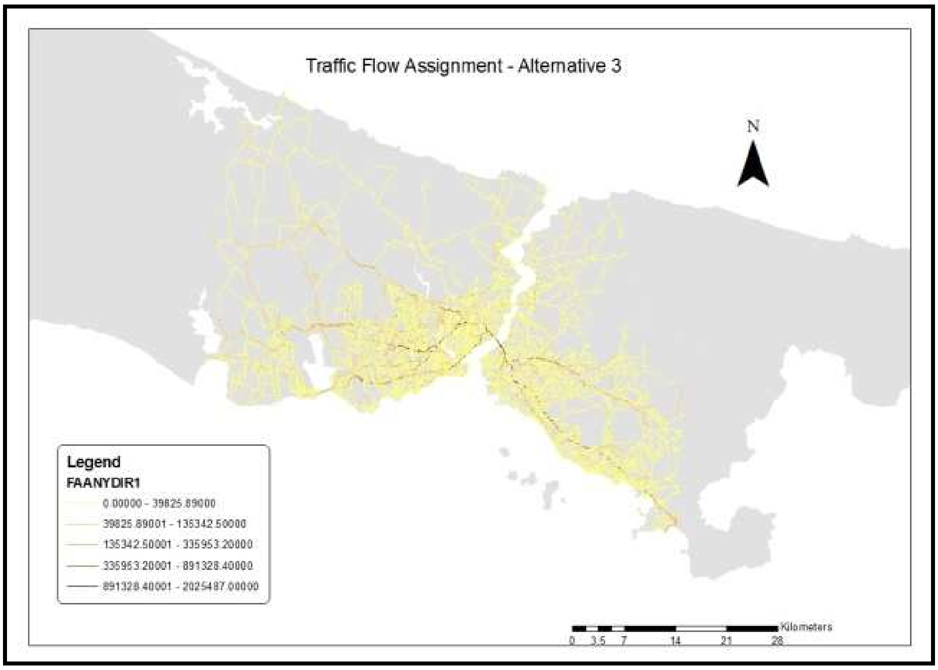


Congestion levels 2

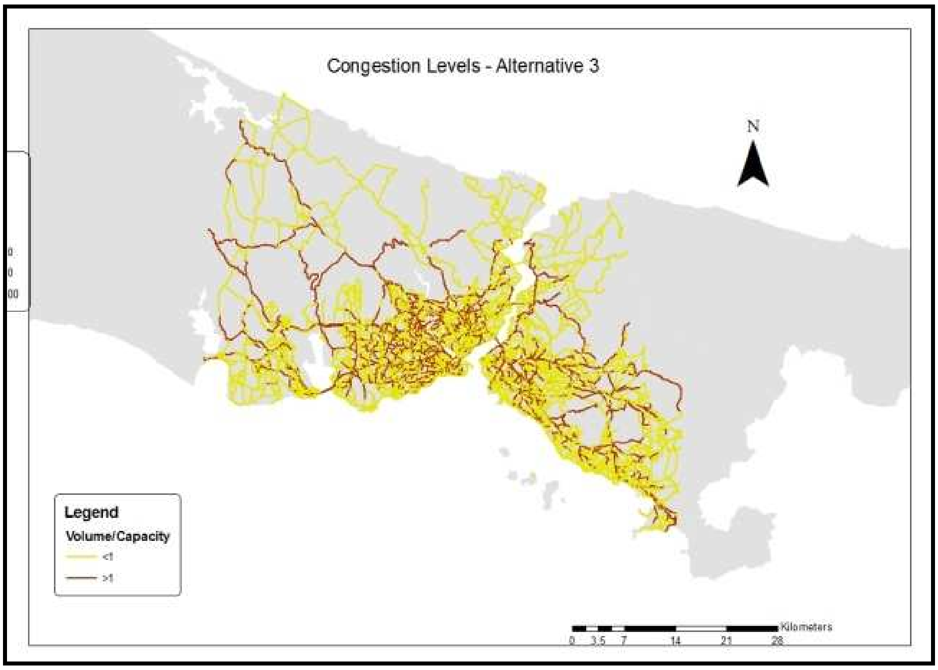


Alternative 3

Traffic Flow Assignment 3

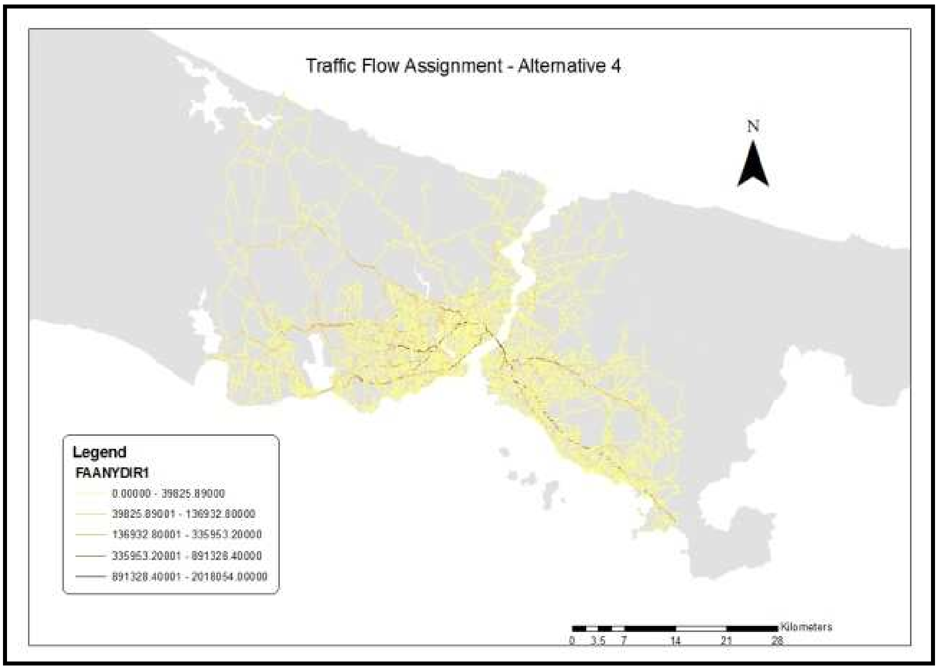


Congestion Levels 3

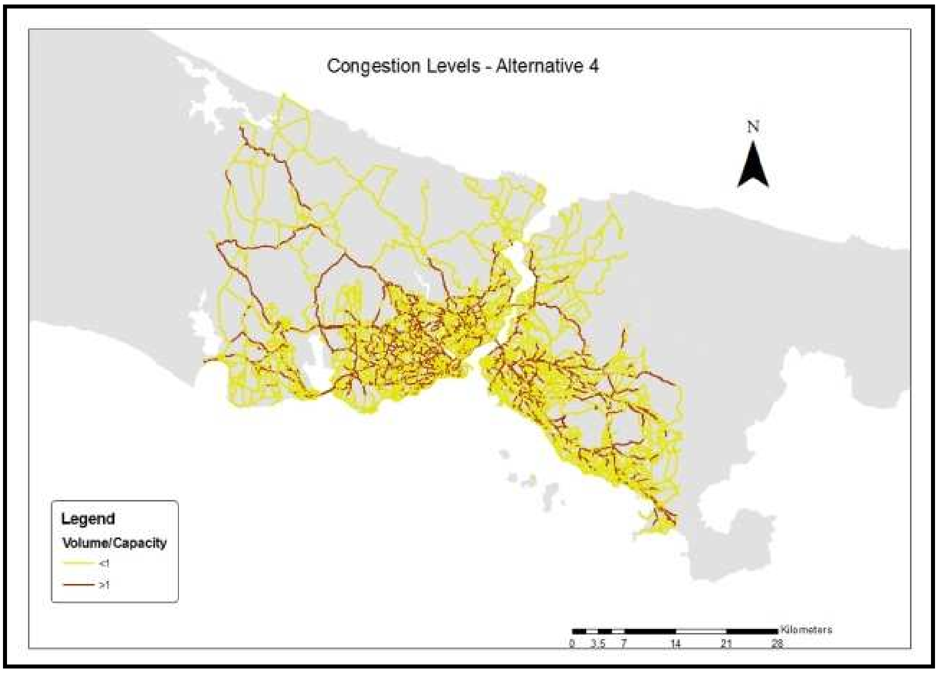


Alternative 4

Traffic Flow Assignment 4

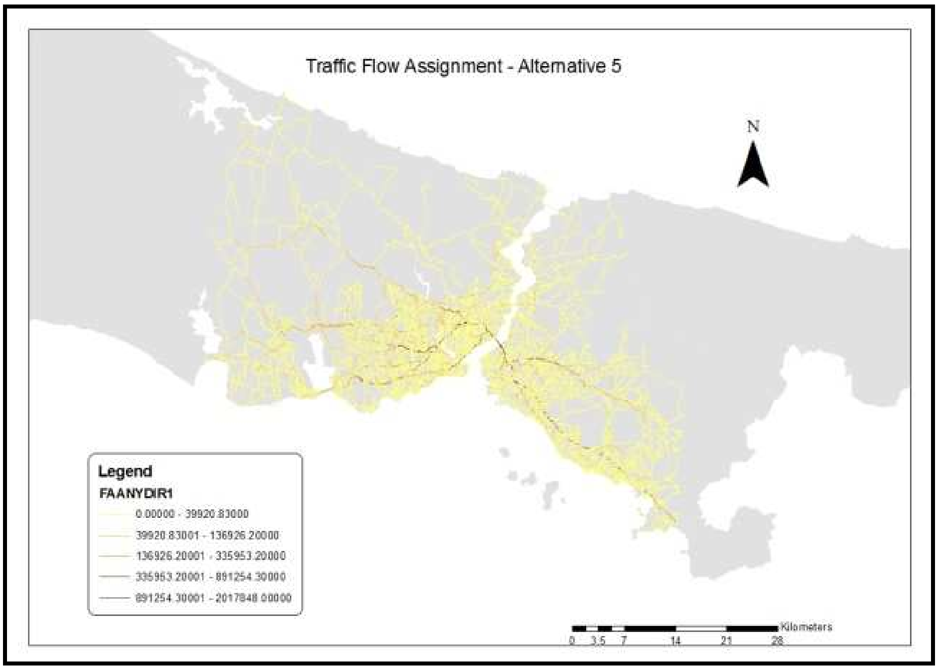


Congestion Levels 4

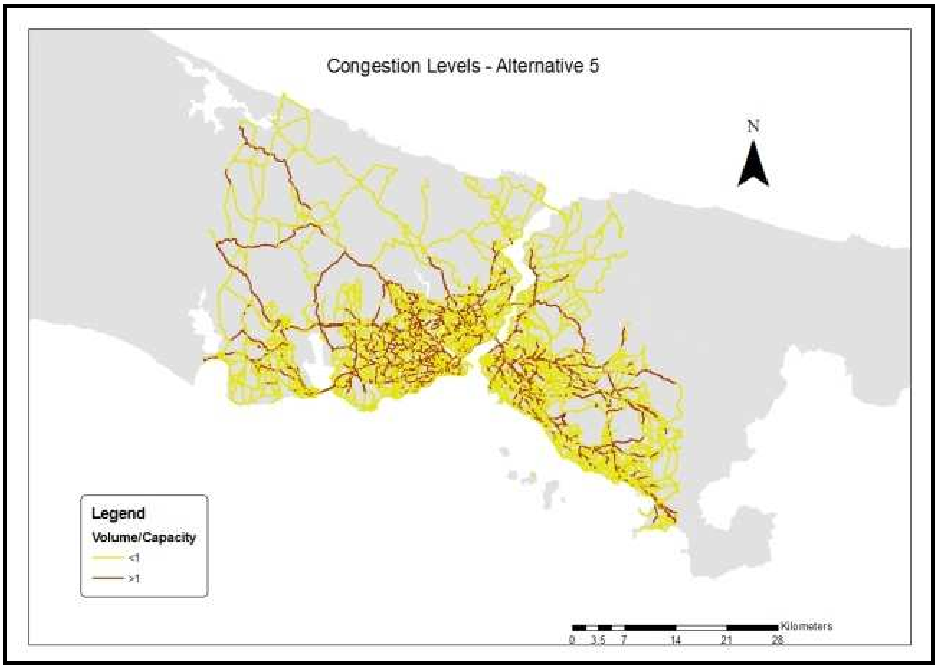


Alternative 5

Traffic Flow Assignment 5



Congestion Levels 5



The above maps represent the daily traffic flows and congestion levels for the five alternative routes. It can be seen that Alternatives 4 and 5 have the least number of road segments that are congested. Alternative 2 proved to have the most number of road segments that have a Volume over Capacity ration of greater than 1. It should also be noted that these are forecasted traffic flows for the year 2023, the capacity of each road link used to calculate the congestion levels are the existing capacity situation in Istanbul. In reality the capacity for 2023 should be much higher; however this serves as a good indicator for planners to increase the capacity of their roads. The table below summarizes the number of congested road segments for the five alternatives.

