Network based indicators for prioritising the location of a new urban transport connection: Case study Istanbul, Turkey

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by

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Abstract

The city of Istanbul in Turkey is divided by the Bosphorus strait which currently has two suspension toll bridges. Recent population increases has brought immense pressure on the bridges in terms of containing the flow of traffic. There are therefore plans by city authorities for additional connections to improve traffic flow. Key among these improvement proposals is the third bridge location over the Bosphorus strait. Five options have been tabled and there is the need to decide on one of these choices. This research considers three of these options located within the old municipal boundaries of the city, where most congestion occurs.

To address the issue, the aim of this research is to operationalise network indicators that can be used to prioritise the location of a new transport connection. Current indicators to measure network performance do not always consider network structure analysis. The main idea is that some transport connections are more important than others and that the relationship can be realized from analyzing the structure of transport networks. To do this, graph theory indicators of alpha, gamma, beta and space syntax parameters are explored at different degrees of network aggregation. Another method of assessing networks is by the traditional Volume to Capacity (V/C) ratio; this is also used to evaluate traffic conditions on the existing and proposed network improvement options over the Bosphorus.

The results show that indicators such as the alpha, gamma and beta at various aggregation scales are too much aggregated and could be used with other indicators like the space syntax measures to obtain meaningful results. The space syntax parameters of local and global integration were used to show effects of additional network connection on indicator performance. It was realised that with addition of a new connection, global integration values for areas around the first bridge increase. The V/C ratio will be used to correlate results from space syntax parameters to analyse whether similar patterns are realised. Conclusions from this work will determine whether graph theory measures are useful indicators in this kind of decision problem or whether a combination with demand and supply based indicators like the V/C are the most appropriate. As a result, the most effective new connection will be suggested.

Key words:
Bosphorus strait, Congestion, Alternatives, Indicators, Transport model

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List of abbreviations

GIT	Gebze Institute of Technology
IMM	Istanbul Metropolitan Municipality
IMP	Metropolitan Planning and Urban Design Center
ITU	Istanbul Technical University
TAZ	Traffic Analysis Zone
TCC	Traffic Control Center
TEM	Trans European Motorway
V/C	Volume to Capacity Ratio

1. Introduction

1.1. Introduction

The current development of transport infrastructure networks is deemed unsustainable (Greene and Wegener 1997; Wegener and Greene 2002); resulting among others in increasing traffic growth, recurrent and non-recurrent congestion, second order traffic generation and fragmentation of landscapes. This poses a problem for the future if infrastructure network planning is not done in a more systematic way.

The city of Istanbul, one of the largest cities in Europe and Asia is faced with increasing pressure on its transport network, mainly in terms of traffic congestion. This has resulted in increased travel time between locations and threatens economic development. Transportation is the wheel that moves economies and almost all activities rely (directly or indirectly) on the transport system. Transportation plays an important role in cities and therefore the need for better planning and implementation strategies.

Istanbul, the largest and fastest growing city in Turkey has a growth rate of about 4.13% each year. The current population is around 12 million people (2009). It is the only city in the world situated on two continents; Europe and Asia. Istanbul is surrounded by water – the Golden Horn (Halic), the Bosphorus (Istanbul Bogazi), Black Sea and the Marmara Sea (Marmara Denizi). The Bosphorus is the strait between the Black Sea and the Sea of Marmara. In 1950, 20% of the city's population was on the Asian side of the Bosphorus strait. However by 1990 the population increased to 32% as a result of improved access through construction of the bridges. Economic activities either start or end in Istanbul with most economic activities located on the European side. The city's trade and industry are centered on the European side, which has always accounted for the city's high population. This was as a result of mechanization of agriculture which prompted people to move from rural areas to the growing industries of the city. There are high migration rates, producing massive suburban sprawl on Istanbul's outskirts. The city is rapidly growing in the east, west, northeast and northwest.

There are currently two (2) suspension toll bridges on the Bosphorus strait. The Bogazici Bridge opened to traffic since 1973. It is 1074 meters long, with six (6) lanes and is between Beylerbeyi and Ortaköy. The second, Fatih Sultan Mehmet Bridge has been opened to traffic since 1988. It is 1090 meters long, with eight (8) lanes and is between Anadolu Hisari and Rumeli Hisari. This second bridge connects to the Trans European Motorway (TEM). Recent population increases (Alpkokin and Hayashi 2003) has resulted in immense pressure on the bridges in terms of containing flow of traffic. The two existing bridges over the Bosphorus strait are not sufficient enough to contain the increasing traffic situation on the two sides of the city, therefore there are plans by the city authorities of additional connections to better link the two parts of the city (Kubat, Kaya et al. 2007). Istanbul's location makes it very important for movement of people and freight between Europe and Asia.One thing worth noting is that any solution to the city's traffic situation, will not benefit the city surroundings only, but also has national and continental impacts. The city's transport networks carries traffic across countries and continents (Alpkokin and Hayashi 2003) as a result of its unique location.

Planning for expansion or upgrading of existing transport infrastructures, involve analysis of the current state of affairs; problem solving through design and generating alternatives; and decision making. The study aims to develop network indicators that can be used to prioritise where to expand the infrastructure network, like to locate new transport connections.

1.2. Background and justification of research

1.2.1. Background

Cities the world over require various transport infrastructures to aid the movement of people, goods and services from one location to another. Transportation is a means to an end; it does not create welfare on its own, that is done by final activities for which transport is used (Vickerman 2001).

Cities face problems of traffic congestion and its negative effects. Government approaches to minimize traffic congestion include creation of a new link in a congested network, the provision of new infrastructure, augmenting the capacity of existing transport networks (Scott, Novak et al. 2006), Intelligent Transport Systems, Manipulating infrastructure demand, promoting public transit, and land use policies and regulations (Button and Hensher 2001). These interventions are seen as one-sided, giving inadequate attention to transport network design (Vuchic 2007). Also Scott, Novak et al. (2006) argue that adding more capacity to an existing segment in the network is only a localized solution and the improvement in travel time is only experienced at the local area where the improvement was made.

Yang and Bell (1998) mention of the Braess paradox, which tells that creating a new link in a congested network or adding capacity to an existing link may actually increase congestion levels in the long run. This view is supported by Rodrigue et al. (2009) when they mention that increasing capacity engenders a hidden demand to use that network. However, if the reason for increasing capacity is to cater for new demand (say as a result of new residential opportunities), then these arguments might not hold. These views need to be examined, as there is a growing demand for travel, which brings about the need to improve supply of the transport network. There is therefore the need to assess the effect of a new connection on the general network structure.

The ancient city of Miletus in Asia minor is often mentioned as one of the systematically planned cities since 450 BC (Vuchic 2007). The city had a grid pattern, which showed the importance of transportation at the time. The grid pattern of transport connections is popular in the USA, with some European countries having radial or circumferential street networks (examples include Amsterdam, Versailles, Copenhagen and Cologne). Inadequate attention has been given to transport network design (Vuchic 2007) over the years and as such there is the growing perception that the current trend of transport infrastructure development is unsustainable.

In recent times, the analysis of transport network connections to capture mobility patterns and to assess design qualities is being considered. Hillier (1996), in developing the Space syntax methodology concentrated on breaking transport network (particularly street network) into segments. To better understand how a particular city is shaped, there is the need to go back to its rudimentary stage and analyse the transport network structure. Cities have ignored this important aspect of transport planning (Vuchic 2007).

Consequently, new techniques are being developed for transport network analysis that may be used as (part of) a Decision Support Tool in transport planning. The view of Hillier is to study the network structure and also connectivity within spaces of movement (as in for example streets). These segments are line of sight segments also called axial lines. One characteristic of space syntax is that precedence is given to linear features and not points (Hillier 1996; Batty 2004). Examples of space syntax analysis methods of a transport network are the Integration, Choice and Depth Distance measures. The application areas for most of these studies concentrate on spatial integration of network elements, pedestrian and vehicle flows, human way finding, and criminality at a micro-scale.

Research on analysis of spatial structure of transport networks, found that pedestrian and vehicular movement rates are strongly correlated with certain measures of graph indicators (Hillier 1996; Hillier 1999; Raford and Ragland 2004; Hillier and Iida 2005; Gastner and Newman 2006). However transport network analysis that use certain measures of graph indicators, only capture geometry of the layout. The shape and structure of the transport network in a region will likely affect the characteristics of the region's economy (Button and Hensher 2001).

Several research works focus on transport network structure and its measurements (Desyllas 1999; Batty 2005). The main idea is that some transport connections are more important than others and that the relationship can be realized from analyzing the structure of transport networks. Methods of assessing network performance include, traditional volume to capacity ratios (V/C), centrality and connectivity indicators for networks (Scheurer and Porta 2006), multiple centrality assessment method (Porta, Crucitti et al. 2008), efficiency importance and equity importance (Jenelius 2010) and network robustness index (Scott, Novak et al. 2006) which evaluates the importance of a link to the overall system as a change in the system should that segment become unusable.

Urban planners have always aimed at optimizing transport network design to meet transport cost, safety, land use and other considerations (Nagar and Tawfik 2007). With the increase in traffic congestion, this case study seeks to evaluate Istanbul's urban transport network and to be able to tell which areas are priority areas for intervention and also where to locate new transport connections.

A network in its simplest form consists of nodes joined together by edges or arcs. The arcs in this case are roads, railway lines, tram ways, etc. The nodes could be settlements, cities, intersections, bus stop, etc. Flows or movements occur along arcs of the network and are mostly associated with cost per unit of flow.

The following terms appear in several aspects of the write-up and the definitions given below as it relates to the work.

- Network Geography indicators are those indicators which are based on graph theory principles.
- Individual transport network indicators are the indicators which are measured for one transport network only.

1.2.2. Justification of research

The shape and structure of the network in a region will affect the likely characteristics of a region's economy, social development, accessibility, mobility, security and safety. Also it can give an understanding of spatial variations within a region. Hillier and Iida (2005) mention that topological and geometrical complexities are involved in the navigation or movement in urban transport networks. As such additional network connections may have complex impacts on accessibility on all locations in the network (Button and Hensher 2001).

Space Syntax techniques and network indicators based on graph theory measures are 'relatively new' areas in understanding urban structure and urban form. The technique has developed graph based measures to analyse and understand the complexity of urban street networks (Hillier 1996). The theory behind them has been in existence for some time now, but current research focuses on how to understand the complex nature of cities, when only network connections are analysed. Understanding the topology of urban networks that connect people leads to insights into how cities are organized (Samaniego and Moses 2008). The strength of network structure analysis and space syntax is that it is able to compare spatial properties independent from socio economic data (van Nes 2009). This must not end there; there is the need to correlate these results with empirical data to ascertain its validity.

Existing works on network analysis have focused on path computations to find shortest or fastest path through a network. Others have also focused on analysis of the importance of nodes in a road network; this representation takes a node centered view, which provides an alternative graph representation. The node centered view in this sense is known as the dual of the planar graph as described by Hillier (1996) in his work on space syntax.

This research develops a set of transport network indicators to prioritise new transport investments in a growing city. The focus however is a link-centered approach. Attributes given to each in a transport network will be analysed and prioritized. Research work conducted by Turner (2007) shows that space syntax measures can be combined with transportation network analysis representations for analysis purposes.

1.3. Research problem

In the planning of a transport network, most efforts by the planning authorities are geared towards increasing the capacity and building new transport networks, but little attention is given to the structure of the network. The spatial structure and form of the transport network is relevant to the performance and the utilization of the network; this is because traffic congestion is an issue of concern in many cities today and Istanbul is no exception.

Current research trends in transport and infrastructure planning are now focused on analysis of the transport network structure (Hillier 1996; Hillier 1999). This research follows up on the paper by Kubat et al (2007) on the effects of proposed bridges on urban macroform of Istanbul. Istanbul is separated by the Bosphorus strait, which divides the city between two continents Europe and Asia. The current two highway bridges available are heavily congested during peak hours (Ulengin 1994; Kubat, Kaya et al. 2007). This could be as a result of increase in population and increase in vehicle population without a corresponding increase infrastructure.

In order to address this problem of congestion the Istanbul Metropolitan Municipality (IMM), have tabled several options for network improvements, prominent among them are the Marmaray crossing and the third Bridge across the Bosphorus. The main aim for these network improvements is to make the city more accessible and also improve traffic performance. The main issue of concern is that can these interventions by the IMM achieve the set objectives? And also does Istanbul need a third Bridge? And if the third bridge is required, where should it be constructed? The decision problem is that only one of the options can be selected for implementation.

1.4. Hypothesis

Transport network indicators may be used to prioritise the location of a new transport connection to ensure general improvements in the network structure and performance.

1.5. Goal

To develop network based indicators that could be used to prioritise transport connections.

1.6. Research objectives

The main objective of this research work is to develop and operationalise network indicators that can be used to prioritise the location of a new transport connection.
The more specific objectives are;

a. To explore the use of network based indicators (NBI) for transport network planning
b. To examine effects that additional transport connection(s) have on network structure and traffic performance in Istanbul.
c. To use NBIs to prioritise expansion of the transport network of Istanbul.

1.7. Research questions

In order to operationalise research objectives, research questions have been formulated and specific answers need to be obtained. The table below shows the research objectives with the specific questions to address them.

No.	Research Objectives	Research Questions
1	To explore the use of network based indicators (NBI) for transport network planning	- Which methods have been used to analyse transport network structure and how can they be used for transport network planning?
		- At what scale are these indicators operationalised?
		- What is the spatial distribution of the current transport networks and proposed new connections?
2	To examine effects that additional transport connection(s) have on network structure and traffic performance in Istanbul	- Which transport network geography indicators are suited for network structure analysis and traffic performance?

		-What kind of effects is expected when additional transport connections are introduced in the network?
3	To use NBIs to prioritise expansion of the transport network of Istanbul.	- Can transport network indicators be used to predict the location of a new transport connection? If so to what extent?
		-What are the policy implications of such transport decisions?

Table 1-1: Research objectives and questions

1.8. Conceptual framework

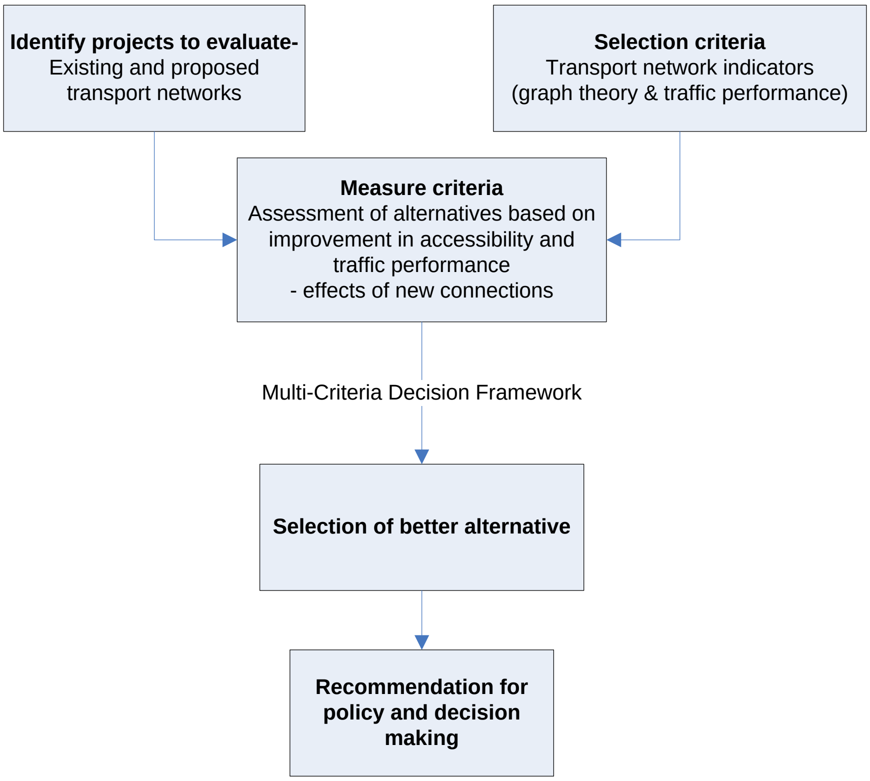


Figure 1-1: Conceptual framework

The framework for the research is organised into these steps or phases;
1. Identification of projects to be evaluated;
2. Selection and measuring of criteria;
3. Assessing various alternatives based on objectives (evaluation) and;
4. Selection of better alternative or best option (Tsamboulas 2007).

In the first step, we identify the new connections that have to be evaluated. This consists of the marmaray crossing and third bridge options developed by the IMM. Next we select and measure criteria to be used for the evaluation, bearing in mind that the new connections have to improve access and traffic performance in the network. This step takes an exploratory form. This is because several indicators are assessed at various degrees of aggregation and suitable ones selected as part of the final set of indicators to use. The selected indicators should be relevant, understandable by the whole community, provide long term view and based on reliable information. This will most importantly benefit decision makers, as it will be useful and easy to collect. In order to develop indicators that can support decision making, there is a need to incorporate existing transport network indicators. Lastly an assessment of all the criteria is made based on the score from the various options and then the better option is selected.

The IMM has specific plans and policy visions for the city's transport supply situation. Turkish Ministry of Transportation unveiled the strategic plan for 2009-2013. The strategic goals relevant to this study states that, 'ensuring a transport system with a balance between modes of transport to serve in a technically and economically efficient manner'. For example in Goal 1 objective 1.2, the ministry will carry out operations on top priority arterial roads with heavy traffic and also to realise new roads and motorway projects. Among such priority projects is the 3rd bridge on the bosphorus strait and Marmaray project which is the main focus of this research.

1.9. Research design

Figure 1.2 below shows the procedures and processes that were followed in undertaking this research work. The research problem basically is about selecting the better option among a list of network improvement options across the bosphorus.

Data that was used for the field work was identified through literature review and also in consultation with the Istanbul Metropolitan Planning and Urban Design Centre (IMP). The IMP acts as a planning and design centre for the Istanbul Metropolitan Municipality (IMM). This is with the reason that the municipal authorities are in a better position to give meaningful insights on certain indicators that will be practical and those that might not be. It was assumed this will link theory to practicality in Istanbul.

As shown in figure 1.2, concepts were developed and operationalised based on literature review. After developing various network indicators they were analysed and operationalised under different scales of aggregation. The indicators are analysed for the existing and proposed transport network. Based on the findings, recommendations and conclusions are proposed.

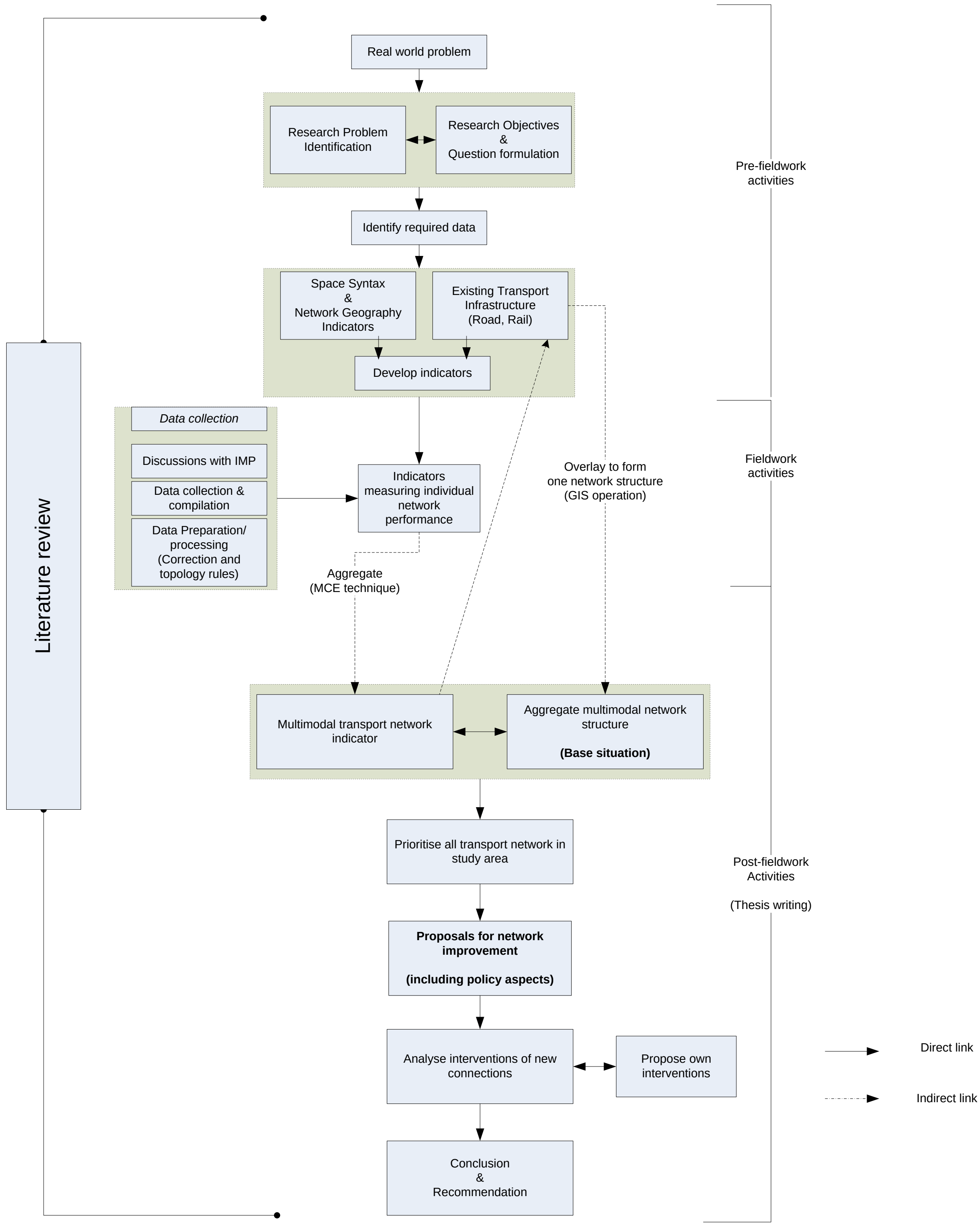


Figure 1-2: Research design

1.10. Research matrix

The table below shows the research matrix; it shows the objectives, research questions, data required and sources of those data, data acquisition tools, method of analysis and the time frame within which to achieve each objective. This matrix adds up to achieve the overall objective of the research work which is to develop and operationalise network indicators that can be used to prioritise the location of a new transport connection.