Table 9 Congestion Levels

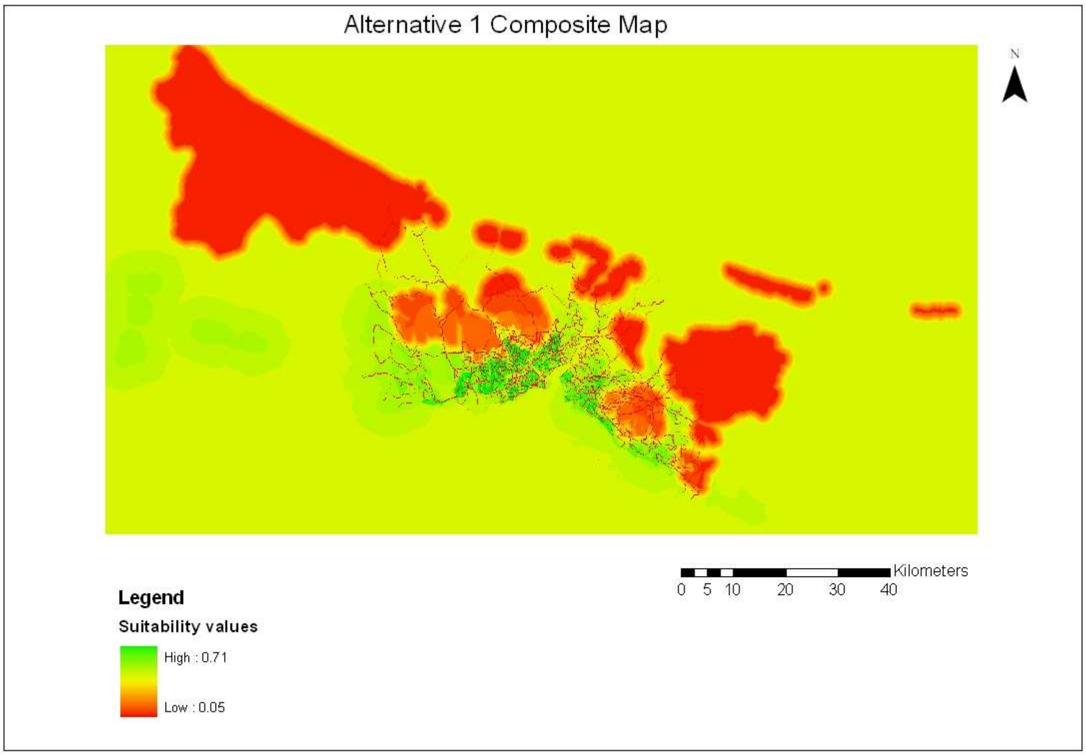
Alternatives	No of road segments congested V/C >1	Total No of road segments
Alternative 1	4119	14042
Alternative 2	5582	14042
Alternative 3	4088	14042
Alternative 4	3892	14242
Alternative 5	3894	14042

5.3. Spatial Multi Criteria Evaluation Results and Assignment of Values

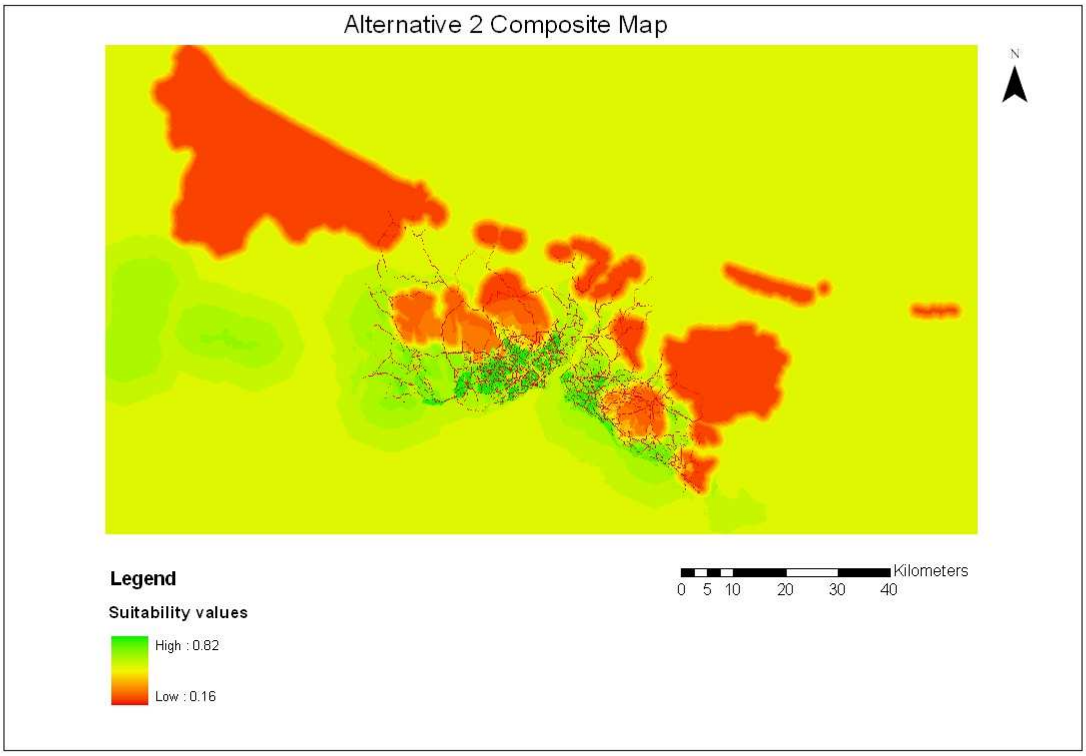
After running the spatial multi criteria evaluation on ILWIS the results are illustrated in the figures below. These five different composite maps represent the suitability values of each alternative route based on the user defined criteria. It should be noted that the criteria maps for population density, working population density, ecological areas, economic development areas and historical and archaeological sites are the same for the five alternatives. The difference in the ultimate composite maps lies in the different congestion level of the five alternatives and its network connectivity.

The base criteria maps and the standardized maps can be viewed in the Appendix. It basically illustrates the base criterion maps and the resulting standardized maps.

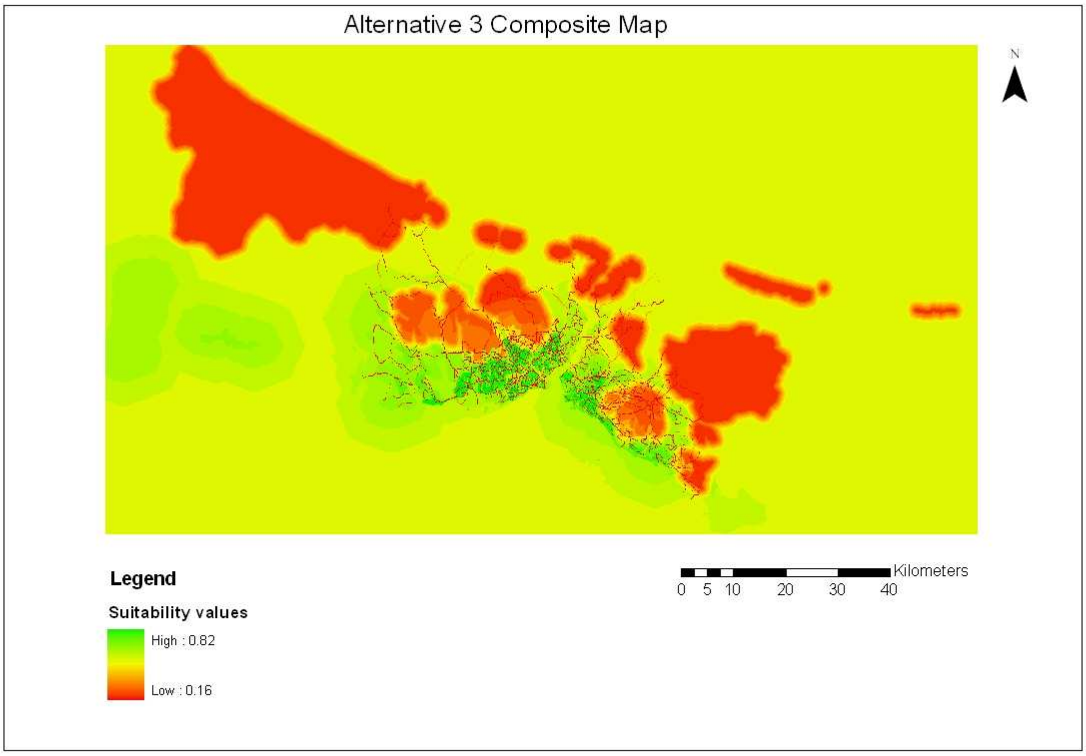
Alternative 1



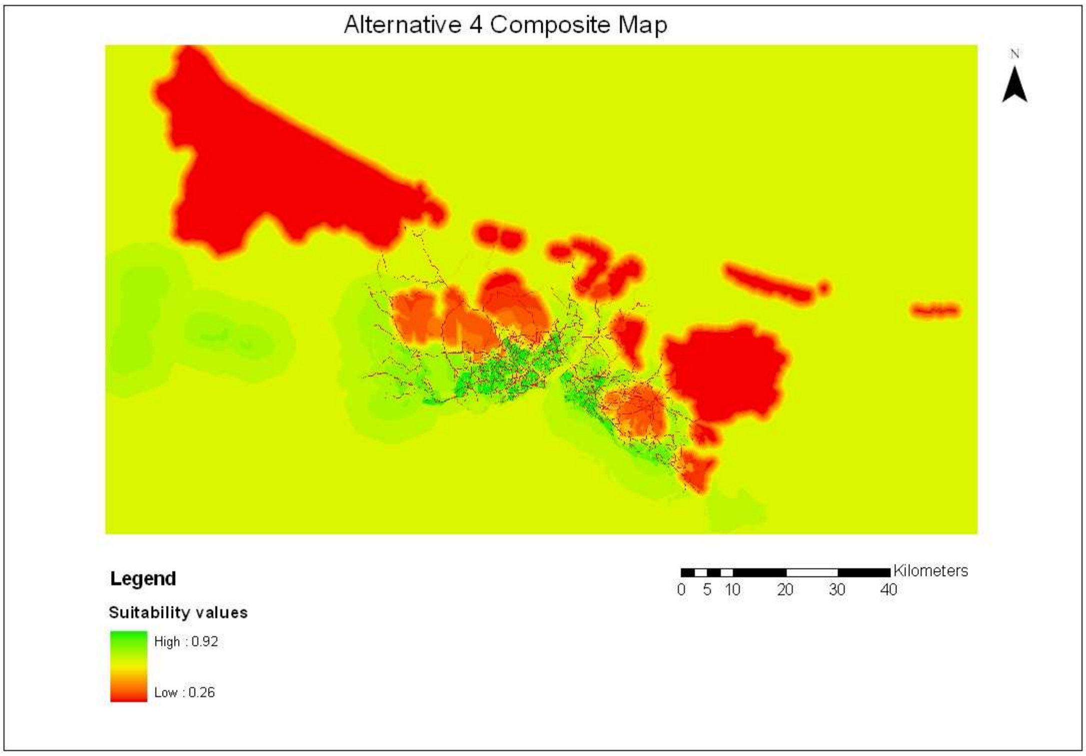
Alternative 2



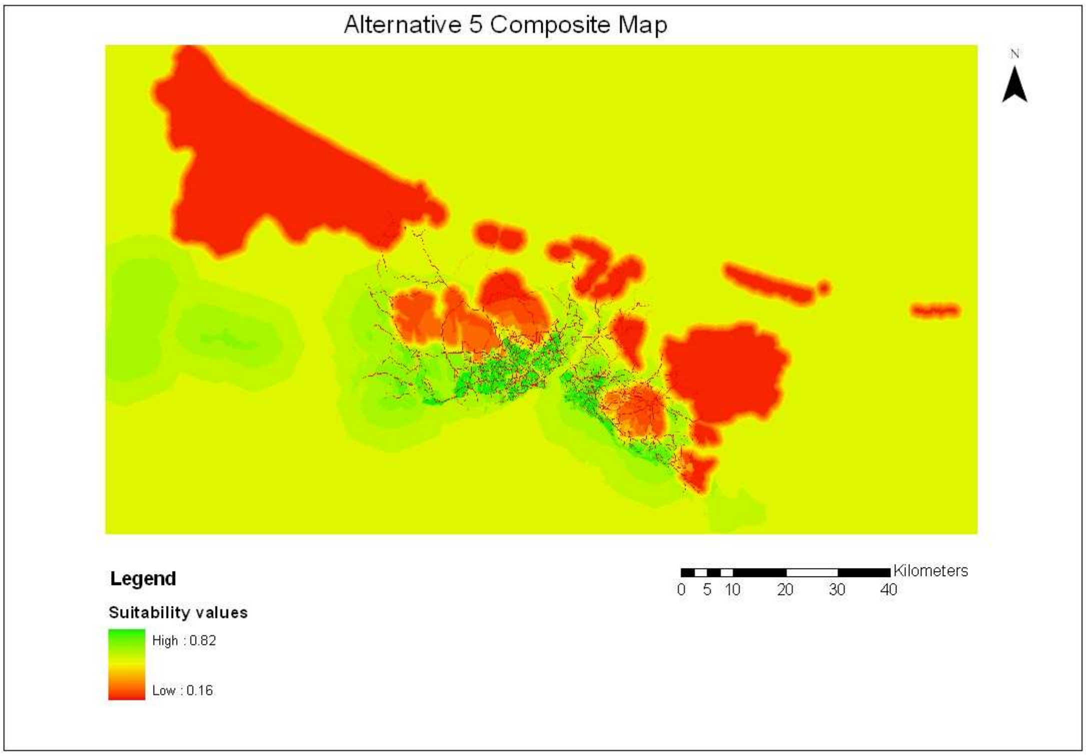
Alternative 3



Alternative 4



Alternative 5



These five buffered alternative routes are then assigned suitability values from the composite maps that it overlays. The results show that Alternative route 5 has the least total suitability values and Alternative 5 had the largest total suitability values. This is logical as Alternative 1 has the shortest route implying it covers a lesser extend of suitable areas in comparison to Alternative 5 and the other routes.