No	Specific Research Objectives	Research Questions	Data Required	Data sources	Data acquisition tools	Time (when?)	Methods of analysis
1	To explore the use of network based indicators (NBI) for transport network planning	Which methods have been used to analyse transport network structure?	Relevant literature on transport network structure Land use and transport data Transport network data	Secondary data	Literature search	Pre-field work/ field work	Literature review
		At what scale are these indicators operationalised?	Transport network data	Secondary data	Literature search	Pre-field work/ field work	GIS analysis
		What is the spatial distribution of the current transport networks and proposed new connections?	Network structure of proposed transport alternatives Transport network data	-	-	Field work and Post field work	GIS analysis
2	To examine effects that additional transport connection(s) have on general structure of the city of Istanbul.	Which transport network geography indicators are suited for a multi-modal network structure analysis?	Relevant literature Documentation on network structure quantification Transport network data	Secondary data	Literature search	Pre-field work/ field work	Literature review
		Which multi-modal transport indicators are available in literature and can be applied in this context?	Relevant literature Documentation on network structure quantification Transport network data	Secondary data	Literature search	Pre-field work/ field work	Literature review
3	To use NBIs to prioritise expansion of the transport network of Istanbul.	Can transport network indicators be used to predict the location of a new transport connection?	Data from previous analysis	-	-	Post field work	Analyse the results from the indicators developed

		What are the policy implications of such transport decisions?		-	-	Post field work	Analyse the results from the indicators developed

Table 1-2: Research matrix

1.11. Survey methodology and design

The survey methodology comprised of selecting the area of study, data requirements and type, selection of the survey method and the methods of analysis.

In an attempt to analyse the transport network structure of Istanbul, graph theory and traffic performance indicators are used. This research work employed the use of transport link oriented analysis.

The analysis of proposed improvements to the existing transport network structure was based on the policy vision of the Greater Istanbul Municipality. Already, the municipality has proposed several options to improve the transport infrastructure; this invariably has effect on the structure of the city. This was evaluated to analyse the improvement or otherwise of the structure of the city based on the multimodal indicator developed.

1.11.1. Study area selection

The study area comprises the whole metropolitan area of Istanbul. However, at certain stages in the analysis it was restricted to only the urban areas around the Bosphorus strait and coastal regions of the Marmara Sea. However, extent used for prioritising a new connection in the network was restricted to the old municipal boundaries of the city because of data availability. This is key to the realization of the main problem and objective of the research work. The study area was however defined by availability of data for the field work. A map showing the whole of Istanbul is shown in figure 1-3 below.

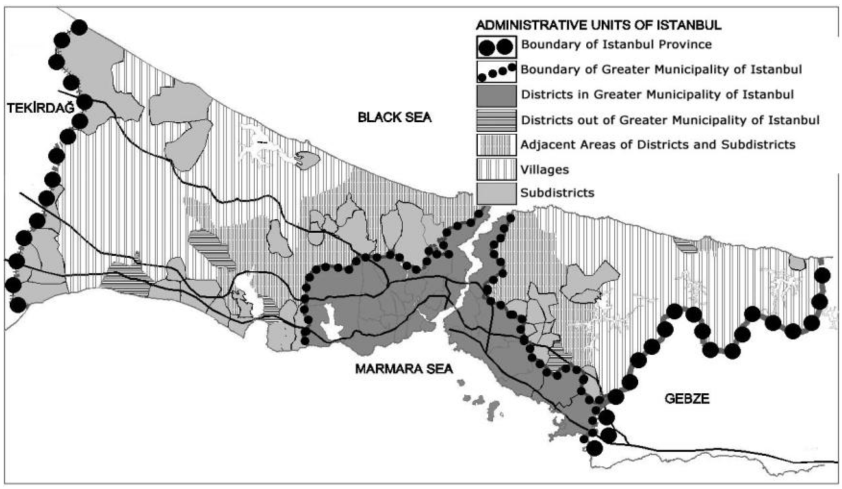


Figure 1-3: Study area - Istanbul

1.11.2. Data requirements

Data required for the thesis comprised of the following;

- Map of administrative regions of the city of Istanbul – this is to aid in delineating study area

Transport supply data

- Transport network map of Istanbul like for roads, rail and pedestrian walkways – for analysis purposes the following transport attribute data are required;
  length of each connection, hierarchy of each connection, capacity (road, rail), travel speeds/ time, and socio-economic data (for trip generation model.
- Map of proposed new transport connections in Istanbul – this comprises of transport connections under construction and new transport connection plans not yet under construction.
  Examples of projects to be evaluated include;
  The Marmaray Project (http://www.tcdd.gov.tr/tcdding/marmaray_ing.htm; http://www.marmaray.com/), Ankara-Istanbul High Speed Train Project,
- Population distribution data for the city of Istanbul
- Land use/ land cover data of Istanbul
- Master plan of Istanbul (particularly the Transport Master Plan)

1.12. Beneficiaries of research

The research work will be of benefit in a number of ways;

1. Provide researchers and policy makers a method of assessing transport networks by incorporating graph theory and traffic performance indicators within one assessment framework.
2. Provide further insights in transport network structure, algorithms and models for the case of Istanbul.
3. Successful implementation of this method will mean that decision makers can use it as (part of) a Decision Support Tool.
4. The researcher will also gain insights to what extent transport network indicators can be used for transport planning purposes.

1.13. Structure of thesis

This thesis is structured into 8 chapters.

Chapter 1: Introduction

This chapter outlines the background to the research problem. It defines the research problem, objectives, research questions and conceptual framework in order to achieve set objectives.

Chapter 2: Transport network indicators

This chapter focuses on transport network indicators as a whole. It discusses a number of indices, how they can be measured and the interpretation. The chapter also provide a review of literature in this field and what other researchers have focussed.

Chapter 3: Methodology and data collection

Details the methods used in the research and also provide an overview of primary and secondary data sets collected during fieldwork. Data quality and data limitations are also presented in the end.

Chapter 4: Study area profile

This chapter discusses land use and socio-economic attributes of Istanbul and how it affects transportation. The concluding sections focus on the transport dynamics and network integration within the city.

Chapter 5: Current and future transport development in Istanbul

Here we discuss the various transport network used for analysis. This chapter presents proposed network improvement projects by the Istanbul Metropolitan Municipality (IMM), locations and implementation year. At the heart of this chapter is a description of network scenarios developed for analysis and this forms the basis for all the analysis as outlined in chapter 6.

Chapter 6: Network based indicators (NBI) analysis

Chapter 6 focuses on all the indicators measured for both graph theoretic and transport performance indicators. A definition for each of the indicators, the models used and interpretation of output results for each of the network options are analysed. The analysis of especially the graph theoretic measures is done at various degrees of network aggregation. The chapter concludes by discussing the suitability of the indicators for further selecting ‘best option’ among a list of 3 network options that the subject of evaluation.

Chapter 7: Discussion – evaluation of network based indicators used

This chapter continues the discussion from chapter 6. In this chapter a brief overview of the indicators selected for evaluation is outlined and specify which ones are selected and why?

Chapter 8: Conclusions and recommendations

This last chapter summarizes key findings and give recommendations for future research direction.

2. Transport network indicators

This chapter expounds on network indicators in general and the examples of the indicators used in this research are explained. The focus of this chapter is to discuss graph theory approaches to the representation of networks and its significance. We start by discussing the concept of transport network representation as graphs. We later discuss some of the indicators for both network geography and space syntax. Various indicators are discussed in terms of how they are computed and their usefulness. The chapter concludes by reviewing the process that the analysis will take.

2.1. Transport network

The term network refers to the framework of routes within a system of locations, identified as nodes. A network can also be defined as an arrangement of intersecting lines. A route is a single link between two nodes that are part of a larger network that can refer to tangible routes such as roads and rails, or less tangible routes such as air and sea corridors (Rodrigue, Comtois et al. 2009). The transport link (or connection) has individual characteristics which include length, number of lanes, direction, capacity and free flow speed. The provision of a transport network especially, has implications for mobility and access. A transport network is made up of permanent tracks (for example road and rails) or a scheduled service (for example airline).

Transport networks carry people and goods from one location to another. In order to understand the complex nature of networks, indicators are used to measure network structure and form. This is used to determine the performance of the network. There is the need to know what is being measured in order to understand the dynamics of transport networks.

The efficiency of a transport network can be measured using graph theory, network analysis and traffic performance indicators. Graph theory is a branch of Mathematics concerned with the encoding and analysis of graphs. A graph is a simplified representation of reality, consisting of links and nodes.

2.2. Transport network representation as graphs

> *"The graph eliminates the flesh and blood, as represented by the sinuosities and the flows … for what is left are the skeleton. As in any skeleton, there are links joined at specific places … By reducing the complex transportation network to its fundamental elements of nodes and links, it is possible to evaluate alternatives".*
> (Lowe and Moryadas 1975)

The above quotation gives an overview of what transport network representations by graph theory is all about. It takes out the many complexities and leaves the analysis to a study of the basic structure within the city; in this case the transport network.

Urban form is usually represented by a pattern which identifies certain elements such as locations or areas and their inter-relatedness. The relationships among the elements are often associated with linear transport routes or networks. The representation of various components of urban structure are measured in a literal manner (Batty 2004); an example of such measurement is along transport networks. The usual representation is that network junctions are represented as nodes and routes between them are represented by arcs (links) as used in planar graphs.

Urban structures are not limited to a two (2) dimensional domain, cities are essentially planar in structure (Buhl, Gautrais et al. 2006). This concept of network representation by graph and its analysis is not a new concept at all. There is a long tradition of urban form representations through graph theory principles. Some of the application areas include measures in regional central place (Nystuen and Dacey 1961), transport network measurements (Kansky 1963) and accessibility. Haggett and Chorley (1969) mention that these kinds of analysis are central to spatial analysis.

Graph theory deals with abstract representations of lines and points, and this representation has been applied in many fields of study. Transport network representation as a graph can also be described as a set of discrete points joined by lines (Marshall 2005; Gastner and Newman 2006). This structure of representation is suitable for topological representation of transport networks.

In the bullets below a discussion of graph theory concepts and their transport equivalences are given.

- Link – a link is an imaginary straight line representing a finite length of road, railway or bus route.
- Node – a node is an imaginary point where links intersect. It represents transport network intersections (for example road intersections, railway junctions, locations of stations or bus stops).
- Dummy link – a dummy link is an additional link not corresponding with any real section of the transport network, but included to represent either the connection of a zone centroid with the network or public transport waiting time at each station or bus stop.

Taaffe and Gauther (1973) and Fullerton (1975), as cited by Black (1981) mention that the powerful aspect graph theory exploited in transport analysis is that networks and their connectivity properties can be defined exclusively in numerical terms. This means that links can be quantified and analysed.

In transport networks, links in the network become the edges (arcs or links) in the graph. It is then possible to use various graph theoretical indicators to analyse network structure and capture properties such as connectivity.

2.3. Different modes

Networks support movement and can be viewed from a modal perspective. The edges represent among others roads, rail, and maritime routes and the nodes represent terminals. Different modes of transport are used in fulfilling the daily demands of mobility. Some of the different modes include roads, railways, tramways, bus routes, bicycle paths, strait crossing ferries and foot paths.

Currently the modal share of motorised transport in Istanbul is that 80% are for private transport, 5% for sea transport, 5% for rail transport (Istanbul Metropolitan Municipality and JICA 2008).

Istanbul has 17 different modes of transportation. They are grouped in three categories; modes that use the road, rail and water networks.

2.4. Transport indicator categories

In transport studies different kinds of indicators may be used to measure the performance of the network. There are different categories that can be used to describe transport indicators. Some are grouped broadly as Economic, Social, Environmental and System indicators. Others are also grouped as Demand and Supply based indicators.

Demand based indicators are indicators that measure people's use of the transport network while Supply based indicators are indicators that measure the performance of transport networks. Conventional transport indicators measures mostly traffic conditions. These include Roadway level of service (LOS), average travel speeds, average congestion delay, system-wide travel time, unused capacity in the network and volume to capacity ratio.

There are no standardized indicator sets for comprehensive transport planning (Litman 2007). Each institution develops their own set of indicators based on the need and institutions abilities.

A great amount of research concerning networks has been based on topology, which mainly focuses on network structure. Many algorithms exist for analyzing transport networks.

Section 2.5 describes some graph theoretic network indicators and how they are measured. Also the indicator's scale of application and relevance is also assessed.

2.5. Some network indices and measurements

This section discusses some network measures and indices and how they are measured. Linear graph theory is a branch of the mathematical field of combinatorial topology which deals with the properties of graphs (Morlock 1967). Network measures and indices are used to evaluate the properties or performance of a transport network. Quantifiable indicators can abstract the properties of complex network structures and helps to explore structure from a spatial perspective (Xie and Levinson 2006). Indices are used to evaluate the properties of a network graph. One of the indicators used to measure network performance is the connectivity measure. Connectivity is the primary purpose of any transportation network (Dill 2003), as it links the places that people will want to travel between.

Some examples of network measures and indices are explained below.

2.5.1. Detour index

The detour index (DI) measures the efficiency of a connection in the transport network. The formula for the DI is expressed as the straight or airline distance divided by the network distance.

$$DI = \frac{d}{L} \tag{1}$$

where DI denotes the detour index
d is the Straight distance (in kilometres) and
L is the Network distance (in kilometres)

The closer the detour index gets to one (1), the more spatially efficient. It is however rare to have networks with detour index of 1. This indicator is dimensionless and takes values from zero (0) to one (one). In terms of scale of operation, the detour index could be analysed at the whole city level, but it makes more meaning when individual routes in a network are analysed; say a particular bus route.

2.5.2. Network density

Network density (ND) is the kilometer of network per square kilometer of surface. Network density measures transport network development depending on the scale of analysis. Cities with limited infrastructure score low (like less than 10%).

$$ND = l/A \tag{2}$$

where ND denotes the network density
l is the total length of transport network in study area depending on scale
A represents the area of say the city, district or traffic analysis zone

The dimensions are normally in [km/km^2] depending on scale of network. A smaller area might be more meaningful to represent in m/m^2. This indicator can be measured at various degrees of aggregation at the city scale.

2.5.3. Pi index (π)

Pi index is the relation between total length of graph and its diameter

$$\pi = \frac{l}{D} \tag{3}$$

l denotes the total length of graph and D its diameter. The Pi index is applicable and makes more meaning if it is analysed at the city level.

2.5.4. Eta index (η)

The eta index (η) measures the average edge length in the network and is used as a measure of speed in a traffic network. The formula is as below.

$$\eta = \frac{L(G)}{e} \tag{4}$$

Where

L(G) represents the summation of all edges in the network (the unit of measurement is kilometers) and e represents the number of edges in the network.

The eta index is used as a measure of speed in a network. The index is the sum of the length of all the segments within the network, divided by the number segments. The assumption is that the longer the segments in the network, the better it is to ensure maximum speed of the segment concerned. Adding a new link will cause decrease in eta as average length per link declines. The scale of application of the index is meaningful at the city level.

2.5.5. Theta index (θ)

The theta index measures functions of a mode, average amount of traffic per intersection. The higher the theta index the greater the load of the network.

2.5.6. Beta index (β)

The beta index, which is also known as the link-node ratio, measures the “completeness” of a graph. The index measures the level of connectivity of the transport network. The beta index for connectivity can be derived from the simple formula below.

$$\beta = \frac{e}{v} \tag{5}$$

The formula reads as Beta index equals number of segments (edges - e) divided by number of nodes, v. The nodes are the transport network intersections or the end of a cul de sac, and the edges are connections between the nodes. Beta index ranges from 0.0 for a network, which consists just of nodes without any arcs, through 1.0 and greater where networks are well connected.

Simple networks possesses values less than 1.0, a connected network involving a single circuit has a value of 1.0, while networks of greater complexity, which include several circuits, have values higher than 1.0. The beta index is very useful in very simple networks where no circuits are involved.

A perfect grid has a ratio of 2.5. A beta index of about 1.4 (which is say half way through the extreme of values) is a good target for network planning purposes (Dill 2003). Increasing the links in the network increases connectivity measure. This index does not however reflect the length of the links in any way. Therefore a perfect grid with a 1000 blocks will have the same beta index as one having 200 blocks.

The scale of application of this index is normally at the city level. In this research work, a more disaggregate area of analysis is used. The index is analysed using the TAZ and also a 1 by 1km grid cell of the urban area. The only problem is that if the network is disaggregated, some portions of the network where the index is measured do not form a network. Since the network is ‘cut’ in many portions and some segments may seem not to connect.

2.5.7. Alpha index (α)

The alpha index uses the concept of a circuit – a finite, closed path starting and ending at a single node (Dill 2003). The alpha index (α) for connectivity is the ratio of the number of fundamental circuits to the maximum possible number of circuits which may exist in a network. This index is a measure of the redundancy or duplication in the system. The alpha index measures the ratio of the number of observed fundamental circuits in a graph to the maximum number of fundamental circuits which may exist (Morlock 1967).

$$\alpha = \frac{e-v+1}{2v-5} \tag{6}$$

Where e is the number of segments (edges) and v is the number of nodes in the network.

The alpha index values range from 0 to 1. The higher the alpha index the greater the degree of connectivity. Simple networks will have nil values. An α value of 1 indicates a highly integrated network in which every possible link exists between the various nodes. But in some instances the alpha index value can be negative and this is due to poor connectivity of transport networks in the study area.

The index is normally applicable at the city scale, however it can be disaggregated to traffic analysis zones (TAZ).

2.5.8. Gamma index (γ)

This index is the ratio of the actual number of segments (edges) in the graph to the maximum number of segments (edges) which may exist in the graph. Gamma index measures the theoretical maximum connectivity of a network. The gamma index is a simple ratio of the actual number of edges in the network to the maximum possible number of edges. In numerical terms the gamma index connectivity is given by the formula below.

$$\gamma = \frac{e}{3(v-2)} \tag{7}$$

Where e denotes number of segments (edges) and v is the number of nodes in the transport network.

The values range from $0 < \gamma < 1$. The value of 1 indicates a completely connected network and the value 0 indicates a poor connectivity. Taaffe and Gauther (1973) mention that when the gamma index is 0, it indicates incomplete connectivity. The values of the gamma index are normally expressed as a percentage of connectivity, for example, gamma index of 0.57 means that the network is 57 per cent connected.

The index is applicable at the city scale, but can also be disaggregated further.

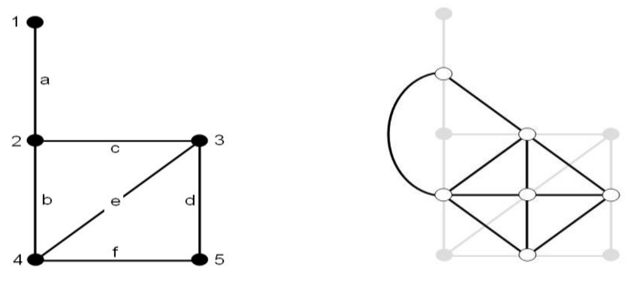
Morlock (1967) mentions that many of the concepts and measures of graph theory are not applicable in transport analysis. The reason for this view is that these theories were not developed with transportation applications in mind. But then it should be noted that graph theory is the mathematical basis for representing networks (for example the arc-node model) (Miller and Shaw 2001). The applications of graph theory to transportation have treated two possible types of graph; the planar and the non-planar. In this work the transport network layer used is a non-planar one. The graph theory measures do not take the characteristics of a particular road segment into consideration in computing the various indicators. Two of the useful indicators which are seemingly important in transportation analysis according to Morlock (1967) are the so-called alpha and gamma indices described above. According to Morlock, these indices are relevant and can be used to measure the efficiency of the transport network. The results for the alpha, gamma and beta indices give interesting insights to connectivity levels of the networks at various degrees of aggregation.

The next section 2.6 also discusses another aspect of graph theory indicators known as space syntax. We discuss the main concepts, parameters and indicators that can be measured.

2.6. Concept of space syntax measures/ indicators

Space syntax is a set of theories and tools used for spatial morphological analysis (Jiang, Claramunt et al. 2000). For morphological analysis, space syntax provides a range of spatial property parameters derived from connectivity graph. Space syntax is a graph measure, but only a 'higher' form of accessibility measures. Different components of urban structure are measured along streets (Batty 2004) and this concept can be extended to other transport networks.

Space syntax makes use of planar graphs and measures topological relations between street (transport) networks. Conventional theoretic representations of street networks are shown as graphs, where the nodes typically represent junctions of transport networks and segments represent streets. There is however another representation of networks, where the nodes represent the connections within the network. This according to Batty (Batty 2004) makes interpretations easier; as the focus is on the lines and not junctions.



a. The Planar graph b. The Dual of the planar graph

Figure 2-1: Conventional Graph- Theoretic Representation of the Street Network [adopted from (Batty 2004)]

In the above figure 2-1a., the focus is on accessibility of the nodes which is refered to as the primal problem. However in figure b. the focus is on accessibility of the streets within the network, which gives another graph representation called the dual problem. The dual problem as Batty mentions has not found favour in spatial analysis. This is because the focus has mostly been on the nodes and not the transport links (arcs) (Scheurer and Curtis 2008). However the dual problem has been widely developed by space syntax, figure 2-1b (Hillier and Hanson 1984; Batty 2004).

Space syntax basically measures accessibility of streets with relation to other streets using graph measures. In its current form it is a toolbox of simple techniques to measure accessibility of streets. One important feature in space syntax is that linear features are the focus and not point features. Initially, computations were based on axial line maps (which are "lines of sight"), but now other representations can be used such as road center-lines (Turner 2007).

Space syntax provides some insights into the structure of urban street networks. The focus on linear elements sets it apart from conventional graph theoretical treatment of networks (Marshall 2005). It captures properties of urban street networks that other methods based on links do not.

2.6.1. Space syntax parameters and concepts

In this kind of spatial analysis, there are some concepts and parameters which are used to describe outputs among them are the following continuity, connectivity, control, depth and integration. They are described below.

(a) Continuity – number of links that a route is made up of or the length of a route measured in links.

(b) Choice – initial load, each time an intersection occurs the remaining value of flow is divided equally among splitting streets. Streets with highest total values of accumulation flow are said to have highest choice values.

(c) Control value – is defined as a parameter which expresses the degree choice each node represents for nodes directly linked to it. The control value ***(V_i)*** of a node ***(i)*** is determined according to the formula provided by Jiang, Claramunt et al. (2000).

$$V_i = \sum_{j=1}^{k} \frac{1}{C_j} \qquad (8)$$

Where ***k*** is the number of directly linked nodes of a considered node ***(i)*** and ***C_j*** is the connectivity of the ***jth*** directly linked node.

(d) Connectivity – measures the number of segments (in this case links or arcs) to which a specific segment is directly connected. Connectivity reflects both the number and nodality of joints along a route. Connectivity is defined as the number of nodes directly linked to each individual node in the connectivity graph (Jiang, Claramunt et al. 2000),

$$Ci = k. \qquad (9)$$

Where k represents the number of nodes directly linked.

The next concept is used to describe distance in space syntax theory. The concept is known as the step distance. Distance (step distance) – is the shortest number of steps to go from one segment (edge) to another. Space syntax parameters of depth and integration are explained below;

(e) Depth – The notion of depth can be defined as the number of steps from one segment to all other segments. The depth in space syntax explains linear distance from center point of each segment in a network to the center of all other segments. The depth of a transport network is the number of segments connected to a particular segment after each increasing step. It measures how distant a segment (or edge) is from a particular datum measured in number of steps of adjacency. It can also be said that it measures the compactness of a graph.

The more steps distant a segment is from the datum the 'deeper' it is, the fewer steps distant the 'shallower'. The convention is that the datum line has a depth of 1 and links connecting directly to the datum will have a depth of 2 and so on. From the computations, links with the lowest depth distance values are said to be nearest to all the other streets.

Higher values = deeper
Lower values = shallower

$$\sum_{s=1}^{m} s \times N_s \begin{Bmatrix} connectivity & iff & s=1 \\ local \quad depth & iff & s=3 \\ global \quad depth & iff & s=m \end{Bmatrix} \tag{10}$$

s is the shortest distance (steps) from a given segment (edge) to another.

From this general depth notion, other measures of depth can be measured. Mean depth is the number of steps required to reach a line from all other lines in the network; the higher the mean depth, the less the movement in the network.

(f) Integration – is the degree of integration of a line with other lines. Integration of a line is by definition expressed by a value that indicates the degree to which a line is integrated or segregated from the whole network (global integration) or from few steps away (local integration). Jian, Claramunt et al. (2000) mention that integration is one way to calculate accessibility of an urban pattern. Integration can be measured with either Relative Assymmetry (RA) or Real Relative Assymetry (RRA). The integration value represents the accessibility and penetrability of a given line (in this case a segment).

$$RA_{i=}\frac{2(MDi-1)}{n-2} \tag{11}$$

$$RRA_{i} = \frac{RAi}{Dn} \tag{12}$$

The Dn value is represented by the formula below;

$$D_n = \frac{n log_2^{((n+2)/3)-1} + 1}{(n-1)(n-2)} \quad (13)$$

The Dn-value is intended to provide the standardized value for the integration parameter.[1]

Integration measure says something about how many steps one has to make from a segment to reach all other segments in the network, using shortest paths. Segments that require fewer amounts of turns to reach all other segments are called the most integrated and thus have a higher integration value.

Global integration gives the measure of how integrated a particular segment is from all other segments in the network while local integration is the same as above but for a smaller space of three steps (s = 3). This integration measure uses the step distance method as discussed above. Higher values of both the global and the local integration mean that the segment is better integrated into the network. Theoretically, integration values show the complexity of reaching a segment.

In this research the concept of integration will be applied to analyse accessibility and connectivity patterns of the existing and proposed transport network structure of the city of Istanbul.

2.7. Concept of space syntax measures/ indicators

Many transport networks in cities do not result from the planning process, they emerge or evolve through aggregation rules (Buhl, Gautrais et al. 2006). This is mostly due to the reversal of the 'normal' planning sequence of acquiring the land, servicing, building and occupying. The reverse is true in most developing countries, where the inhabitants occupy, build, then infrastructure is provided and then the whole area is planned. The network which emerges is as a result of local decisions. The resulting topology of such a chaotic system is that it is complex and has many dynamics.

In the study of topological within a city, two different approaches are considered; exploring dynamic patterns or exploring topological organization of transport networks. The dynamic pattern approach analyses how traffic is optimally distributed. In carrying out these kinds of analysis, large detours are avoided and also reduction in cost is an objective.

2.8. Methodological framework

Based on literature review on the various network based indicators discussed, a framework for prioritising new connections in a network was developed (figure 2-2). The procedure for analysis will be performed as described in section 1.9. The ultimate aim is to prioritise which option is best with the

[1] Further explanation of the concept of integration can be found in,

Kruger, M. J. T. (1989). On node and axial grid maps: distance measures and related topics. Paper presented at European Conference on the Representation and Management of Urban Change, Cambridge, 28-29 September 1999. Cambridge.

Jiang, B., C. Claramunt, et al. (2000). "An integration of space syntax into GIS for modelling urban spaces." International Journal of Applied Earth Observations and Geoinformation **2**(3-4): 161-171.

criteria considered. The first phase of the analysis concerns identifying which options of network improvement should be evaluated. An explanation of the network improvement options selected and reasons for selection are provided in section 5.3.

Graph theory indicators (alpha, gamma, beta, and space syntax measures) and traffic performance indicators (volume-to-capacity ratio, system-wide travel time and unused capacity in network) were explored measured at various degrees of aggregation. The results are discussed later in chapter 6. An assessment is made of the score of the various options and a decision made on the better option. Framework for deciding on the best option is provided in figure below. The output results of network improvement options developed will be evaluated and if there is no dominant alternative then a multi-criteria evaluation (MCE) will be performed based on equal weighting of all the indicators.

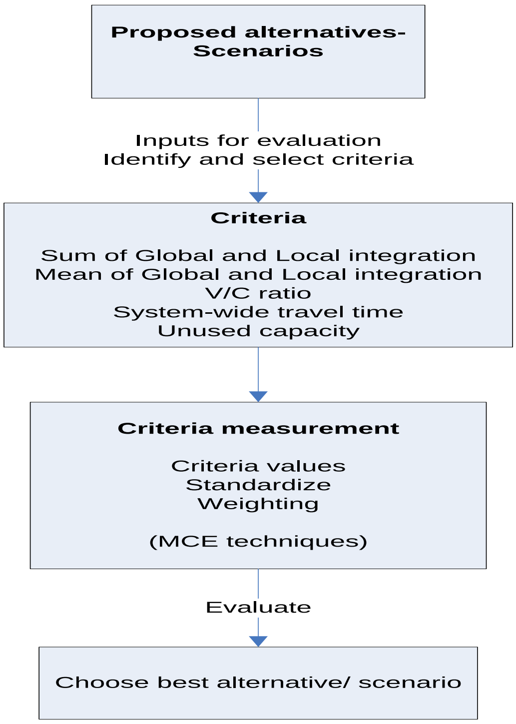


Figure 2-2: Framework for prioritising proposed transport options

2.9. Summary

This chapter discussed transport network representations as graphs. An attempt was made to categorise various network indicators. Various network indicators and how they are computed are also discussed. Based on the review of literature a framework is developed in the end for assessment of the various network improvement options.

3. Methodology and data collection

This chapter describes the method and data requirements used in the research work. The first part of the chapter outlines the data sets used in the work and their source. Activities performed during and after fieldwork are discussed in this chapter; which includes interviews, pre-processing of data and data limitations.

3.1. Research methodology

The research methodology employed in this thesis outlines the steps used to answer research questions as described in section 1.2. A key data source used for the entire study is the transport network layer for the whole city (which was comprised of road, rail and pedestrian walkways). The research relied mainly on secondary data sources, however some data was derived from primary sources, key among them was through unstructured interviews.

3.2. Field work data collection: Approach and method

The data collection process involved the collection of secondary data. A list of secondary data sources is provided in the table 3.1 below.

Some of them are digital sources, where as others were hard copies. Three proposed transport highway links was digitized. Most of the data set used in this work is from the Istanbul Greater Municipality – Metropolitan Planning and Urban Design Center (IMP).

Data	Format	Source
Existing transport network 2006 (highways, highway junctions, arterials, rail, pedestrian walkways)	Shape file	IMP
Proposed transport network (rail and highways)	Shape file and paper map (highways)	IMP
Traffic Analysis Zones (2007) with socio economic attributes (population, number of students, household size, household income, personal income, number of employed in each zone)	Shape file	IMP
Metropolitan and district boundaries	Shape file	IMP
Transport Master Plan Report 2007 (JICA report)	Report	IMP
Callibration report 2006	Report	IMP
Land use map 2008	Report	IMP
Land use master plan 2008	Report	IMP

Table 3-1: Data list

The Transport Master Plan Report 2007 (JICA report) was particularly helpful as it gives a comprehensive study on the current transportation trends in Istanbul. It also outlines the results of the household survey used for the transport planning and also the models used for the 4-step transport modelling.

3.2.1. Primary data

I interviews conducted with key stakeholders and officials from the municipality, consultants and educational institutions working on transportation planning issues in Istanbul. They were selected using the snow-ball sampling technique. They included Prof Dr. Haluk Gercek and Dr Hande Demirel, Faculty of Civil Engineering ITU; Gulay Cerik, Senior Planner – IMP; Ihsan H. Karadeniz, Deputy Director Transport Department IMP; Serap S. Cetinkaya and Orhan Aktas, Transport Department IMP; Dr. Darcin Akin, City and regional planning department GIT; Ismail Adar and Batuhan Y. Altun, Trafik Kontrol Merkerzi (Traffic Control Center - TCC); Orhan Demir, Consultant.

Discussions centred on the transportation dynamics of Istanbul and network performance measures and how they are measured in the city. A series of meetings were organised and the aim was to discuss the transportation development of the city. I also interviewed stakeholders from the IMP, ITU, Traffic Control Center and also private transportation consultants. Also I also gained some insights into the traffic congestion problems of the city and how the municipality is trying to remedy the situation. Issues discussed include the following;
- traffic congestion problems,
- effects and
- possible remedies to the problem, and these are further elaborated in later parts of the research. The reason for these discussions was to move away from just collecting data for analysis, and really understanding the issue of congestion and how to mitigate the problem in the Istanbul context.

Discussions with some stake holders during field work (Istanbul, September 2009)

3.2.2. Study area analysis

The extent of analysis was at different levels of aggregation especially for the graph indicators.

- The whole metropolitan city scale,
- Old municipal boundaries of the city,
- the next was at the TAZ level (with 451 zones) of the city and
- 1*1km grid cell of the urban area of the city. The urban area of the city was digitized along the Bosphorus and Marmara Sea

An analysis of the network indicators at various levels of aggregation was performed. A more elaborate discussion of the process and analysis is presented in chapter 6.

3.3. Data processing

The primary and secondary data were prepared for analysis. A general procedure is given in this section; however a more detailed procedure as to what was done at each stage is given in chapter 6.

3.3.1. Primary dataset

The information realised from interviews with key stakeholders were more of documentary evidence of the transport situation in Istanbul. Some were reports of ongoing research work, maps and power-point presentations.

3.3.2. Secondary dataset

Reports, maps and power-point presentations were used for references. A personal geo-database was created out of all the individual transport layers received from the IMP. Also land cover shape file, TAZ shape file and other socio economic attributes were added to relevant layers. It should be noted that although these data sets were in a database, it was received as shape files.

Below was the process involved in the preparation of the transport network layer. The layer had the following attributes; type of segment (whether existing or proposed – highway, highway junctions, arterials, rail), direction, and shape length.

a. The format for the transport network layer (existing road, existing rail and proposed rail) was a shape file in ArcGIS format. The transport network layer was 'cleaned' to ensure that topology was maintained. More so some portions of the transport network layer (vector) was 'edited' to avoid double counting of segments etc. Some segments were digitised twice and as such had to be cleaned.
b. Then the sea transport network was removed as this was not used in the analysis.
c. Applying network analysis techniques in GIS, the number of segments and nodes in each of the networks was determined.
d. Relevant indicators (that is network density, alpha, gamma and beta indices) were then measured at various levels of aggregation and disaggregation. Output from measured indicators were analysed, first considering existing transport infrastructure then doing same for existing and proposed infrastructure.
e. Discuss results with the aim of using it to prioritise the location for new transport infrastructure.

3.4. Data quality

The transport network data came in shape file format of ArcGIS. Some portions of segments had to be extended or reduced to ensure topology. The most current transport network data available was for 2006, which was similar to the current situation. The TAZ layer used was the one used by the JICA team for the study on the Istanbul Master plan of 2008. The layer had all the socio economic attributes used for the 4-step transport modelling of the traffic analysis for 2006 and 2023.

3.5. Data limitation

There were some unconnected segments in the transport network. Digitising of the segments was done in such a way that there were a number of very short segments, which made computations quite difficult and not realistic. As a result these were not used in the graph theoretic analysis as it was difficult and not possible to use such in the indices measured.

3.6. Network indicators and geographical scale of analysis

The indicators explained above can be implemented on various scales of analysis, like at national, regional and city levels. Specifically some of the analysis was done at the city or metropolitan scale. However that approach is too aggregated and the result does not really show city dynamics. There was therefore the need to disaggregate the indicators, but then the issue of scale comes to play. There is always the question of which scale to analyse transport networks to be able to understand the dynamics. The first attempt was to analyse indicators at the traffic analysis zone (TAZ) scale. Another attempt was to use a 1km by 1km grid cell to analyse the alpha, gamma and beta indices of the transport network of the urban areas of the city of Istanbul. One interesting aspect of the output from space syntax measure is that, each segment within the network at whatever scale it is being computed for gets a value. Unlike other indicators which more or less aggregates the value.

3.7. Summary

The main source of data used for the research was from the IMP. Transport network data collected include traffic analysis zones and socio-economic data. The key data set required for this research work was the transportation network of the city, with the following attributes, speeds, capacity (vehicles per day), length and travel time. These were relevant in computing graph theory measures and traffic performance indicators. The most recent data available was for 2006.

Secondary data was the main source of data used in this research. Interviews conducted during field work provided further insights to traffic dynamics in Istanbul and probable effects of a third bridge in terms of traffic performance.

4. Study area profile

This section describes the study area and gives some background information to its location, population, land cover/ land use, topography, and transport dynamics within the city. This information is an attempt to give the reader an idea of the dynamics within the city of Istanbul and how this relates to transportation issues raised.

4.1. Location

Istanbul is a cultural and economic crossroad between the Black Sea and the Mediterranean Sea and also between Europe and Asia. Istanbul's location also serves as a bridge between the trading centers of Europe and the Middle East. We could say that Istanbul is strategically placed between Europe, Africa and Asia, and this is sort of a central location in the world.

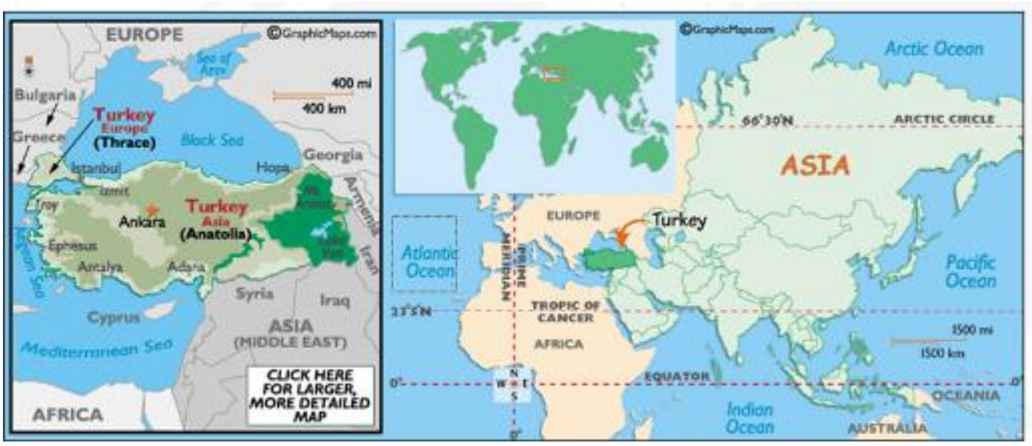


Figure 4-1: Location of Turkey and Istanbul in the world
Source- www.worldatlas.com

The diagram below shows its location schematically in a global context.

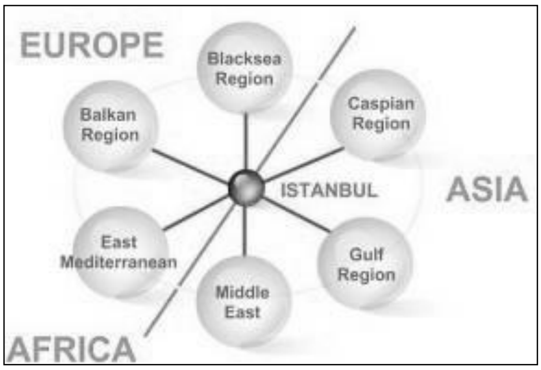


Figure 4-2: Schematic representation of Istanbul from a global context
Source: IMP

Istanbul, with its location as a bridge combining Europe and Asia, not only by means of geography, but also its culture has made the city more attractive besides its beautiful scenery and history. It is also the biggest and most important settlement for Turkey, since many essential national economic transactions start or end in there (Alpkokin and Hayashi 2003).

4.2. Population

Istanbul has grown from a city population of three (3) million in 1970 to about thirteen million people in 2009. It is however interesting to note that as some research work mention that there are severe population increases (Alpkokin and Hayashi 2003), the city's population trend has been in a steadily declining annual growth. The growth peak was in the 1970s and annual population growth rate has been declining ever since. The most possible reason for this decline is attributed to land use conversions from residential to commercial uses through urban redevelopment projects.
The table below shows the population growth of Istanbul from 1970 to 2005.

Year	Population	Annual Population Growth Rate (%)
1970	3,019,032	
1980	4,741,890	(70-80) 4.6
1990	7,195,773	(80-90) 4.3
2000	10,018,735	(90-00) 3.4
2005	11,606,341	(00-05) 3.0

Table 4-1: Population growth of Istanbul from 1970 to 2005
Source : (Istanbul Metropolitan Municipality and JICA 2008)
Istanbul's urban area was limited to coastal areas along the Marmara sea and the Bosphorus strait with small sea-port towns including the historical peninsula (Eminőnű), Zeytinburnu, Bakirkőy, Uskűda and Kadikőy. The smaller sea port towns merged to form a large urban area on both the European and the Asian side of the city to give it its current structure.

Studies conducted by the IMP conclude that the sustainable population of the city is sixteen (16) million inhabitants. That is looking at the city of Istanbul now; it can only cater for 16 million inhabitants. The question to be asked is what will happen in terms of traffic congestion if the city grows beyond its sustainable limits? The estimated population for 2023 is 22 million people.

4.3. Topography/ geography

As understood from the name of the city as the "City of 7 hills", the urban areas developed from hill to hill. Most of the settlements developed on lands below 100 meters. Settlements which are located on steeper hills are mostly squatter settlements along the industrial valleys. The eastern side of the city is relatively more hilly than the western portions side. Surface water (which is one of the prominent features of the city) runs through the Bosphorus strait, Golden Horn to other smaller rivers. The slope analysis of Istanbul shows the percentage of slope and area covered (table 4-2). About 50% of the city has a gentle slope and that is where most human settlements and urban areas have developed.

Slope area (%)	Area (km^2)	Area (%)
0 – 10	2,710	50.18
11 – 20	1,761	32.61
21 – 30	618	11.44
31 – 40	226	4.18
41 – 65	85	1.57
Total area	5,400	100

Table 4-2: Slope analysis of the city

Source: (Istanbul Metropolitan Municipality and JICA 2008)

4.4. Land use and dynamics

Land use in Istanbul is mostly characterized as ‘mixed land use’ containing different land uses like residential, commercial, office among others on the same street. The city is made up of compact development, due to unavailable land for further expansions. Most of the congested areas (that is areas around the central parts of the city – West of the historical peninsula, North of Golden horn and east of the Bosphorus strait) have reached saturation point with its high environmental and traffic congestion problems. However the periphery is represented by squatter settlements (geçekondu – overnight settlements). Two land cover maps are presented below (figures 4-3 and 4-4).