The figure below presents the resulting table from the zonal statistics procedure. The row "count" represents the total number of pixels that is covered by the buffered route. The row "area" represents total the surface area covered by the route. The "minimum" and "maximum" rows represent the minimum and maximum suitability value that is covered by the route. "Mean" is the average suitability value with regards to the total suitability values in a buffered route. The "sum" is the accumulated suitability value per alternative route.

Stats of "suit1erdas.img" Within Zones of "Alt1buff100"

OID	VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
0	0	1790	1.79E+07	0.06	0.67	0.61	0.384151	0.180172	687.63

Stats of "suit2erdas.img" Within Zones of "Alt2buff100"

OID	VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
0	0	1931	1.931E+07	0.16	0.7	0.54	0.466095	0.18186	900.03

Stats of "suit3erdas.img" Within Zones of "Alt3buff100"

OID	VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
0	0	2020	2.02E+07	0.18	0.7	0.52	0.501614	0.164642	1013.26

Stats of "suit4erdas.img" Within Zones of "Alt4buff100"

OID	VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
0	0	2168	2.168E+07	0.28	0.81	0.53	0.611125	0.157452	1324.92

Stats of "suit5erdas.img" Within Zones of "Alt5buff100"

OID	VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
0	0	2485	2.485E+07	0.17	0.7	0.53	0.504817	0.15055	1254.47

ALTERNATIVES	Route length (km)	Accumulated Suitability Values	Suitability per kn
Alternative 1	90.371	687.63	7.6
Alternative 2	97.684	900.03	9.2
Alternative 3	101.227	1013.26	10.1
Alternative 4	106.710	1323.92	12.4
Alternative 5	125.578	1254.47	9.99

To show the real difference in terms which alternative route is suitable the suitability values per km were calculated for each route. The above results show that Alternative 4 has the highest suitability value of 12.4 per kilometre. Alternative 3 has a suitability value of 10.1 per kilometre followed by Alternative 5 and Alternative 2 respectively with values of 9.99 and 9.2. Alternative 1 proved to be the least preferred route scoring a suitability value of 7.6 per kilometre.

It can be inferred from these results that Alternative 4 is the most preferred route with regards to reg to transport efficiency, accessibility and protection the general environment. Looking over the individual criteria cost maps it can be observed that Alternative 4 scored really well in terms of transport efficiency. It had the lowest congestion levels and the highest connectivity. Moreover transport efficiency was given the highest weight by the stakeholders.

Alternative 1 is the least preferred route basically because it lies in the middle of the central business district, where traffic density is really high, hence congestion levels are high. As congestion levels are assigned quite a significant weight in the criteria tree the alternative 1 route'saccumulated suitability values is low.

6. Conclusion and Recommendations

The main objective of this research has been achieved in that it has formulated a methodological approach to generate alternative and evaluate the alternative routes for five proposed locations to build a third bridge in Istanbul. The approach has been implemented and case studied in Istanbul. The results may serve as an aid for decision makers in the study area. The most preferred alternative route which is Alternative 4 is located up north of the Bosporus strait. This alternative had relatively lower congestion levels as well as being accessible to highly populated areas and areas of employment.

The research questions posed at the beginning of the research have been answered and the main findings are summarized below:

Sub Objective 1

The methods that have been identified to generate and evaluate route alternatives include least cost path analysis. The general idea behind this approach involves generating suitability maps to based on user defined criteria followed by indentifying an optimal route using a least cost path procedure. In defining the criteria for evaluating the alternatives the initial criteria list had to be shortlisted and screened according to the general planning principles of Istanbul and also taking data availability into consideration. Stakeholders preferences were taken into consideration during the early stages of research where discussions were held and feedback were received on the relevant criteria for evaluation in the local context. At this point stakeholder's involvement only involved informal discussions and open interviews. The weighting assignment phase is fundamental to the results of the evaluation as the stakeholder's perception of the different criteria will determine the results of the evaluation.

Sub Objective 2

The process of travel demand modelling was able to simulate traffic flows for the year 2023. This was done on Microsoft Excel and Flowmap. However one of the limitations faced in this phase of the research is that the modal split module was not carried out fully as the Flowmap software has limited functionality with regards to this. The AON traffic assignment may have also introduced errors in the outputs as a result of the underlying assumptions of the AON model. It would have been ideal to carry out the travel demand modelling on software like TransCad where a full modal split analysis and traffic assignment module can be carried out fully.

Sub Objective 3

The question of criteria identification, weighting assignment and assessment of alternatives has been answered. The process of criteria identification involved steps such as generating a preliminary list based on similar projects in Istanbul, screening by a team of experts based on three guiding principles that they defined themselves. The final list of criteria are identified from the screened list based on data availability. It should be noted that criteria such as operational and maintenance costs, land values and air pollution are important criteria that should have been considered in the study but wer not because of issues with data availability.

Ultimately the generated routes were evaluated and compared on ILWIS SMCE platform and zonal statistics function in ArcMap. Following the evaluation Alternative 4 was identified as the most preferred alternative route,, scoring the highest accumulated suitability value as well as the highest suitability value per kilometre of the route.

In conclusion the research has been able to answer the decision problem, which is to develop a methodological framework that will be able to generate and evaluate alternative routes. Additionally the approach should able to be implemented in similar studies and preferably improving the travel demand modelling procedure and also looking closely at evaluation criteria.