From figure 4-4 below, it is realized that the settled area of the city is about 24% of the total land area and about half of the city’s area (50%) represented by forest areas.

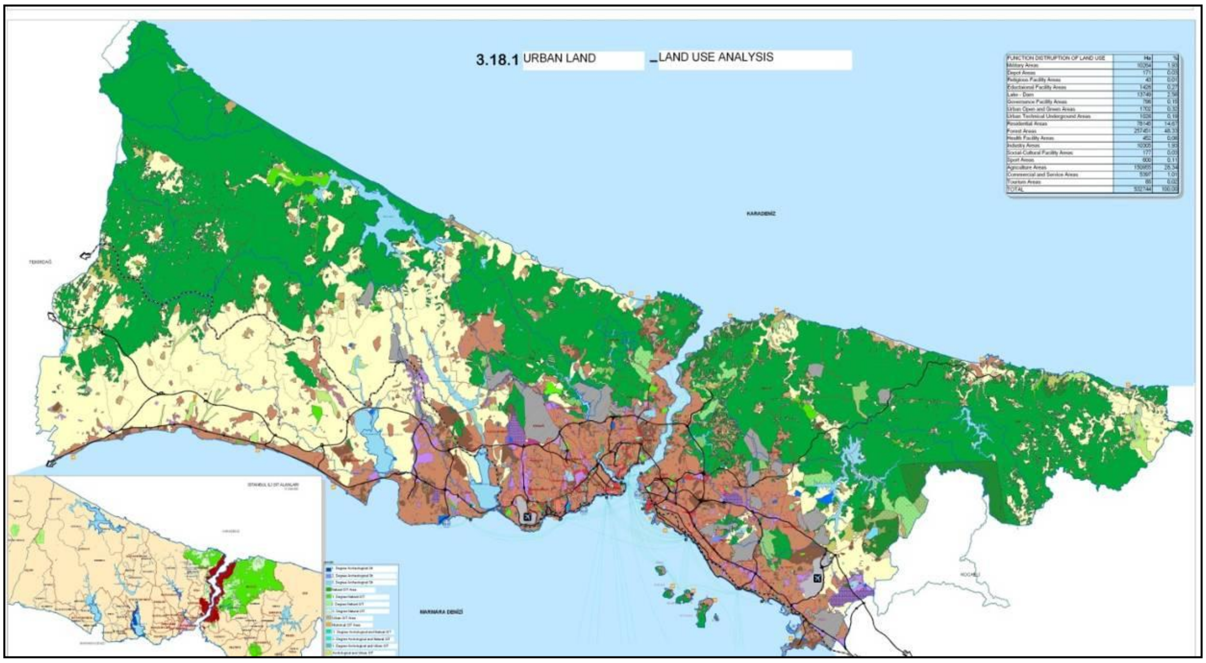
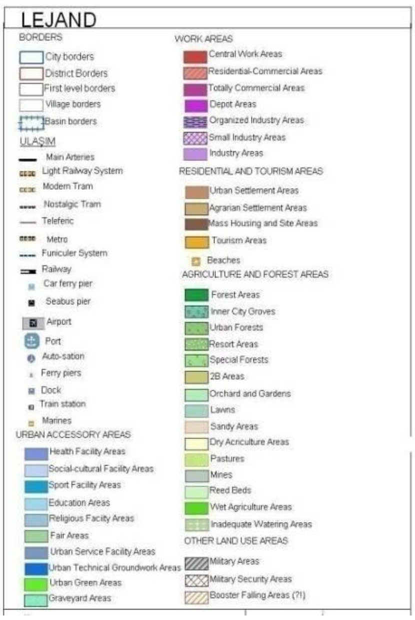


Figure 4-3: Istanbul land cover for 2006 (Source: IMP)



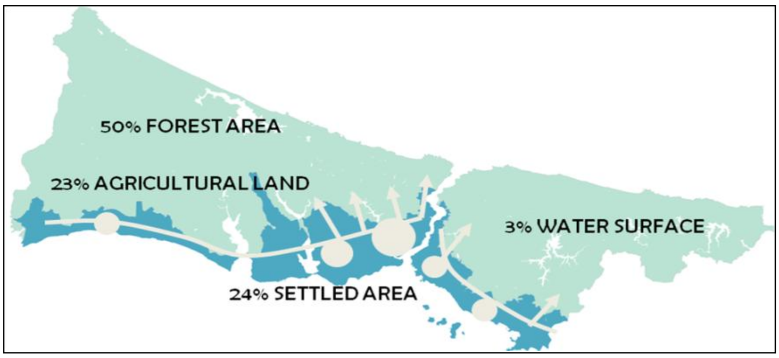


Figure 4-4: Istanbul general land cover, 2006 (Source: IMP)

Transport network infrastructure available and logistics

The existing transport network of Istanbul will be analysed in the following aspects. Firstly we talk about the existing road network, then the rail network and then lastly pedestrian walkways.

Existing road network

Turkey is seen as a transit corridor between South-East Europe and the Middle East. The existing road network adds to this important aspect. Turkey has developed international corridors as a result of the "The Declaration for the Construction of International Arteries (AGR)". Some of the international roads reaching Turkey from Europe pass through Istanbul to the Asian side. Among them are the following the E-80 entering from the Bulgarian boarder (Kapikule) and the E-90 entering from the Greek boarder (Ipsala). The Trans Europe Motorway (TEM) starts at Edirne (Bulgarian boarder), passes through Istanbul via the Fatih Sultan Mehmet Bridge and parts in two from Ankara.

Istanbul is situated at the most important connection point between South-East Europe and Asia, and at the same time is a connection point between the Black Sea and Marmara Sea which are at the entrance points from the Aegen and the Mediterranean Sea.

The road network of Istanbul has a ladder pattern which stretches in the east west direction due to the linear macro form of the urban areas. There are two ring roads around the 'old city center and the Central Business District (CBD)' which are designed as motorways (or expressways). These are the D100 which consists of the Bosphorus bridge and the Mevlana Topkapi street; and the TEM and the Airport Connection road. These two ring roads are 3 to 5 km apart. They were designed for high traffic capacity and have 6 to 8 lanes.

Figure 4-5 shows the hierarchy of roads in the study area. The organizations responsible for roads in study area are the Istanbul Metropolitan Municipality (IMM) and the Directorate General of Highways of the Ministry of Public works and Settlement (KGM). The former is responsible for all roads except for the TEM, highways and the 2 highway bridges which is the responsibility of the KGM.

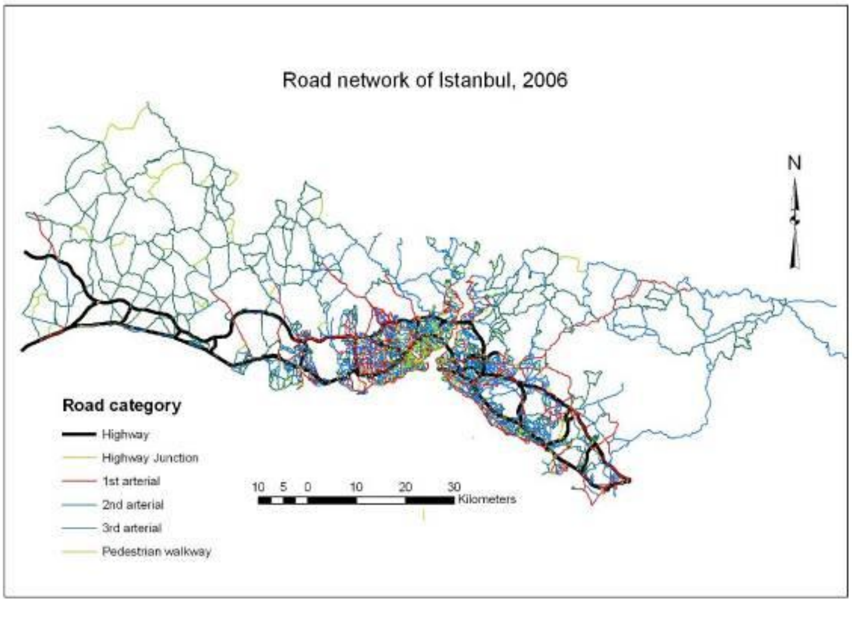


Figure 4-5: Road network of Istanbul, 2006
Source: IMP

4.5. Transport dynamics in Istanbul

With the current traffic congestion in the city, there are proposals for a third bridge across the Bosphorus. But the situation is that after the introduction of the first and second bridge, more people settled along the bridges further worsening the traffic situation. More people have settled along these areas illegally as a result of the improved access.

Istanbul has different modes of transport to offer to its commuting population, these are outlined below;

Vehicles
IETT buses
Ozel Halk Otobus
Service buses
Mini buses
Dolmuş
Private transportation (personal vehicles for individuals)

Rail options
Barliyő
Tram
Light rail
Metro (overland and underground)

Options for water transport
Ferry (cars)
Ships
Motors (small ships)
Dolmuş motors
Sea buses

All these modes of transportation were managed by different private and public institutions. Now there are plans to bring them together under one umbrella organization in order to bring about more integration among the various operators. Some of the organizations involved in transportation are the Turkish State Railways (TCDD), the Municipality, Istanbul Elektrik Tramvay ve Tünel (IETT – public transport), Private bus companies, Minibus operators, Taxis and the Dolmuş. The institution which brings all these individual operators under one skeleton is the iDO.

In terms of the settlement pattern the city has a linear macro form, with most of the settlements along the Marmara coast. The settlements are east west across a shoreline of about 150 kilometers

The Bosphorus strait has been an obstacle separating the two sides of the city from time immemorial. It is estimated that there are 1.4 people in each car that crosses the Bosphorus daily. This is due to high automobile dependency and this trend is increasing. Figure 4-6 below shows vehicle population from 1996 to 2006. It can be seen that after 2004 there is a steep increase by more than 500,000 vehicles and the trend is increasing. Most people prefer using their private cars than using public transport, thereby culminating in worsening the traffic congestion problems in the city. This trend is not sustainable and there is the need to minimize crossings along the existing bridges.

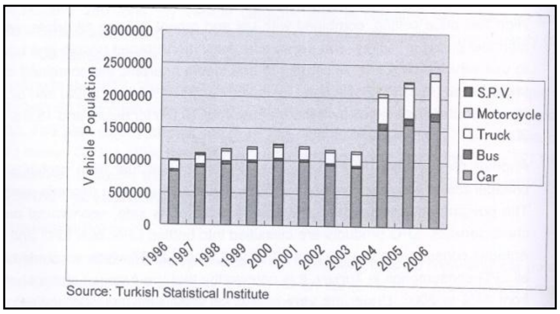


Figure 4-6: Vehicle population in Istanbul, 1996 to 2006

Some of the transportation problems in Istanbul include;
Intersection of the various transport modes is not developed, and as fails to be integrated. The railway existing rail network has high capacity, but the modal share is only 4%.

The current population of Istanbul stands at about 12.6 million inhabitants; this makes it one of the densely populated cities in the world and also very crowded with respect to the land area. The projected population for 2023 is estimated at 23 million. The major driver of Istanbul's economic growth is its industry. The industrial sector is the largest sector in the city's economy. And this is what increases the population of Istanbul apparently. An industry worker brings three (3) more people into the city to settle, swelling the population.

To avert the growing population numbers which results in traffic congestion in the city and carbon emissions, the municipality has plans to develop Istanbul as a Service Metropolis in future. This in the view of the municipality will reduce the growing population numbers. This does not mean that there will not be industries in future. There are already planned industrial areas which are not saturated yet and this will be used for industry if the need be. But most importantly for now the city will be focused on encouraging more of a service sector growth.

This is however not the only intervention of the municipality in curtailing the traffic congestion problems in Istanbul. To 'save' Istanbul in terms of traffic congestion, the way forward includes mass public transport, sea transport and rail transport. Some of the measures include the improvement in existing capacity of transport networks, increasing the infrastructure base and the creation of 2 other Central Business Districts (CBDs), at both the European and the Asian parts of the city. The proposed locations are in Silivri and Kartal respectively. This will change Istanbul's current metropolitan form, from a mono-centric metropolis to a polycentric one. This is to ensure that equal opportunities exist on the two parts of the city so that people do not need to cross the Bosphorus daily for activities. This also means that the Anatolian side should be self dependent and not rely too much on the European side for existence. There are also plans for a new port in the Pankik area to improve sea transportation.

With respect to transport network improvements and new projects, there is the Marmaray project (underground rail project – ongoing), a proposed third bridge across the Bosphorus, extension of the rail network, tram and other road projects. There are also plans to improve sea transport as this also has a potential to improve traffic performance in the city. The third bridge will only solve the problem only in the short term, after that the problem of congestion comes back. Studies on the bridges show that after the building of the second bridge, about 8 million people (Gulay C., 2009 Qualitative interview) settled along the area. The third bridge which is being proposed is not for intra city traffic but for inter-city traffic as it will be a highway for Turkey's European and Asian neighbours. This project is also proposed to link with other international road networks including the Trans European Motorway (TEM). There are many options being considered for the location of this third bridge, but the choice will depend on what the decision makers decide on. The municipality mentions that it will ensure that the introduction of the third bridge will not encourage settlement along bridge location and also will avoid fragmenting forests, agricultural areas and water basins.

There is no 'available land' to contain the growing population. The areas available cannot be developed as they are in environmental sensitive areas (ie the forest areas towards the north of the city, water basins and water catchment areas). Currently some industries are located in water basins and for the sustainable growth of the city this trend of development needs to be prevented. Also there are ecological corridors along the Black Sea coast and according to the Municipal planning authorities these areas need to be safeguard from being encroached by settlements.

4.6. Transport network integration

For now in terms of physical integration of the various transport networks, there is still some works to be done. There however has been the introduction of the 'Akhbil' and the Istanbul transportation card, which is an electronic payment system which uses a chip. It can be used for payment (when loaded with money) on all modes of transport. This is an attempt to integrate the various transport systems, so that with that one chip one can pay for all transport trips. This appears to be a good solution for Istanbul with its 17 different modes of transport. As each of the operators of transport has their own payment system and there is the need to merge all the payment forms under a single organization. This is a step in the right direction.

In terms of physical integration, there are proposals for park and ride facilities across the city (Istanbul Metropolitan Municipality and JICA 2008), and this is to encourage the use of public transport (like the use of the metro and ferry).

4.7. Summary

This chapter discussed generally the physical nature of the city of Istanbul in terms of topography and its land use dynamics. It was realised that the city transportation network is constrained in terms of the geography; Istanbul sits on 7 hills. Istanbul has 17 different modes of transport, but still faces the problem of congestion. Private vehicle population has been increasing rapidly in the last few years and population has almost doubled in a decade. There is therefore the need to avert the problem to avoid worsening of the situation in the future. The road network hierarchy and transportation dynamics are also discussed. One of the conclusions is that with the introduction of the second bridge for the city population increased and also led to illegal housing settlements (*geçekondu*) around the bridge location.

The next chapter identifies some network improvement projects and network options selected for evaluation in further analysis of the research.

5. Current and future transport development in Istanbul

This chapter describes the setting for further analysis of the data. We specify which network segments are considered taking into account existing and proposed transport network infrastructure. The options available for the third bridge over the bosphorus are tabled out. More so an analysis is made of the current state of transport infrastructure development of the city in terms of computing network density in each traffic analysis zone (TAZ).

5.1. Transport network used

The transport network used in the analysis comprised of;

1. Highways;
2. Highway junctions;
3. 1st to 3rd arterial roads;
4. Existing and proposed rails and
5. Pedestrian walkways
6. Proposed railway and proposed highway bridge improvements

5.2. Proposed network improvements

In order to get a clear understanding of the kind of analysis that will be analysed from this point onwards; there was the need to clearly state which transport options are considered for the analysis.

Proposed road improvements
There are many new road improvements being considered in Istanbul among them are the following; Gebze – Orhangazi Highway Project; Kinali – Tekirdag – Malkara – Ipsala road project and Malkara – Canakkale highway project including Canakkale bridge. In this research work only the proposed highway bridges are considered (option 2 and 3).

The third bridge on the bosphorus has been one of the options for highway improvements to better link the two parts of the city. The option for a new bridge over the bosphorus has sparked lots of debate and discussion for some time now. Six options have been tabled and only one choice to make. A map showing the locations of proposed highway options are shown below (figure 5-1).

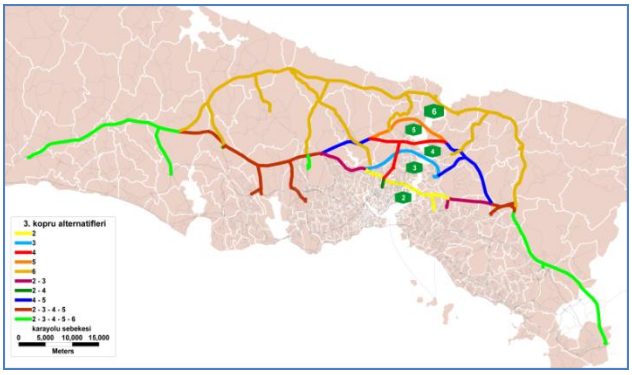


Figure 5-1: Location of proposed highway bridges options over the Bosphorus

In this research, options1, 2 and 3 are the only ones analysed. The reason is that these three options fall within the urban region, but the other options are in the forest areas, where there is probably no demand to warrant such transport investment.

Future rail developments

A maximum railway network is being considered for the city of Istanbul. This is the ideal and realistic network without consideration of schedule for completion. The various options under the maximum network were proposed taking into account priority and budget constraints. The railway projects of the maximum network are classified as follows; under construction projects; committed projects and planning stage projects.

Railway projects under construction as of October 2008 (table 5-1)

Code	**Project section**	**Type**	**Length (km)**	**Operation year**
C-1	Extension of Taksim – 4th Levent Metro (Taksim-Yenikapi)	Metro	5.2	2010
C-2	Topkapi – Erdirnekapi – Sultanciftligi	Tram	3.1	2008
C-3	Kardikoy – Kartal	Metro	21.7	2011-2013
C-4	Extension of Taksim – 4th Levent Metro	Metro	8.0	Mar 2009
C-5	Otogar – Bagcilar	Light metro	5.4	Dec 2008
C-6	Bagcila – Ikitelli – Olimpiyat Koyu metro	Metro	15.9	Dec 2008
C-7	Marmaray project	Surburban railway	76.5	Mar 2012
C-8	Aksaray – Yenikapi	Light metro	0.7	2010
	Total		136.5	

Table 5-1: Railway projects under construction, October 2008

The most prominent project among them is the Marmaray which is expected to be completed in 2012.

The location of the rail way projects under construction are given below (figure 5-2);

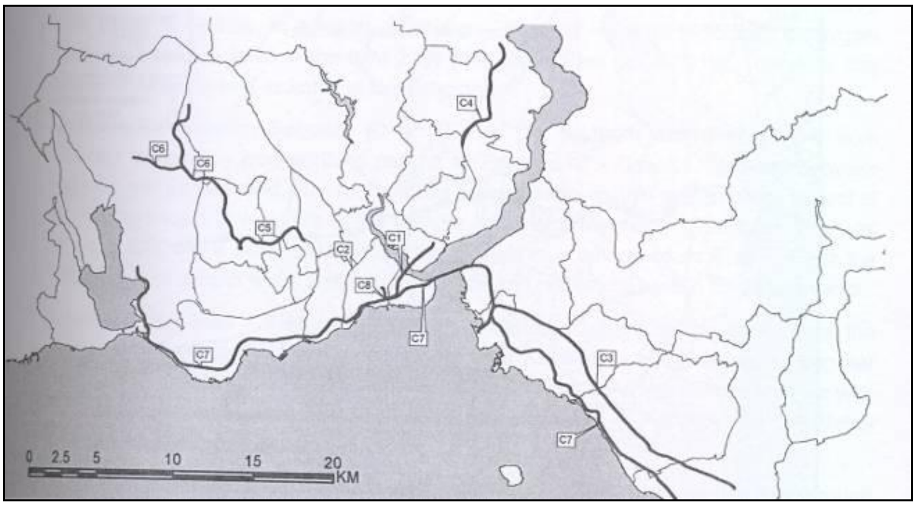


Figure 5-2: Location of under construction projects

Source: (Istanbul Metropolitan Municipality and JICA 2008)
A total of 44.6km of railway projects are at the tender stage and 74.4km under the design stage.

Committed projects consist of two tender stage projects and six design stage projects and are listed in the IMM 2008 investment plan. They are Uskudar-Cekmekoy light metro (19.0km); Bakirkoy-Beylikduzu light metro (25.0km); Bakirkoy-Bahcelievler-Bagcilar metro (7.0km); Kabatas-Besiktas-Sisli-Giymkent-Bagcilar metro (25.5km); Yenikapi-Bakirkoy metro (7.0km); Golden horn tramway (9.6km); Yesilkoy-Ataturk Airport-Ikitelli metro (14.3km) and Beyoglu monorail (10.0km).

In this research work all rail improvements are used in the analysis as almost all rail improvements are being implemented. The only ones not considered are rail improvements across the bosphorus strait. These were modified to suit the scenarios that are proposed by the municipality. For now it is only one bridge crossing over the bosphorus that is being considered. A map showing proposed rail improvements is shown below.

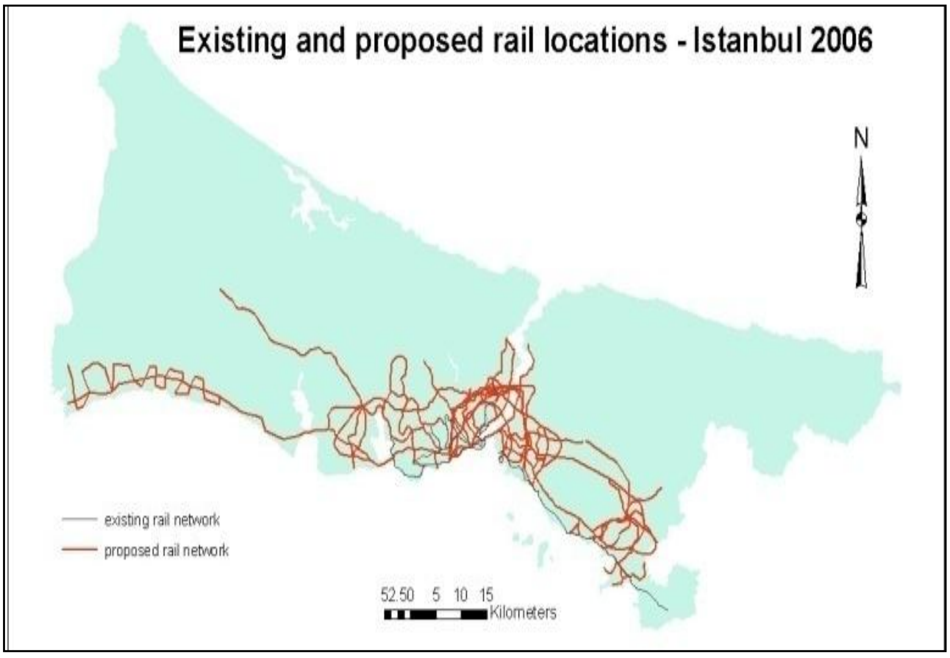


Figure 5-3: Existing and proposed railway locations – Istanbul 2006

5.3. Transport network scenarios developed for analysis

This research investigates the impact of existing transport situation and also proposed improvements. 4 scenarios were developed to analyse improvements or otherwise of transport investments. Figure 5-4 shows the location of all the options used for analysis in this research. From the map, 1 (in grey) represents the existing network; 2 (in red) show the Marmaray crossing; 3 (in yellow) show the highway option in-between existing bridges and; 4 (in blue) show highway option north of the second bridge.

a. **Option1a** – Existing situation (1)
   The first scenario analyses the business-as-usual scenario with no network improvement options
b. **Option1b** – Existing transport network + Marmaray crossing (1,2)
   This scenario considers a tunnel under the Bosphorus to link the two parts of the city from the historic center to the Anatolian side. This tunnel is already under construction but plagued with delays, especially after discovery of important archaeological sites on the European side.
c. **Option2a** – Option1b + highway bridge in-between existing bridges (1,2,3)
   This scenario considers a bridge in between the two existing bridges and the Marmaray crossing. The reason is to build a new third bridge where there will be the demand and also away from the historical center. The reason is to ease congestion on the two existing bridges and also increase accessibility across the two parts of the city.
d. **Option3a** – Option1b + highway bridge north of second highway bridge (1,2,4)
   This scenario considers a highway bridge to be built north of the existing ones and far away from Istanbul’s historical center. The proposed location is between Tarabya and Beykoz. The reason for this location is to move traffic towards the north of the city. Inclusive in this scenario will be the Marmaray crossing.

The Marmaray crossing and proposed third bridge locations analysed in this research extends across the Bosphorus only. These are digitised by the author because the exact locations of other connectors within the network were not available. Istanbul is now in the cradle of development or urban railway network and has started extensive construction works (Istanbul Metropolitan Municipality and JICA 2008). Some of the proposed connections are already under construction; top among them is the Marmaray crossing. It should also be noted that some critics are against the construction of a third bridge in Istanbul citing instances of sprawl (unplanned settlements) being an issue to contend with. The argument is that traffic management in the metropolis have to change, otherwise Istanbul will require more additional bridges.

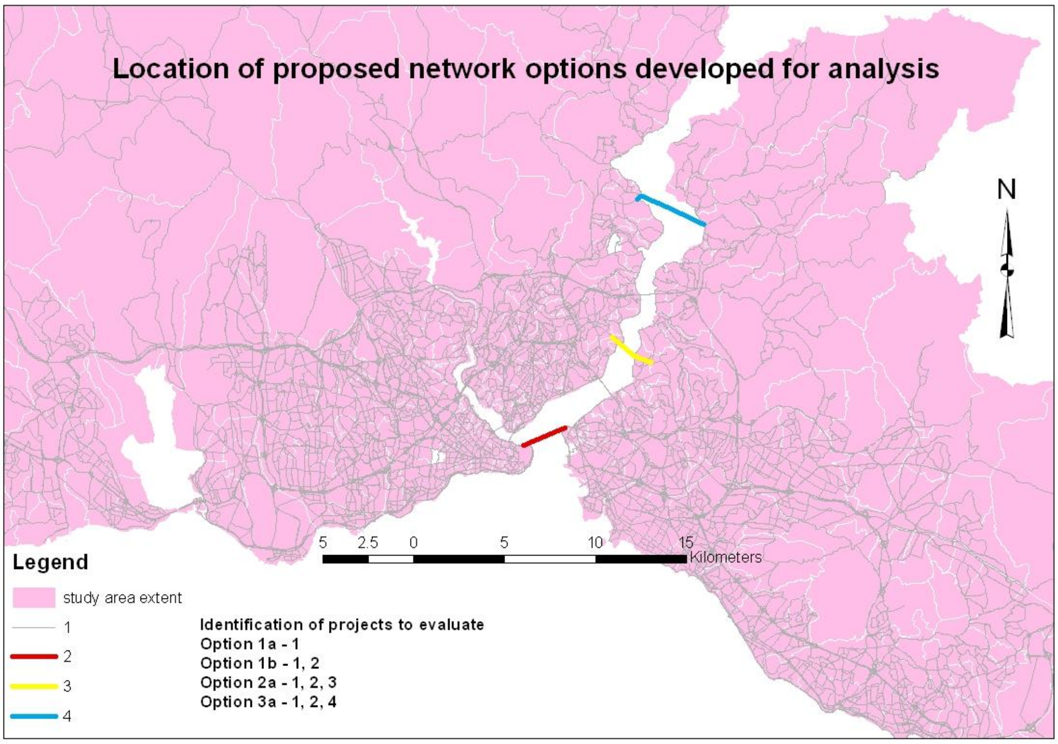


Figure 5-4: Location of proposed network options developed for analysis

In the next section we explore the network density of the city at the TAZ scale for the existing situation.

5.4. Existing network density in each Traffic Analysis Zone (TAZ)

This indicator measures how many kilometers of road per square kilometer (km/km^2) in each TAZ (figure 5-4) for the existing transport network of the city. The indicator tells something of the level of network development as explained in section 2.5.2 equation (2). The network that was used in calculating this indicator was the existing network, which comprises of all existing highways, highway junctions, arterials, railway and pedestrian walkways. It is interesting to note that the central areas show more transport network development than all the other areas. The 2 most developed portions of the region are in the Beyoglu district the others are mostly around the old city center; Fatih and Eminonu.

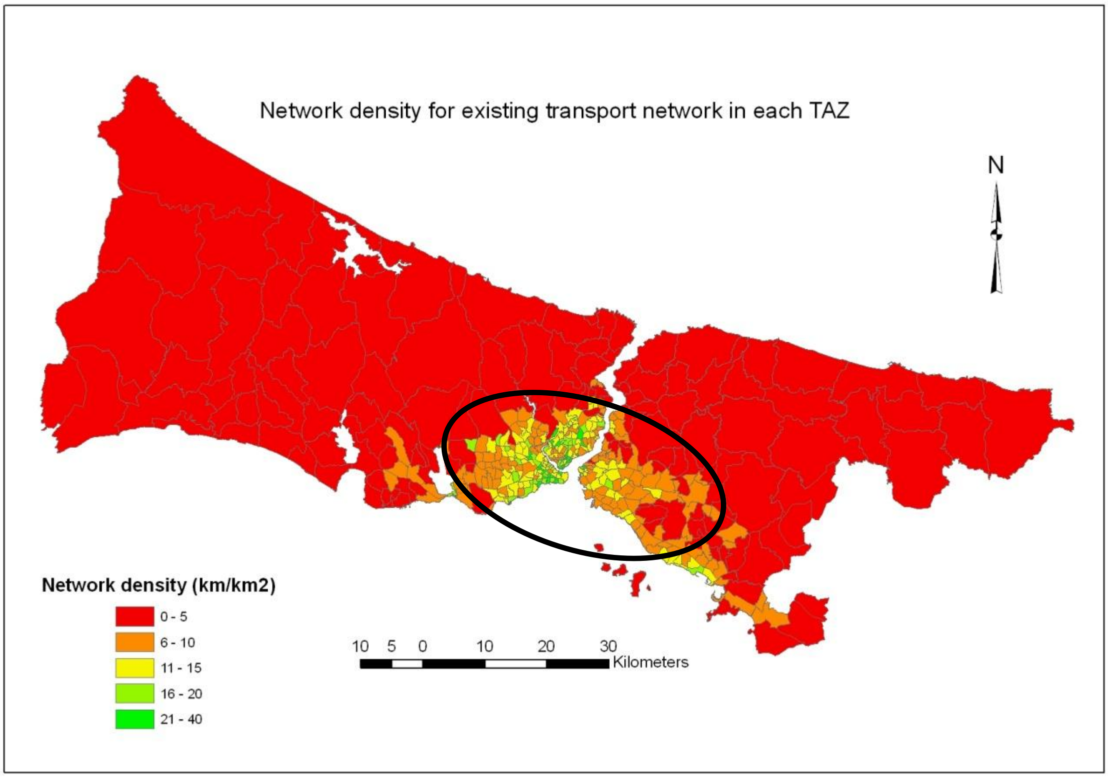


Figure 5-5: Network density for existing transport network in each TAZ, 2006

The map below (figure 5-6) shows the expanded part in the oval in figure 5-5. The mean size of TAZ is about 12km^2. From the frequency distribution histogram, it is realized that the bars are skewed to the left with a mean density of about 9km/km^2 .It can also be realized that only a few of the TAZs have a density above 15km/km^2.

The map shows that the most developed parts of the network are located in the south- central portions (shown in black circle in figure 5-5) of the city. This area consists of the residential areas in Istanbul and most probable areas for high congestion as should be expected. The portions in red are mostly the forest areas with densities below 5km/km^2 as expected.

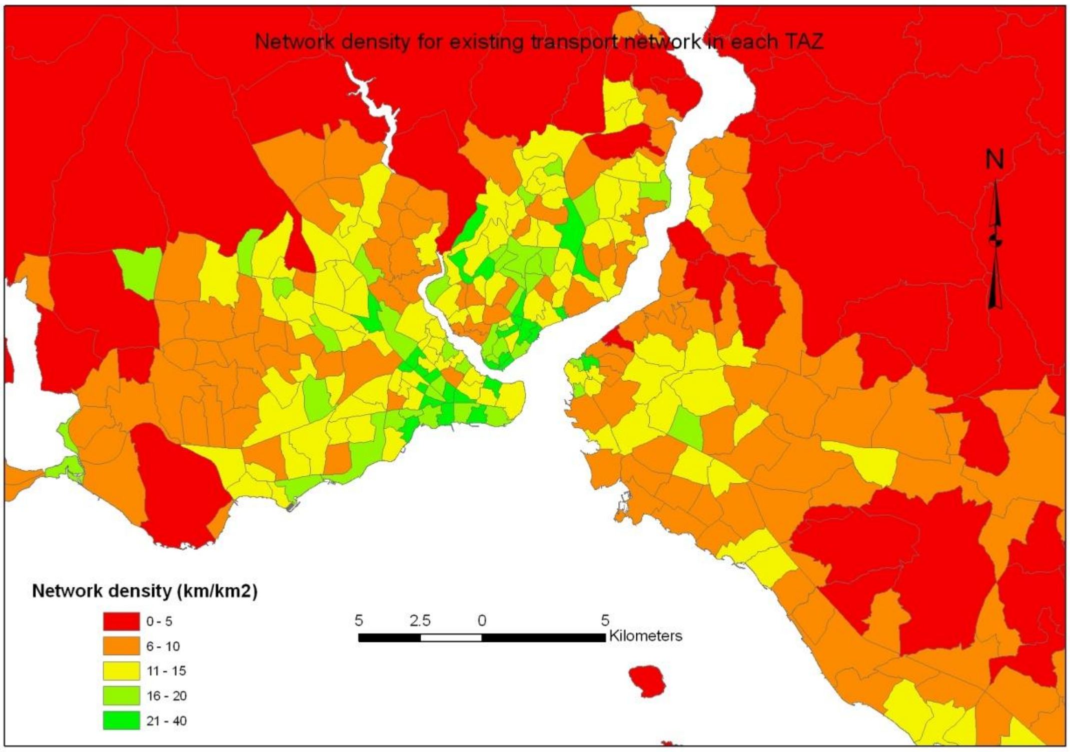


Figure 5-6: Network density for existing transport network in each TAZ, 2006 – Central portion of city

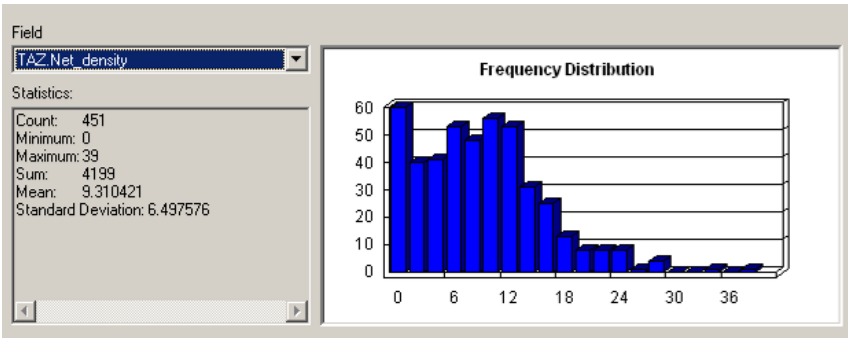


Figure 5-7: Network density histogram for existing transport network

5.5. Summary

In this chapter we discussed various network improvement options that the IMM is undertaking or proposing to. We specified the network options that were selected for evaluation and reasons for their selection. At the end of the chapter we compute network density at the TAZ scale. Higher network density as we mention are found in the south central portions of the city which are expected to be congestion prone.

The next chapter discusses a number of network based indicators used for analysing network structure of the city. We consider graph measures of the alpha, gamma, beta and space syntax measures; and also traditional transport network indicators such as the volume-to-capacity (v/c) ratios. These indicators are measured at various scales for the city.

6. Network Based Indicators (NBI) analysis

This chapter discusses the various network based indicators as applied in this research. We start with measuring the graph indicators (of the alpha, gamma and beta) at various network scales. Each level is discussed to assess its relevance or otherwise. The next part discusses the parameters of space syntax at both local and global scale. In the last sections of this chapter traffic performance indicators (system-wide travel time, volume-to-capacity ratio, unused capacity of the network) are computed for the old municipal boundaries of the city for the network analysis scenarios developed in section 5.3.

6.1. Alpha, Gamma and Beta indices

The alpha, gamma and beta indices were calculated for the city at 4 different scales. These are;

- The Istanbul metropolitan city scale,
- Traffic analysis zone (TAZ) scale, comprising 451 zones,
- Settled areas or urban scale of the city and
- Central portions of the city

The reason for these different scales was to find if there will be differences in terms of performance of the indicator at different scales to inform decision making. For the various computations we considered the effects of introducing new connections within the network and whether differences can be easily observed.

We now do a recap of what the indices stand for as previously discussed in sections 2.6.6 to 2.6.8. The alpha index uses the concept of circuity and is defined as the ratio of fundamental circuits which may exist in a network. The index measures the redundancy or duplication within the network. The gamma index measures the ratio of actual number of edges in a network to the maximum number of edges which may exist. Gamma index is normally expressed as a percentage of connectivity. And lastly beta index measures the completeness of a graph, with simple networks having beta values below 1 and complex networks with values greater than 1.

To generate the alpha, gamma and beta indices, there was the need to estimate the number of segments (e) and nodes (v). The researcher used the network dataset analyst in ArcGIS© to generate the nodes for each of the segments and used it for the computations. The first thing done was to analyse the existing situation and network improvement options and then analyse the trend.

6.2. Alpha, Gamma and Beta indices at the Istanbul metropolitan (city) scale

The table below (table 6-1) shows the alpha, gamma and beta indices for the transport network at the metropolitan (city) scale for different network combinations. This was done with the view that an additional link(s) in the network should improve the index. The strategy was to analyse the existing situation and then compare it with network improvement proposals by the Istanbul Metropolitan Municipality (IMM).

Network	e	v	$\alpha = \frac{e - v + 1}{(2v - 5)}$	$\gamma = \frac{e}{3(v - 2)}$	$\beta = \frac{e}{v}$
1	15333	10276	0.2461	0.4975	1.4921
2	15442	10387	0.2434	0.4957	1.4867
3	16848	10961	0.2686	0.5125	1.5371
4	16115	10876	0.2408	0.4939	1.4814
5	17524	11171	0.2847	0.5232	1.5691

Table 6-1: Alpha, gamma and beta indices for transport network (both existing and proposed)

The results shown above represent the following levels of aggregation of the networks. The networks are defined below;
Network 1 – 1^{st} 2^{nd} 3^{rd} Arterial roads, Junctions and Highways
Network 2 – 1^{st} 2^{nd} 3^{rd} Arterial roads, Junctions, Highways and existing Railway connection
Network 3 – 1^{st} 2^{nd} 3^{rd} Arterial roads, Junctions, Highways, existing Railway connection and Pedestrian walkways
Network 4 – 1^{st} 2^{nd} 3^{rd} Arterial roads, Junctions, Highways, existing Railway connection and proposed railway connection
Network 5 – 1^{st} 2^{nd} 3^{rd} Arterial roads, Junctions, Highways, Pedestran walkways, existing Railway connection and proposed railway connection

Generally, with the addition of new segments, representing improvement in the network the indicators should improve. Save for network 2 and 4 which shows a decline in all the indicators even when 'improvements' take place. The possible reason for the bad performance and not following the normal trend might be as a result of not including the existing pedestrian walkways in the analysis.

For network 2 it is quite interesting to see that by addition of existing railway to existing road network, the indices reduces from the values from network 1. Alpha index reduces from 0.2461 to 0.2434, gamma index reduces from 0.4975 to 0.4957 and the beta index also reduces from 1.4921 to 1.4867. The existing railway connection in the city is not extensive (and does not also form a network), and the results suggest that existing rail network does not add to improve the existing connectivity levels within the city of Istanbul. In terms of the meaning of the indicators, the reduction in alpha value shows that there is no redundancy as a result of improvement. Gamma index, which measures the percentage of connectivity of the network, did not change much, as difference is negligible (0.002). The beta index at the various scales of aggregation still shows a complex network.

For network 4, pedestrian walkways were not used in the computations; the reason for this was to see if pedestrian walkway played a key role in improving connectivity for the whole network. It proved to be important in as it links many locations that are not accessed by roads or rails.

6.3. Alpha, Gamma and Beta indices at the traffic analysis zone (TAZ) scale – existing transportation situation

In the next stage of analysis, an attempt is made to disaggregate the alpha, beta and gamma indices to a smaller extent other than for the entire network at the city scale as seen in the previous section. For that reason the Traffic Analysis Zone (TAZ) was chosen to measure the alpha, gamma and beta indices. The reason for disaggregating to the TAZ level was because it represents a smaller area with similar socio-economic attributes and relative homogeneity. This analysis zone was the same used for the transportation master plan of Istanbul in 2007. It has 451 zones and is an addition to previous transportation master plan studies in 1997 which had 250 zones. The maps that follow (figures 6-1, 6-3 and 6-5) were arrived at after calculating the indices in each zone.

Generating alpha, gamma and beta indices at the Traffic Analysis Zone (TAZ) level
First an intersection of the TAZ layer with the existing transport connection in Istanbul was performed. The existing transport network connections used included all three levels of arterial roads, highway junctions, highways and pedestrian walkways; same as network 3 as described earlier. The resulting layer was aggregated using the unique ID of the TAZ to summarize how many segments fall within each TAZ. This output was stored as a table in dbf format and later joined to the TAZ table using the arcMap join feature.

The network dataset operation was used to generate number of nodes in each TAZ. It should however be realized that using the intersect feature in ArcMap creates additional segments because some segments which extend to two or more TAZs are split at the borders. This also creates extra nodes at the borders, especially for the segments which extend to say two other TAZs, it automatically creates two nodes on the border one for each adjoining border.

After computing the counts for the number of segments and nodes in each TAZ, the formula for generating the alpha, gamma and beta indices was used to compute the indicator within each TAZ. The resulting maps are shown below first for the existing situation (figure 6-1, 6-3 and 6-5) and then for the improvements in the network.