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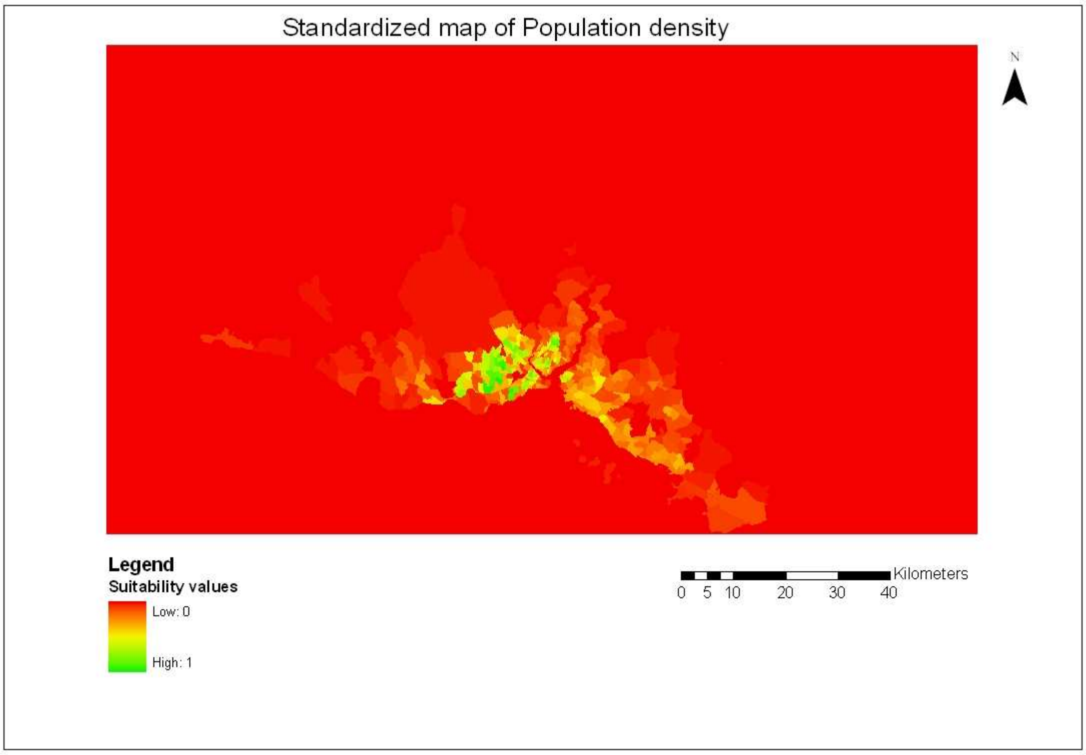
8. Appendix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N
Legend
Suitability values
Low: 0
High: 1
Kilometers
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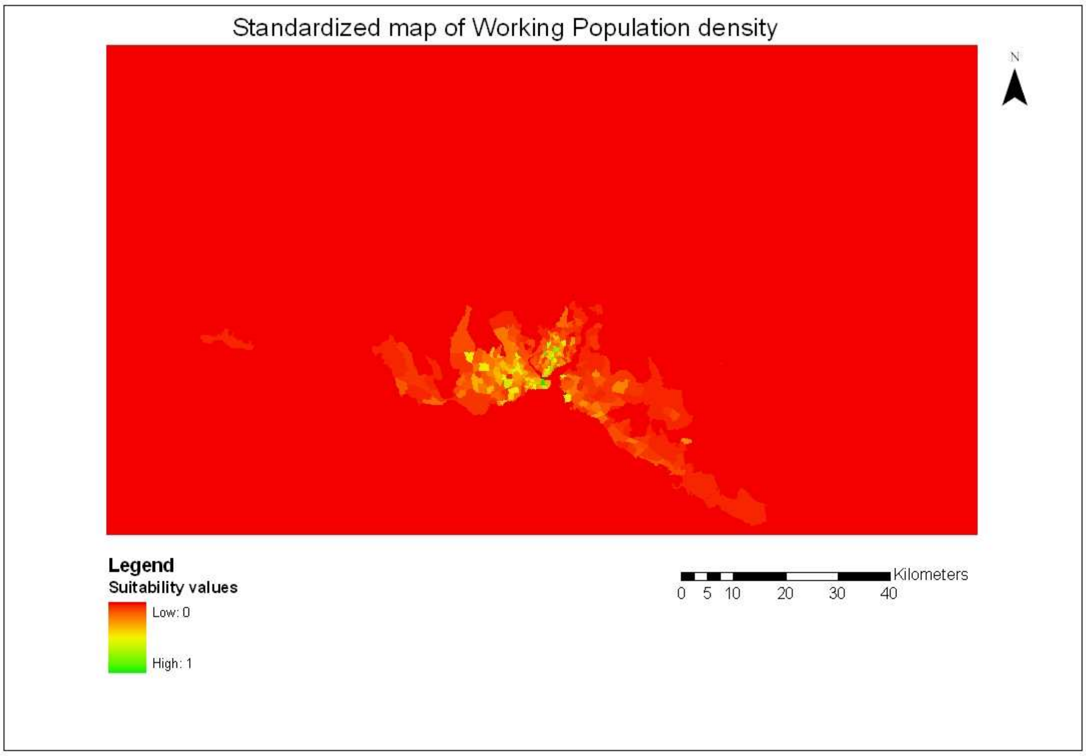
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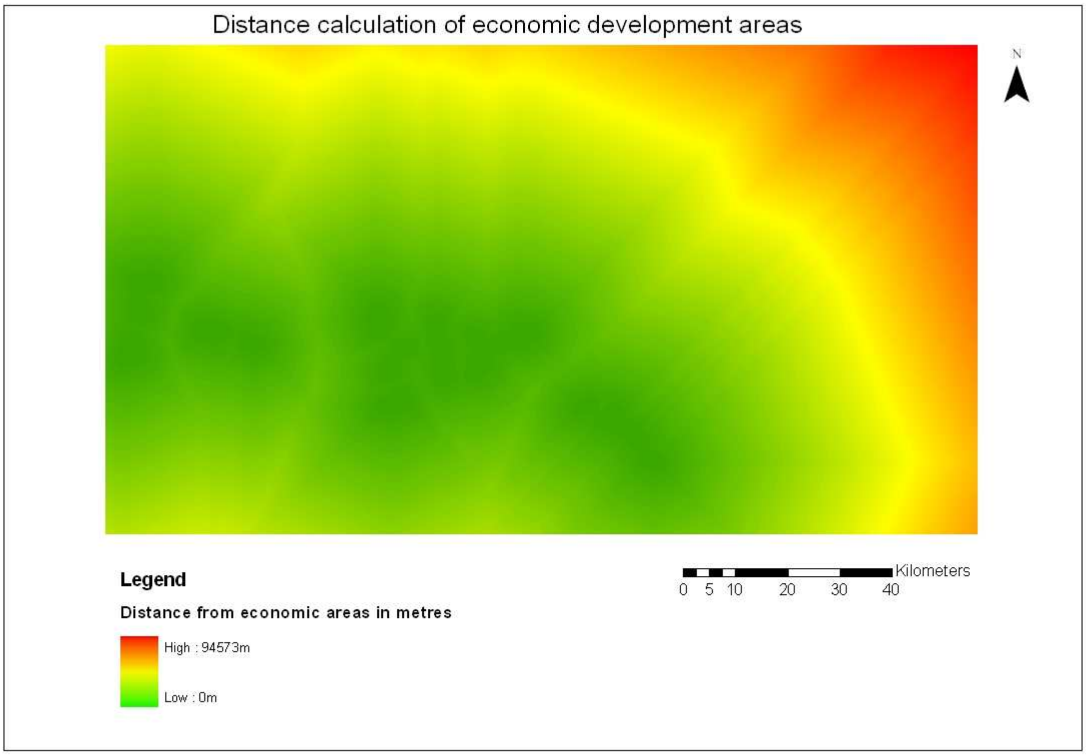
Distance calculation of economic development areas
N
Legend
Distance from economic areas in metres
High : 94573m
Low : 0m
Kilometers
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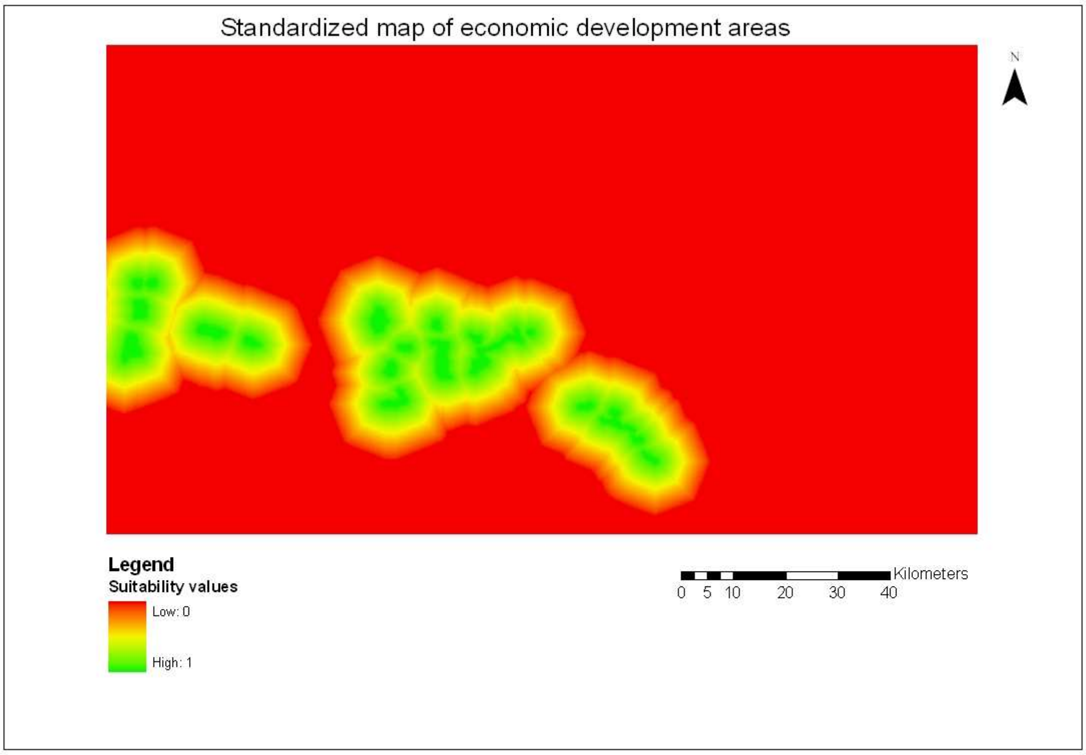