6.3.1. Alpha index

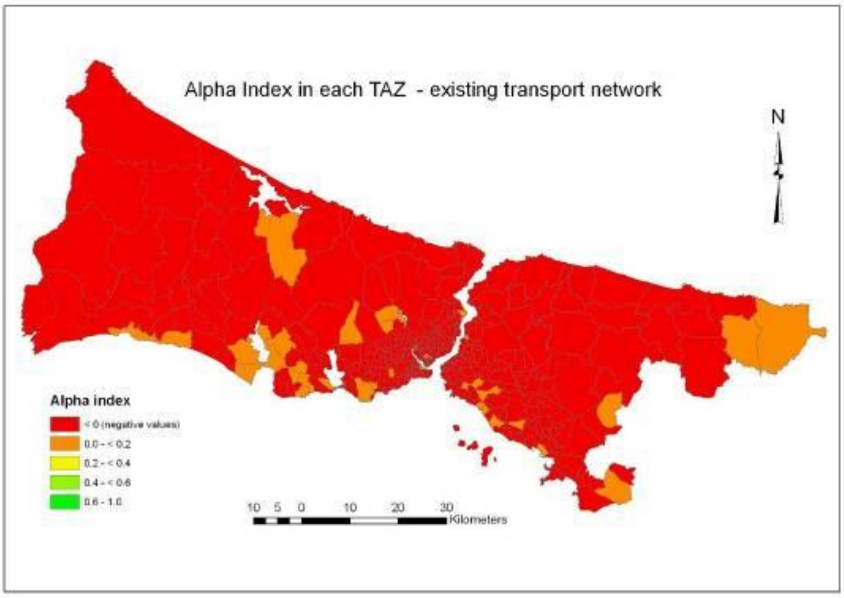


Figure 6-1: Alpha index in each TAZ – existing transport network

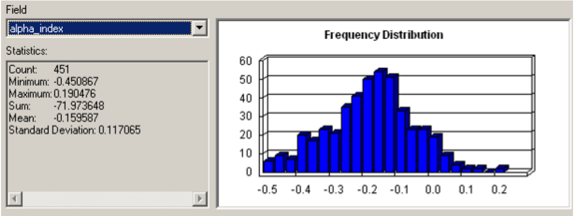


Figure 6-2: Frequency distribution – alpha index existing network

The alpha index (α) for connectivity is the ratio of the number of fundamental circuits to the maximum possible number of circuits which may exist in a network. This index is a measure of the redundancy or duplication in the system.

The alpha index values range from 0 to 1. The higher the alpha index the greater the degree of connectivity. Simple networks will have nil values. An alpha value of 1 indicates a highly integrated network in which every possible link exists between the various nodes. But in some instances the alpha index value can be negative and this is due to poor connectivity of transport networks in the study area.

It can be realized from the frequency distribution (figure 6-2) that it assumes a normal distribution with values ranging from – 0.45 to 0.19. 90% of the values (representing 405 out of 451 zones) are in the negative which show that there is poor connectivity in those zones. 8.4% of the zones (representing 38/451 zones) are greater than zero (0) and less than 0.2. The higher the index value the better and the lower the value it means that there are lots of redundancies in the network. In the existing transport network used for the analysis, the results suggest that there is poor connectivity of transport networks in 90% of the TAZs.

6.3.2. Gamma index

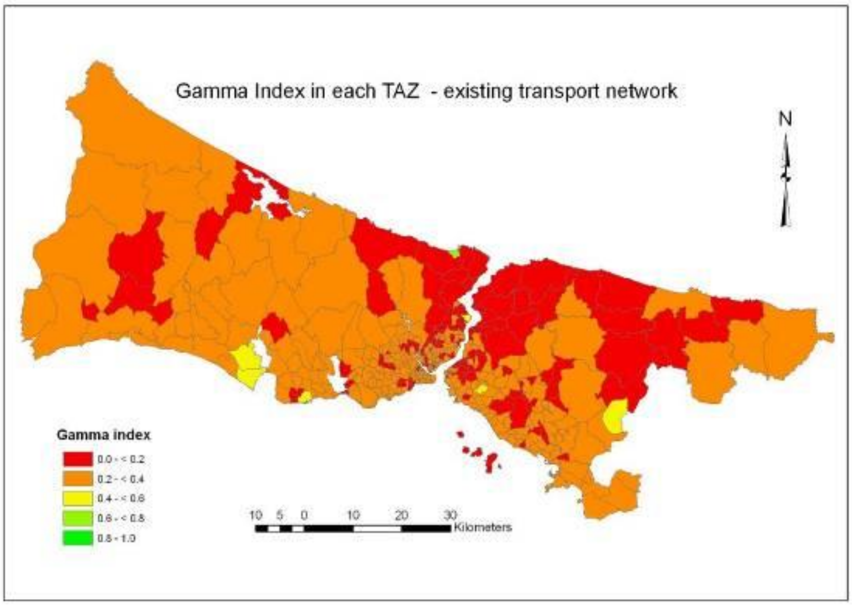


Figure 6-3: Gamma index in each TAZ – existing transport network

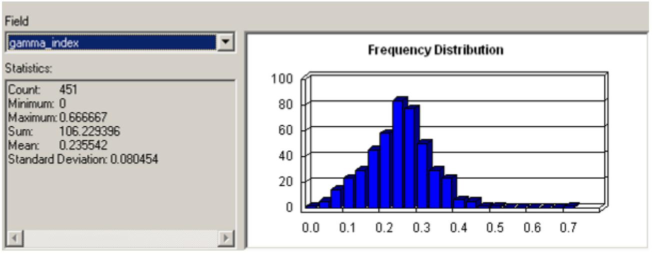


Figure 6-4: Frequency distribution – gamma index existing network

The gamma index is a simple ratio of the actual number of edges in the network to the maximum possible number of edges. The values range from $0 < \gamma < 1$. The value of 1 indicates a completely connected network and the value 0 indicates a poor connectivity. Taaffe and Gauther (1973) mention that when the gamma index is 0, it indicates incomplete connectivity. The values of the gamma index are normally expressed as a percentage of connectivity, for example, gamma index of 0.57 means that the network is 57 per cent connected.

5 classes were used to represent the results with a class interval of 0.2 from red (least values) to green (higher values). Taking a look at the resulting map (figure 6-3), it shows that most of the zones have values between 0.2 and 0.4 (which is 310 out of 451 zones) representing about 69% of the zones. The frequency distribution of the gamma index measure assumes a normal distribution with a mean gamma index of 0.24. Out of the top 10 values of the gamma index, 8 of them are found at the European side of the city and the other 2 at the Asian side.

6.3.3. Beta index

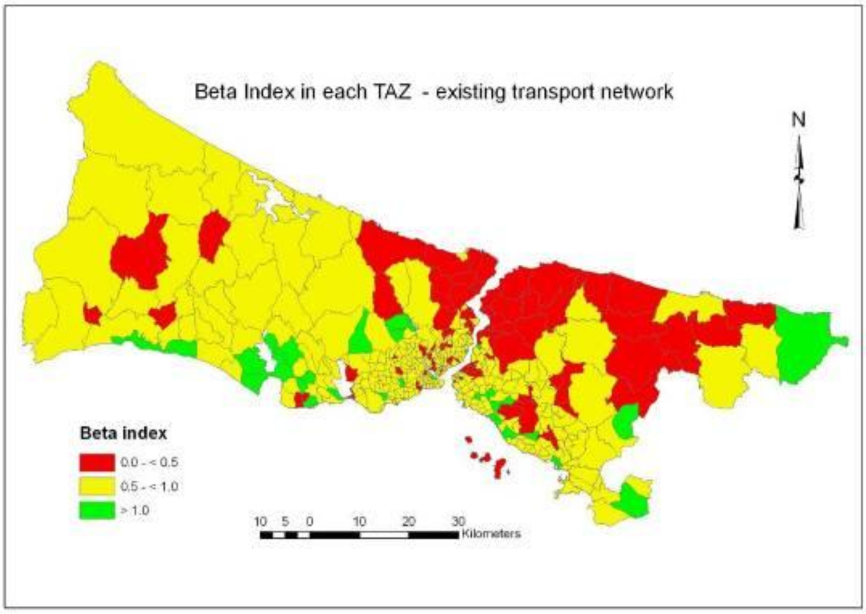


Figure 6-5: Beta index in each TAZ – existing transport network

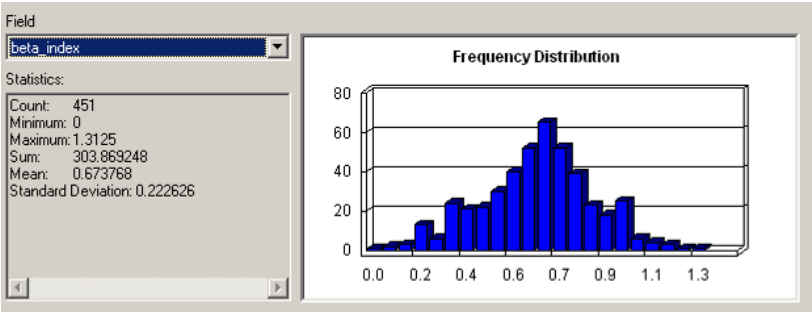


Figure 6-6: Frequency distribution – beta index existing network

The beta index, which is also known as the link-node ratio, measures the "completeness" of a graph. The index measures the level of connectivity of the transport network. Beta index ranges from 0.0 for a network, which consists just of nodes without any arcs, through 1.0 and greater where networks are well connected. Simple networks possesses values less than 1.0, a connected network involving a single circuit has a value of 1.0, while networks of greater complexity, which include several circuits, have values higher than 1.0. The beta index is very useful in very simple networks where no circuits are involved.

The frequency distribution (figure 6-6) here can also be said to assume a normal distribution. The results realized from calculating this indicator suggests that about 92% (representing 413 zones) of the zones have a simple network structure at the TAZ scale. The rest of the 8% indicate complex networks at the zonal level.

A perfect grid has a ratio of 2.5. A beta index of about 1.4 (which is say half way through the extreme of values) is a good target for network planning purposes (Dill 2003). Increasing the links in the network increases connectivity measure. The maximum measure for this indicator is 1.3 and according to Dill, the target for planning purposes has not been reached yet. Improvements are still necessary to ensure better connectivity.

This index does not however reflect the length of the links in any way. Therefore a perfect grid with a 1000 blocks will have the same beta index as one having 200 blocks. Dill (2003) mentions that the beta index is less intuitive and may not be attractive to use as a policy tool. But he however does not mention it cannot be used. Some researchers have used it to explain connectivity of certain networks.

6.4. Alpha, Gamma and Beta indices of urban Istanbul using 1*1km grid cell

Generating alpha, gamma and beta indices for urban areas in Istanbul using a 1km by 1km grid

With the grid analysis there was the need to delineate urban areas within the city to perform the analysis. This was digitized by the researcher and covered both parts of the bosphorus. The area stretches to cover most parts of shore line of the Marmara Sea. The extent of urban area is shown in figure 6-7 below and covers an area of about 1380km^2. This area was digitised from settlement areas (2006) which had dense transport network and also part of the urban core. The area outline in red shows the extent of this further analysis.

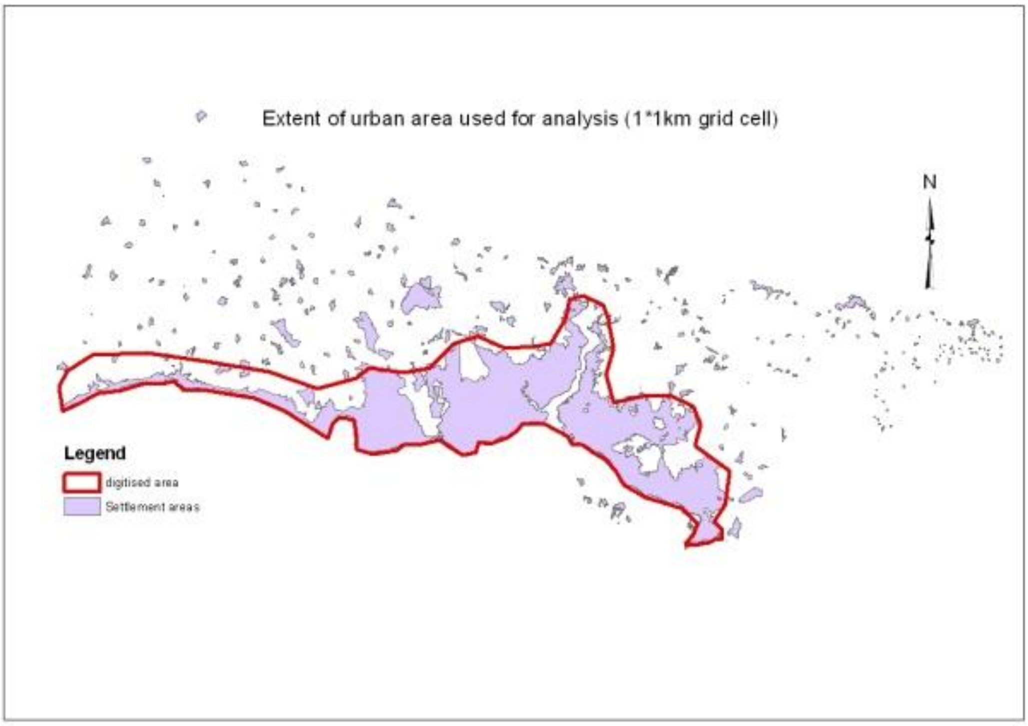


Figure 6-7: Extent of urban area used for analysis

First we created a regular square tessellation of 1km by 1km grid cells. The extent of the urban area was then clipped to the grid cells and also to the various transport networks (both existing and proposed), using the arcGIS operation. A further detailed analysis required restricting the analysis to only urban area of the city which had a dense network and also to where the 2 new Central Business Districts will be situated; Kartal and Silivri.

The grid layer was intersected with the transport network. The resulting layer was aggregated using the unique identifier of the grid layer. The number of segments in each grid cell was aggregated and joined to the grid layer's table. The network dataset operation was used to generate the number of nodes in each grid and this was intersected with the grid layer. A similar aggregation method as mentioned above was used to join the aggregate number of nodes in each grid to the grid layer.

The next thing done was to compute the alpha, gamma and beta indices for the various networks scenarios. Various scenarios of network improvements were used for this analysis, which are based on Istanbul Transportation Master Plan study 2006. The various transport network options used for analysis are as **outlined in section 5.3**.

a. **Option1a** – Existing transport network only (business-as-usual)
b. **Option1b** – Existing transport network + Marmaray project and other proposed rail improvements
c. **Option2a** – Option1b + highway bridge in-between existing bridges
d. **Option3a** – Option1b + highway bridge north of second highway bridge

* highway options mentioned above are same as options in JICA and IMM master plan report (Istanbul Metropolitan Municipality and JICA 2008).

6.4.1. Alpha index

The alpha index maps below (figure 6-8), show the existing situation and proposed improvements (figure 6-10). The colour scheme used for output maps are from red (low values of alpha) to green (high value for alpha). An ash colour grid cell in map shows that for that particular grid no transport network exists, as such no data. A high value in the grid cell represents a high alpha accessibility measure. The output maps show 2 alpha index maps and their corresponding frequency histograms. The first shows the existing situation and the next, the proposed network improvements. Only one proposed improvement map is shown because the other alpha indices of the proposed network improvement (options 1b and 3a) showed the same result.

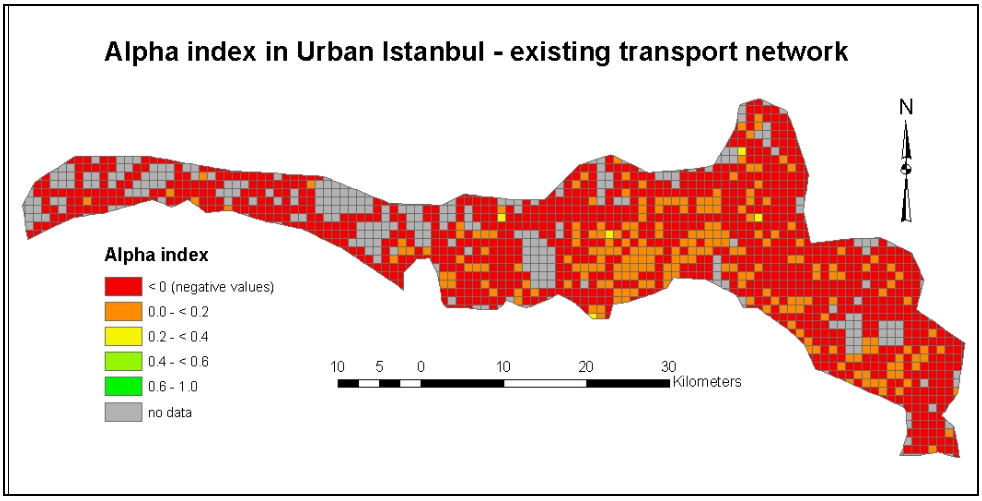


Figure 6-8: Alpha index of urban Istanbul – existing network

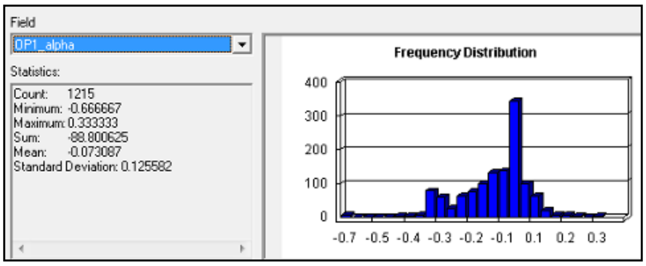


Figure 6-9: Histogram - Alpha index of urban Istanbul, existing network

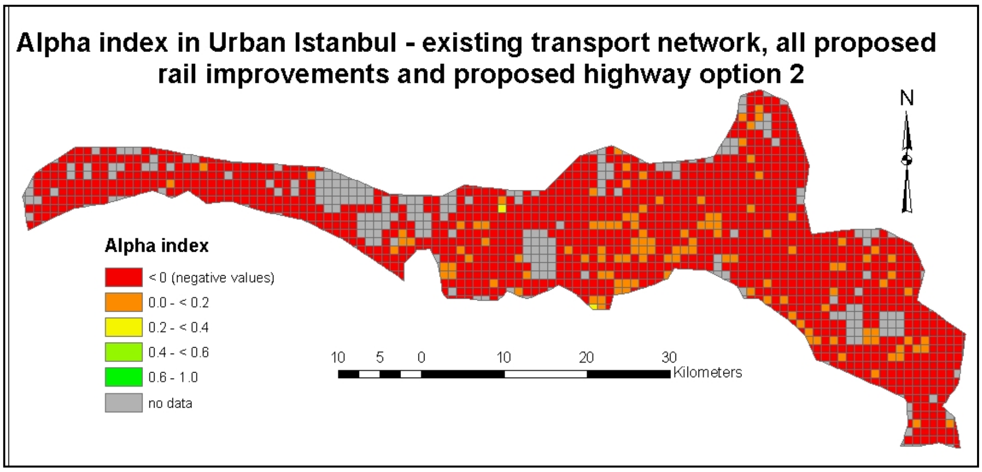


Figure 6-10: Alpha index of urban Istanbul – existing transport network, all proposed rail improvements and proposed highway option 2

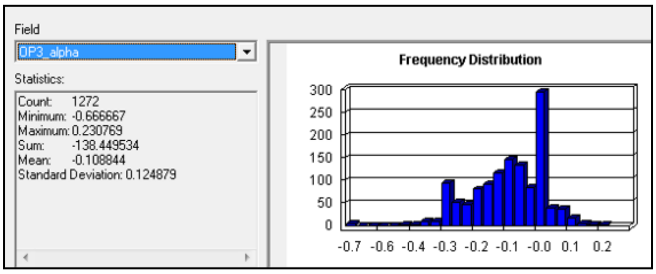
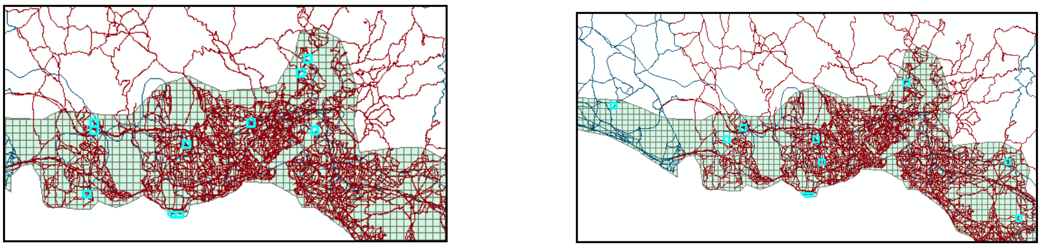


Figure 6-11: Histogram - Alpha index of urban Istanbul: existing transport network, all proposed rail improvements and proposed highway option 2

With the existing network, the highest value for alpha index was 0.33 which was for a grid cell in-between the first and second bridge (around Vanikoy on the Asian side). After network improvement highest value of alpha reduced to 0.23 being the highest value of alpha for a grid cell. This is located in a grid south of Ataturk airport on the European side.

The existing and proposed locations of best performing grids are shown in figure 6-12. A look at the top 10 alpha index values (ranging from 0.17 to 0.33) for the grid cell for the existing situation are located along the TEM highway, some areas close to the Ataturk airport and also north of the Bosphorus. With improvements in the network 6 of the top 10 alpha values (ranging from 0.12 to 0.23) are located around the Ataturk airport and the rest at the fringes of the urban boundary. The reason for this overview is to consider the location of best performing grid and how they change as network improvement occurs.



Existing Proposed

Figure 6-12: Top 10 alpha indicator in grid for existing and proposed situation (highlighted in blue)

6.4.2. Gamma index

The gamma index maps below show the existing situation (figure 6-12) and proposed improvements (figure 6-14). A high value in the grid cell represents a high gamma accessibility measure. The index compares the existing number of edges to the maximum possible in the network. The gamma value in a grid cell represents the percentage of connectivity. The corresponding frequency histograms show the existing situation (figure 6-13) and the proposed network improvements (figure 6-15).

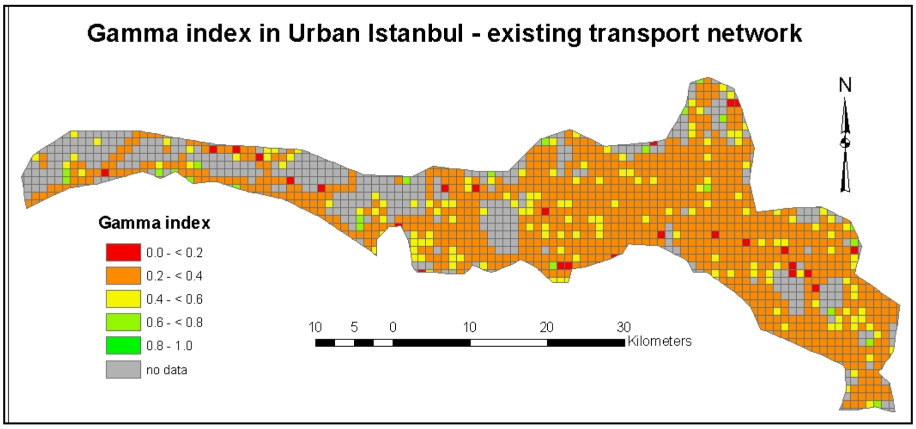


Figure 6-13: Gamma index of urban Istanbul – existing network

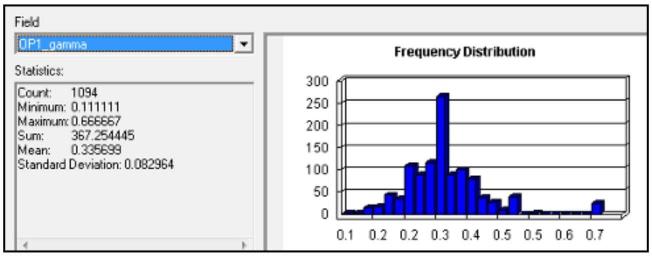


Figure 6-14: Histogram - Gamma index of urban Istanbul, existing network

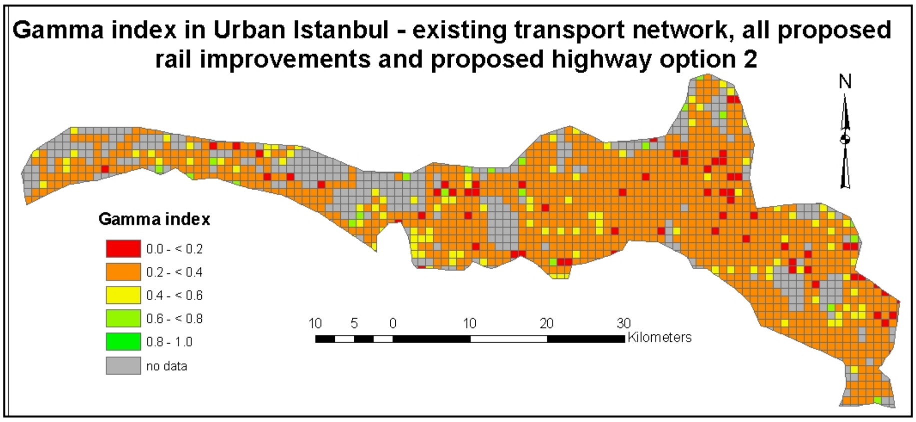


Figure 6-15: Gamma index of urban Istanbul – existing transport network, all proposed rail improvements and proposed highway option 2

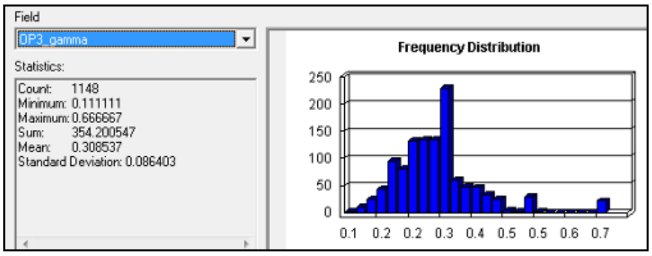
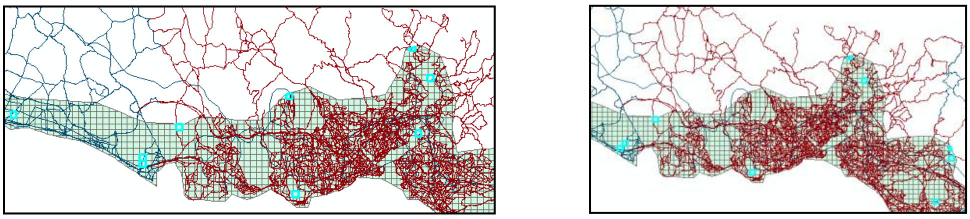


Figure 6-16: Histogram - Gamma index of urban Istanbul: existing transport network, all proposed rail improvements and proposed highway option 2

With the existing situation, a gamma value of 0.67 is recorded as the highest. 23 cells together have this same value of 0.67. Network improvements result in a total of 21 cells with a value of 0.67. This means that in these grid cells they are 67% connected compared with the maximum connectivity levels in those cells. These results rather suggest that the existing situation is better than when network improvement take place, which rather sounds odd. This is because it was expected that an improvement in connections in the network should rather improve network connectivity. A total of 23km^2 have a high gamma value of 0.67, while this value decreases to 21km^2 with network being improved.

The existing and proposed locations of best performing grids are shown in figure 6-17. A look at the top 10 gamma values all have a value of 0.67 and their locations are analysed. For the existing network, top 10 cells are all located at the fringes of the dense network in the city. 3 of these locations are around the bosphorus and the rest around the Ataturk airport. With network improvements it is realised that the highest performing gamma indices are all located at the periphery of the dense network or the city. There are 2 locations along the bosphorus which maintain same locations even with network improvements.



Existing Proposed

Figure 6-17: Top 10 gamma indicator in grid for existing and proposed situation (highlighted in blue)

6.4.3. Beta index

The beta index maps below show the existing situation (figure 6-18) and proposed improvements (figure 6-20). A high value in the grid cell represents a high beta accessibility measure. The index measures the link-node ratio in the network. The output maps show 2 beta index maps and their corresponding frequency histograms. The first shows the existing situation and the next, with proposed network improvements.

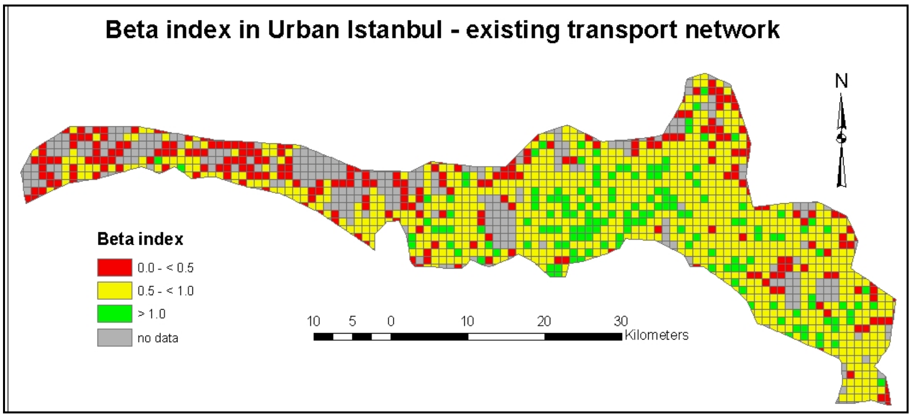


Figure 6-18: Beta index of urban Istanbul – existing network

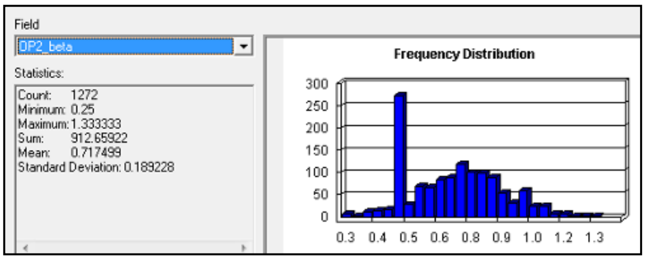


Figure 6-19: Histogram - Beta index of urban Istanbul, existing network

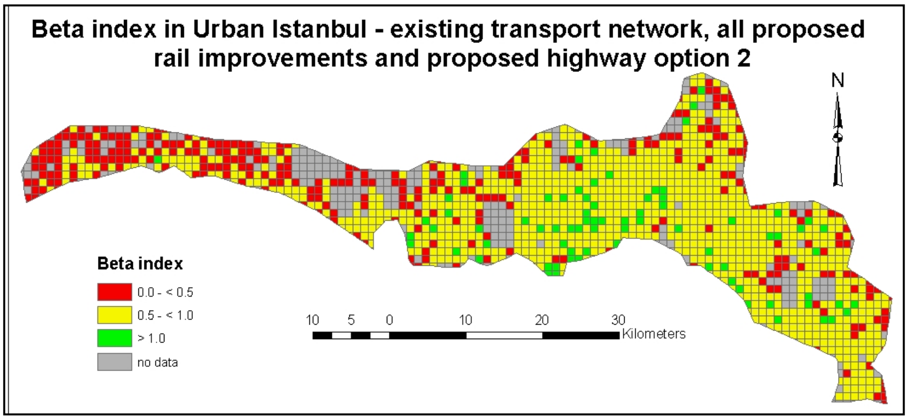


Figure 6-20: Beta index of urban Istanbul – existing transport network, all proposed rail improvements and proposed highway option 2

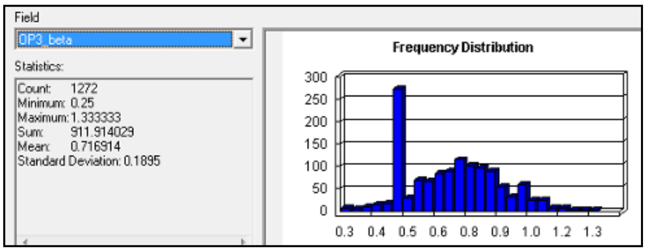
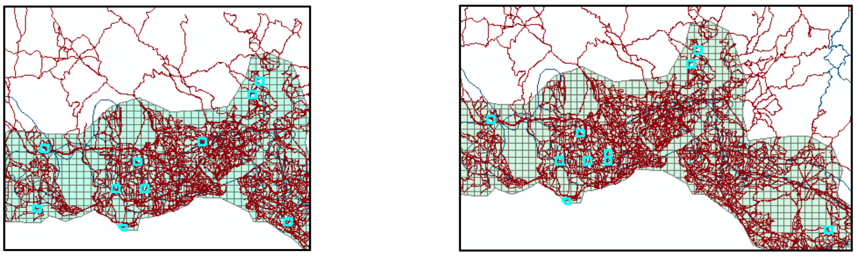


Figure 6-21: Histogram - Beta index of urban Istanbul: existing transport network, all proposed rail improvements and proposed highway option 2.

The alpha values for the urban area as shown above shows the complexity of the network for this scale of 1*1km. For the existing situation the highest alpha value computed is 1.33 and after improvements in the network the highest value computed was still 1.33. A further quest was the location of the best 10 performing grid cells in terms of the beta value. This is shown in figure 6-22.



Existing Proposed

Figure 6-22: Top 10 beta indicator in grid for existing and proposed situation (highlighted in blue)

The best 10 locations of beta are all around the airport and Cayirbasi area. It is realised that with new proposed network improvements there are few shifts of location of best performing cells. 7 out of the 10 grids do not change locations.

A table was further computed to examine whether there are variations in the minimum (min.), maximum (max), mean and standard deviations (sd) of the various options computed for the various network scenarios (table 6-2). The assumption was that an improvement in network should bring about a change in say the maximum and the mean values of the indices measured. It was realised that an improvement in the network (like option 1b, 2a and 3a) brought about a small change in the alpha, beta and gamma indices measured for each cell. It was realised that for network improvements (like for options 1b, 2a and 3a) the minimum, maximum, mean and standard deviation remained same.

	alpha					gamma					beta				
	Cnt	min	max	mean	sd	Cnt	min	max	mean	sd	Cnt	min	max	mean	sd
1a	1215	-.67	.33	-.07	.12	1094	.11	.67	.34	.08	1215	.25	1.33	.77	.21
1b	1272	**-.67**	**.23**	**-.11**	**.12**	1148	**.11**	**.67**	**.31**	**.09**	1272	**.25**	**1.33**	**.72**	**.19**
2a	1272	**-.67**	**.23**	**-.11**	**.12**	1148	**.11**	**.67**	**.31**	**.09**	1272	**.25**	**1.33**	**.72**	**.19**
3a	1272	**-.67**	**.23**	**-.11**	**.12**	1148	**.11**	**.67**	**.31**	**.09**	1272	**.25**	**1.33**	**.72**	**.19**

Table 6-2: Results of alpha, gamma and beta indices using 1*1km grid cells

1a, 1b, 2a and 3a are network options as explained earlier in section 5.3.
Cnt – number of segments involved in analysis
min – minimum value
max – maximum value
sd – standard deviation

Upon analysis of the alpha, gamma and beta maps above at the grid cell scale, all proposed network improvement options (1b, 2a and 3a) yielded the same results (as in the minimum, maximum, mean and standard deviations) as can be seen in the table summary. The output maps also had same results. The existing situation gave slightly different values. But for scenarios 1b, 2a and 3a the alpha and gamma index, the results show that the minimum value and standard deviation are all the same.

The reason for this trend may be as a result of similarity in network improvements used and how the indicator is calculated in terms of the formula. All the improvements from 1b, 2a and 3a all have to do with improvements in rail infrastructure. The only differences realised were the connections on the Bosphorus. As such doing analysis at such a finer scale (1km by 1km grid cell) the differences in the indices did not come out clearly, because difference is ‘only’ a segment or two across the Bosphorus.

In the next section, a final analysis of these indicators was computed using the central areas of the city on both sides of the bosphorus. This was to analyse whether there might be differences in performance of the indicators as new connections are introduced within the network.

6.5. Alpha, Gamma and Beta indices - central area of city scale

A further analysis was done to examine the performance of the alpha, gamma and beta indices. The extent of this further analysis, consisting of 214 TAZs is shown in the map below (figure 6-23) in red outline. To demarcate this extent, TAZs within 10km on both sides of the bosphorus were selected.

The extent is about 424 square kilometres and all segments within this extent were used for computing the indices at various levels of network aggregation.

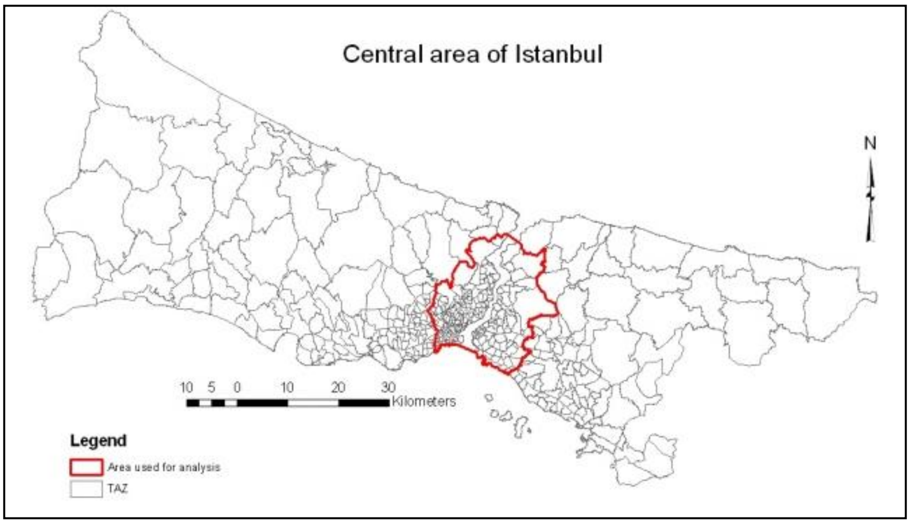


Figure 6-23: Extent of central area used for analysis of alpha, gamma and beta indices

The results of the indices are shown in the table below (table 6-3)

Network	e	v	alpha	gamma	beta
1	598	486	0.12	0.41	1.23
2	909	820	0.06	0.37	1.11
3	910	820	0.06	0.37	1.11
4	910	821	0.05	0.37	1.11
5	3140	2417	0.15	0.43	1.30
6	3452	2706	0.14	0.43	1.28
7	3447	2695	0.14	0.43	1.28
8	3446	2694	0.14	0.43	1.28
9	5055	3637	0.20	0.46	1.39
10	5054	3624	0.20	0.47	1.39
11	5048	3622	0.20	0.46	1.39
12	5050	3621	0.20	0.47	1.39
13	5457	3838	0.21	0.47	1.42
14	5458	3837	0.21	0.47	1.42
15	5454	3831	0.21	0.47	1.42
16	5454	3825	0.21	0.48	1.43
17	6242	4236	0.24	0.49	1.47
18	6294	4242	0.24	0.49	1.48
19	6576	4341	0.26	0.51	1.51
20	6574	4337	0.26	0.51	1.52
21	6572	4325	0.26	0.51	1.52

Table 6-3: Results of alpha, gamma and beta at various categories of network aggregation

e and v represent number of segments and nodes respectively for each network category analysed.

A full explanation of network categories used from 1 to 21 is given in Appendix 1. Network 1 is a simpler network through to 21 being more complex. The indicator was computed for the 3 network improvement options and the existing situation, but varying the network categories involved in the computations. We consider only highways and highway junctions at the initial stages, and continue to add arterials, walkways, existing and proposed railway. An example of 2 of the networks is shown in the figure 6-24 below to show the degree of complexity from network 7 to 20.

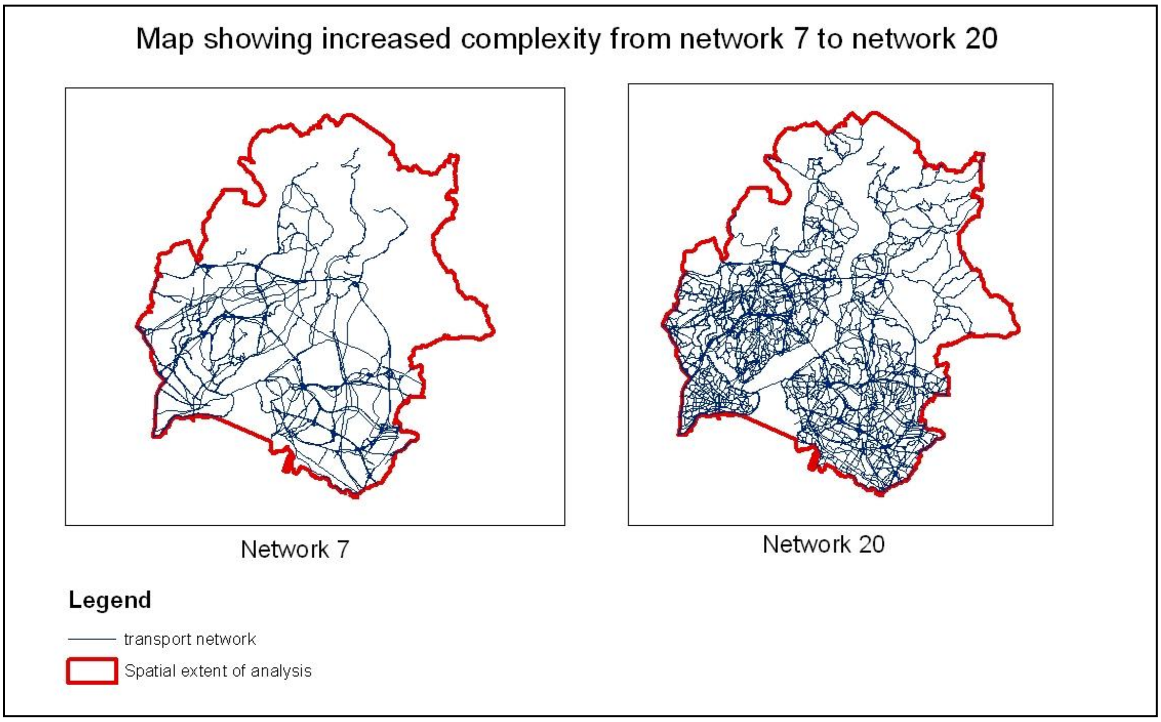


Figure 6-24: Level of complexity from network 7 to 20

The complexity is with respect to the segment categories used to compute the indicator. It was realised that the results were similar as can be seen from the groups of figures highlighted in the table.

From table 6-3 we realise that alpha index ranges from 0.06 through to 0.26. This shows that for the alpha index at this scale there is little or no redundancy in the system. The gamma index values shows that the network is between 37 and 51 percent connected, depending on the level of network detail that was analysed. If we compare actual number of edges to the maximum number of edges which may exist in the network, for the network with say a gamma of 0.51, then it is only 51% connected. The results also show the level of complexity in the network with respect to the beta values. Beta values are all above 1 which explains the complexity in the network structure of the city.

In networks 1 to 4, the categories of segments considered are, highways and highway junctions and the 3 network improvement options. It was realised that the network improvement options (network 2 to 4) recorded same output results. It was concluded that these indicators are not suitable for the decision problem that is being considered. However it should be realised that it gives important information on the level of connectivity at the network scale being considered.

6.6. Conclusion - Alpha, Gamma and Beta indices

With the first set of indicators analysed, there is the need to sit back and ask one of the important questions that this research work had to answer. Whether these kinds of indicators discussed above can be used to prioritise transport investments. The decision problem in Istanbul is that there are various options for transport network improvements (especially the location of the third bridge over the bosphorus strait), but which of the options should be chosen over the others? Alpha, gamma and beta indices were analysed.