Standardized map of economic development areas
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Legend
Suitability values
Low: 0
High: 1
Kilometers
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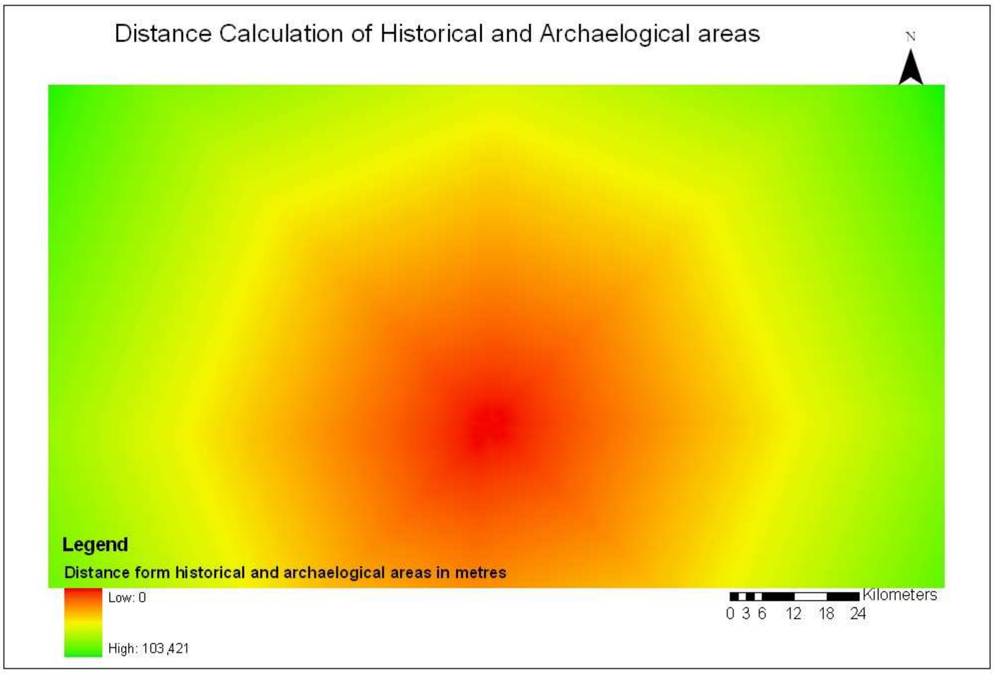
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Legend
Distance form historical and archaelogical areas in metres
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High: 103,421
Kilometers
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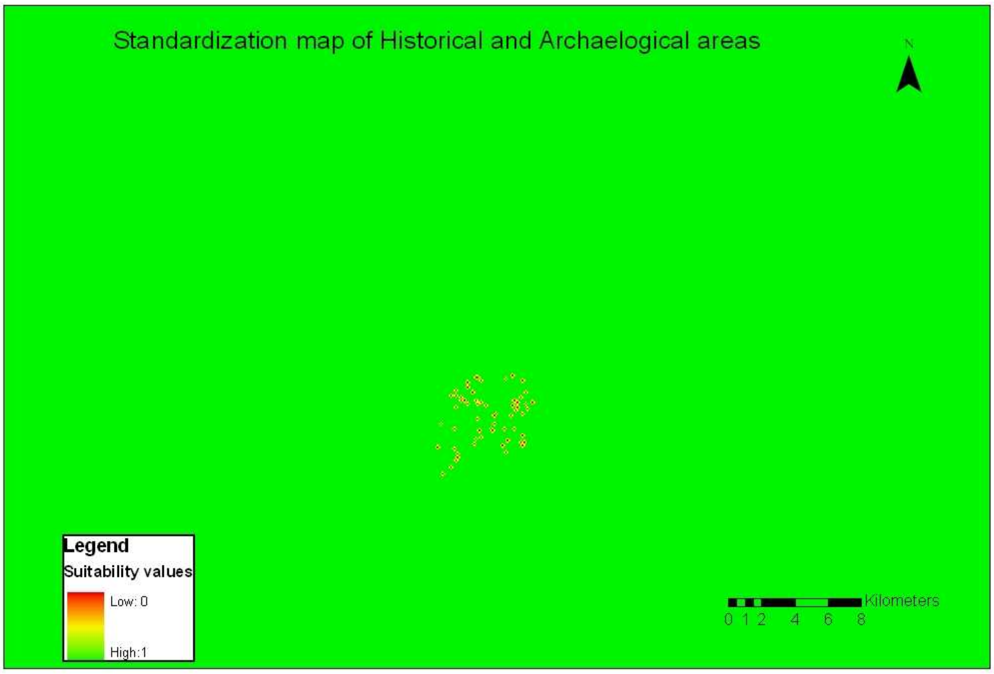
Standardization map of Historical and Archaelogical areas
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Legend
Suitability values
Low: 0
High: 1
Kilometers
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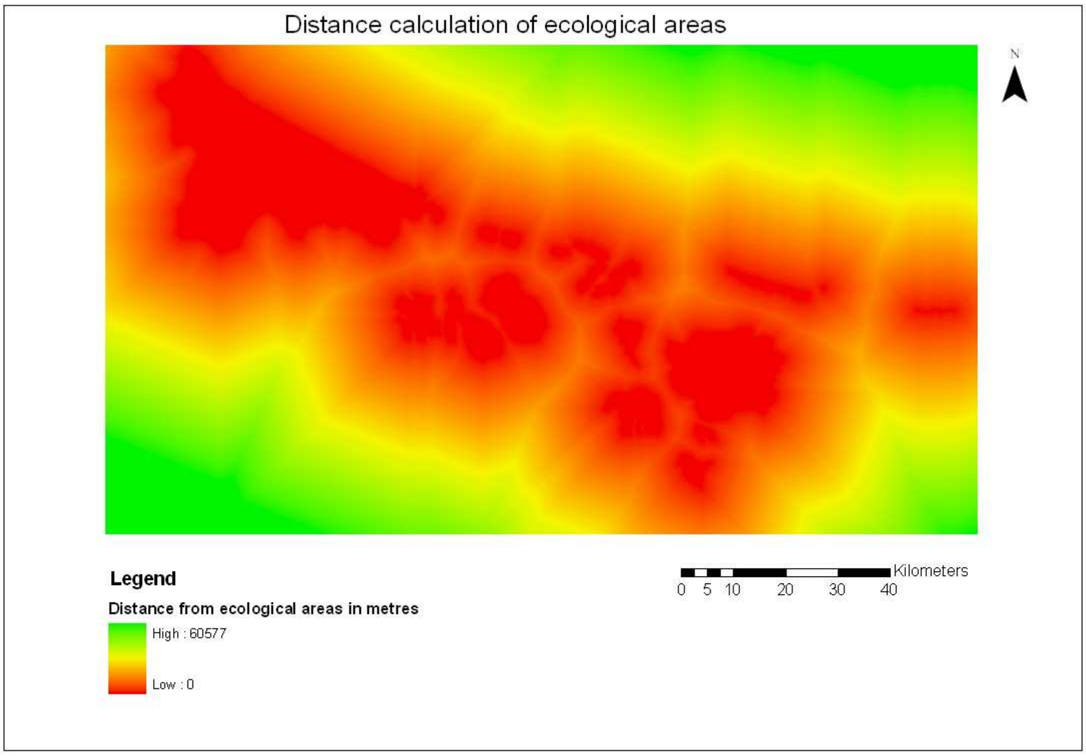
Distance calculation of ecological areas
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Legend
Distance from ecological areas in metres
High : 60577
Low : 0
Kilometers
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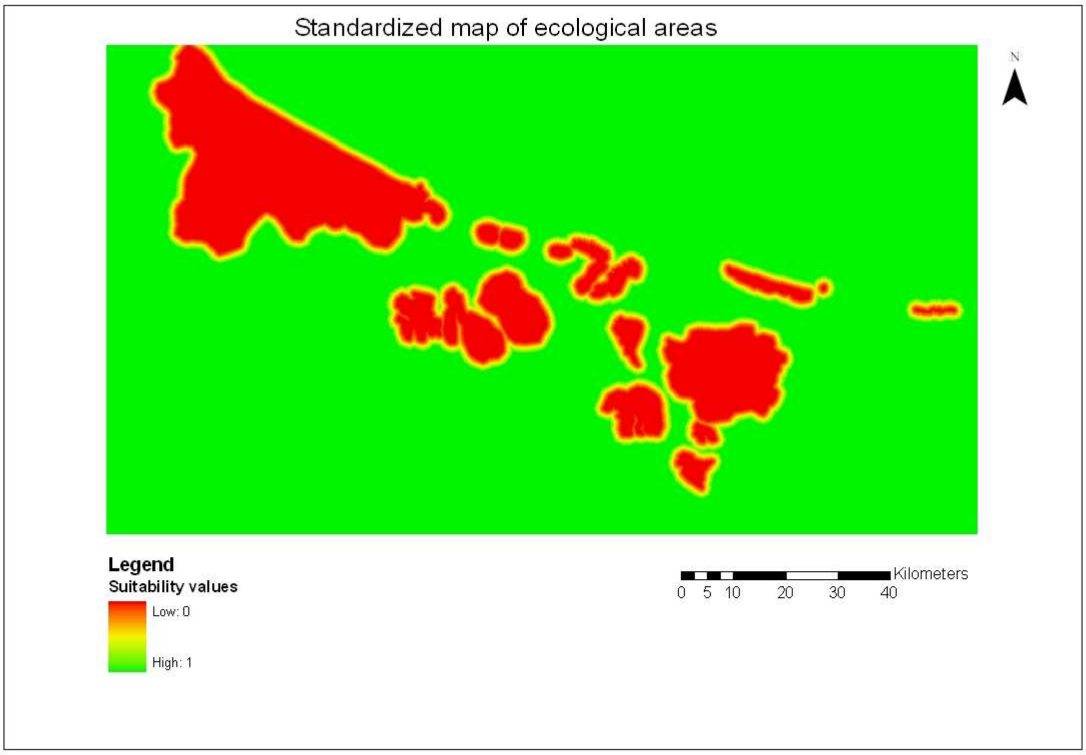
Standardized map of ecological areas
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Legend
Suitability values
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High: 1
Kilometers
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