It should be realised that the alpha, gamma and beta indices are all aggregate indicators as it is computed at the network level. It tells of transport network connectivity measure for a network. Different scales of disaggregation was used in the analysis and it was realised that the more disaggregated the scale of analysis, the more difficult it was observing “changes” or differences in the performance of the network. This was because at a smaller scale of say a 1km by 1km grid cell, the expected improvement or otherwise in the network was difficult to perceive, either because a new connection did not coincide with a particular grid cell or even if it coincided, the difference was insignificant . It was also realised that at the city scale, network improvements rarely brought that corresponding increase in indicator measurement. It was mainly due to the improvement being the addition of a segment in the whole network structure. It should be mentioned that the alpha, gamma and beta indices are good indicators for network connectivity and differences in indicator performance can be seen if network segments for each options being analysed are not equal in terms of number.

Two of the useful indicators which are seemingly important in transportation analysis according to Morlock (1967) are the so-called alpha and gamma indices described above. According to Morlock, these indices are relevant and can be used to measure the efficiency of the transport network. These were explored under various degrees of network aggregation.

At this stage another group of network indicators, space syntax, which computes connectivity for each of the segments in the network is analysed. These are computed at the so-called “global and local integration” scales. An attempt is made to understand the trend, and whether addition of new connections in the existing network improves network connectivity or otherwise.

6.7. Space syntax results (local and global integration)

The local and global integration maps of the city shown below were computed using the [2]Axwoman 4.0 software. The software supports analysis based on both axial lines and natural streets (Jiang 2005). Axwoman is based on a vector data structure of a GIS in order to represent the graph components of the space syntax.

Integration measure uses the step distance method as discussed in section 2.6.1. Higher values of both the global and the local integration mean that the line is better integrated into the network. Theoretically, integration values show the complexity of reaching a segment. Segments that require fewer amounts of turns to reach all other segments are called the most integrated and thus have a

[2] Axwoman 4.0 is an extension for ArcGIS 9.2 and software is publicly available for downloading at http://www.hig.se/~bjg/Axwoman.htm.

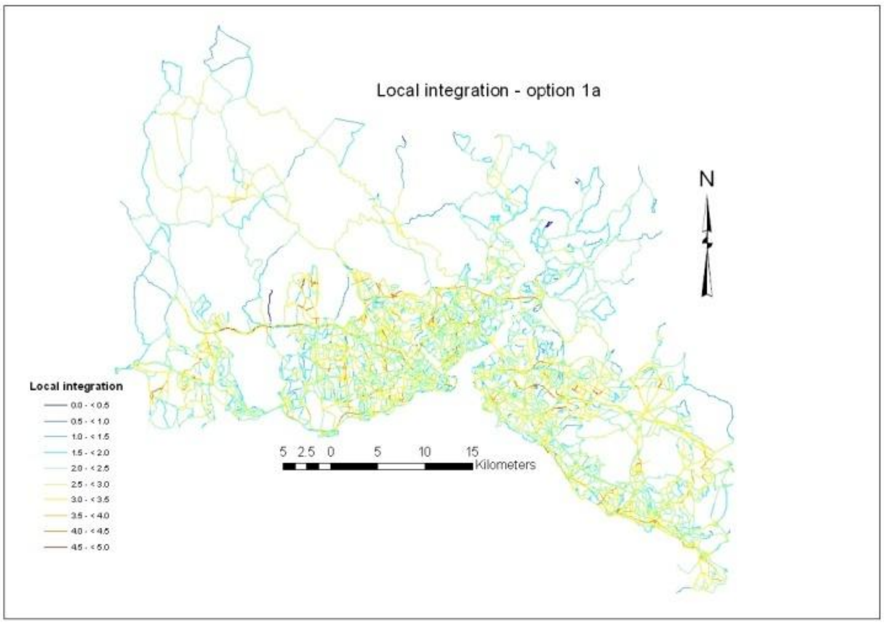
higher integration value. Global integration gives the measure of how integrated a particular segment is from all other segments in the network, while local integration is the same as above but for a smaller space of three steps (s = 3). In this research the concept of integration will be applied to analyse accessibility and connectivity patterns of the existing and proposed transport network structure of the city of Istanbul. These concepts have been discussed in section 2.6.1.

The extent for this analysis only extends to the old municipal boundaries of the city. The reason for this is that in later analysis for the traffic performance indicators, because of data availability, we restricted analysis to that portion of the city only. This is to allow for comparison between this output and traffic performance indicators in section 6.9. The segments that were included in this analysis were only those segments which fell within the old municipal boundaries of Istanbul. This happens to be the central area of the current metropolitan area. We first discuss results for local integration and then global integration.

6.7.1. Local integration results

The outputs for local integration were not standardised (like from 0 to 1), the default values were used. For visualisation purposes 10 classes were used for all local integration maps. Class interval used was 0.5. The reason was to make the various output maps comparable among each other.

Different network categories are applied (as previously discussed in section 5.3) in this analysis to see the trend of improvements or otherwise. The existing as well as proposed new connections are analysed. Based on this premise, 4 local integration maps and their accompanying box plots are displayed below.



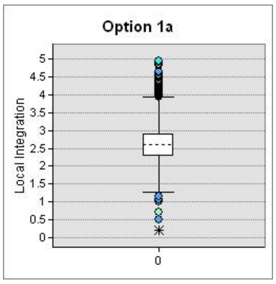


Figure 6-25: Local integration - Option 1a (existing network)

Figure 6-26: Box plot local integration – Option 1a (existing network)

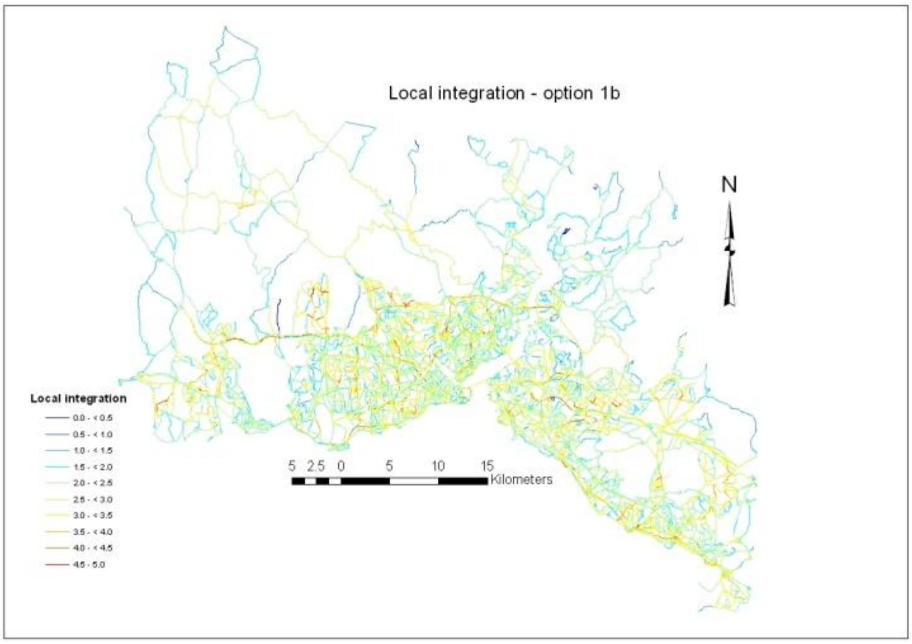


Figure 6-27: Local integration – Option 1b

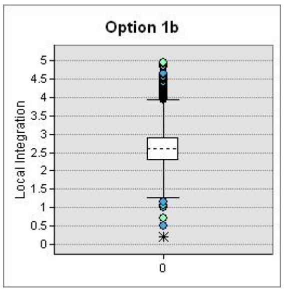


Figure 6-28: Box plot local integration – Option 1b

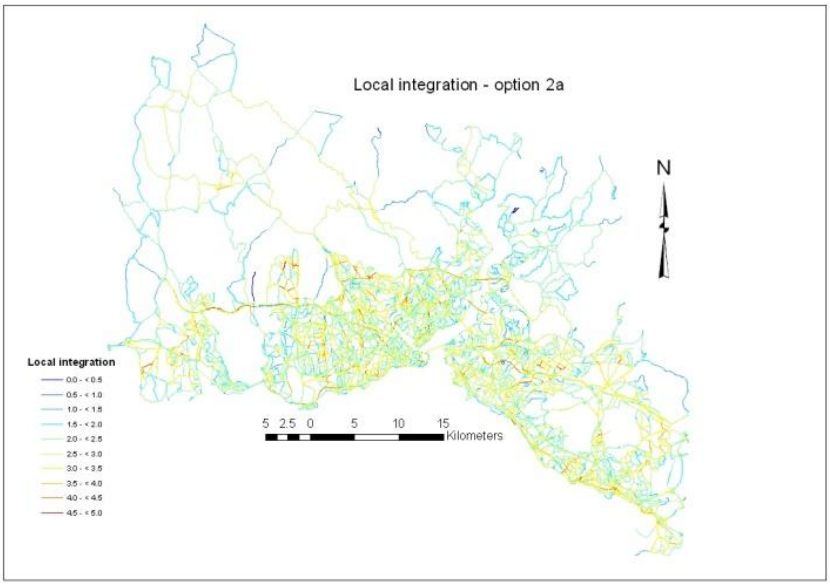


Figure 6-29: Local integration – Option 2a

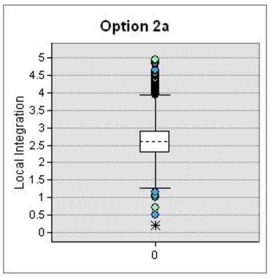
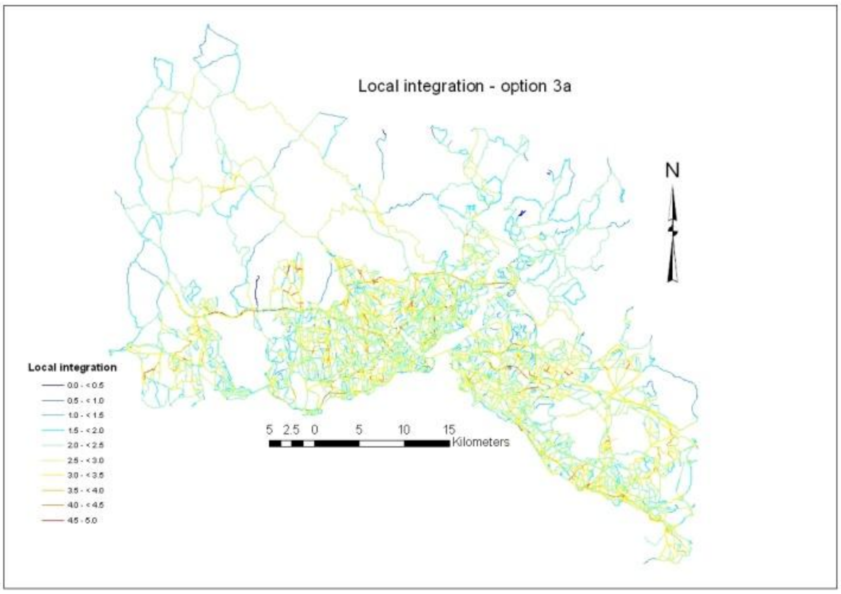


Figure 6-30: Box plot local integration – Option 2a



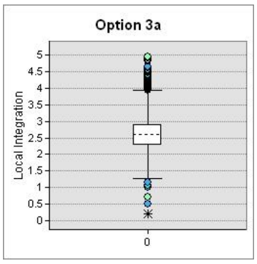


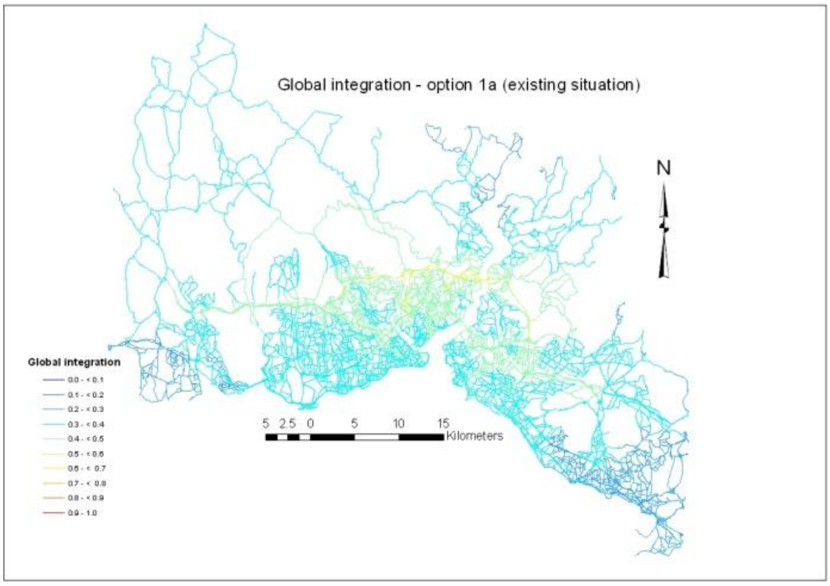
Figure 6-31: Local integration – Option 3a

Figure 6-32: Box plot local integration – Option 3

The local integration maps shown above (figures 6-24, 6-26, 6-28 and 6-30) show the complexity to reach each segment within 3 steps away. The higher the value of local integration, the easily accessible the segment is and vice versa. It can be seen from the maps that most accessible segments are spread throughout the network and not really concentrated in one location. The Sultan Mehmet Bridge records a high value of 4 in all the options considered. This shows how accessible the bridge is 3 steps away. It should be realised that the accompanying box plots for local integration show a number of outliers and therefore not a uniform spread in terms of output results.

6.7.2. Global integration results

In order to generate results which are comparable, the global integration values were standardized to ten (10) classes for all the maps with a class interval of 0.1. The colour scheme used was from blue (low value) to red (high value). This was to ensure that for visual interpretation it becomes easy to compare the output colour schemes.



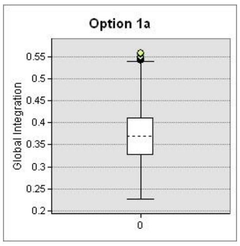
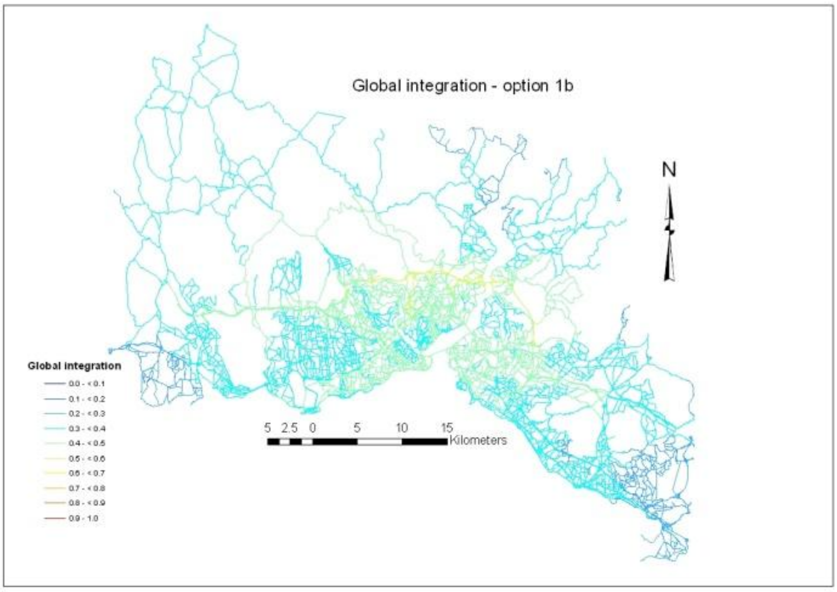


Figure 6-33: Global integration - Option 1a (existing network)

Figure 6-34: Box plot global integration – Option 1a (existing network)



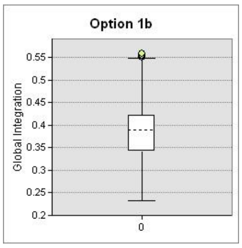


Figure 6-35: Global integration – Option 1b

Figure 6-36: Box plot global integration – Option 1b

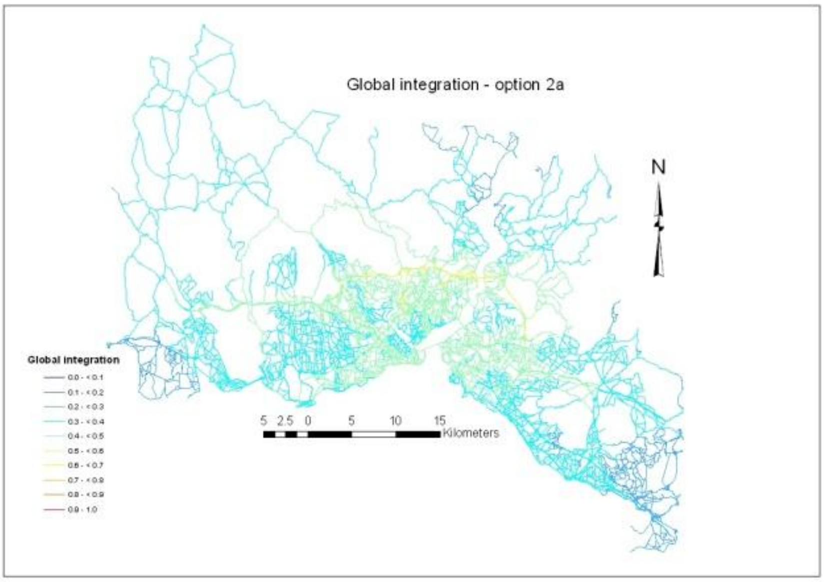


Figure 6-37: Global integration – Option 2a

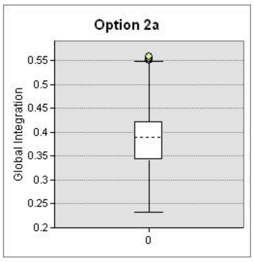


Figure 6-38: Box plot global integration – Option 2a

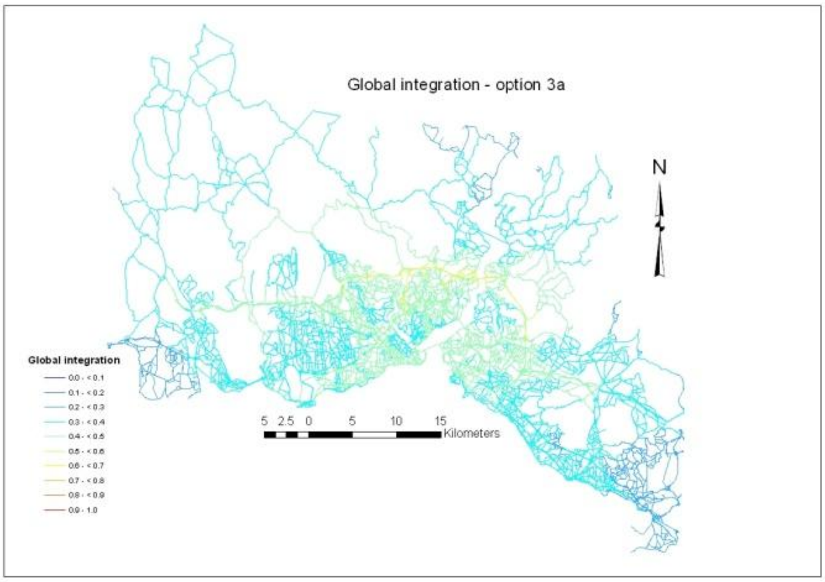


Figure 6-39: Global integration – Option 3a

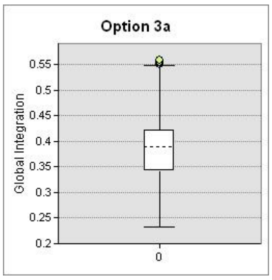


Figure 6-40: Box plot global integration – Option 3a

As mentioned earlier the global integration maps (figures 6-32, 6-34, 6-36 and 6-38), show each segments' accessibility from all other segments within the network. Generally, it can be seen from the maps that the most accessible segments coincide with the Sultan Mehmet bridge (second bridge) and its accompanying highways. The bridges are seen to record the highest values of global integration. The global integration value increased for some segments as a result of new additional connections in the network. For example global integration value for the Bogazici bridge was 0.4699 for option 1a, option 1b recorded a value of 0.4837, option 2a recorded a value of 0.4878 and finally for option 3a

0.4870. These increases are as a result of the new additional connections in the network as well as its location. Location of the new also plays a role in determining whether it improves surrounding areas or not. The maximum and minimum values of global integration values did increase with introduction of new segments in the network. For example the least integrated segment in option 1a (existing situation) was 0.2263, this value increased to 0.2324 as a result of a new connection within network. The accompanying box plots for global integration (figures 6-33, 6-35, 6-37 and 6-39) show a normal distribution for the dataset.

6.7.3. Discussion of local and global integration results

In an attempt to understand the trend of accessibility in terms of global and local integration in the city, the values of certain connections were analysed and results shown in the table 6-4 below. The table shows the global integration (GI) and local integration (LI) for specific connections in the network that cross the bosphorus. These are the 1st and 2nd existing bridges, the Marmaray crossing, highway option 2 and highway option 3. The extent of the segments analysed was from one end of the Bospohorus to the other end. The reason was to analyse whether with a new connection in the network other segments will also improve in terms of indicator performance. This aspect of the analysis was found to be important, as the hypothesis was that a new connection improves accessibility in the system and also specific segments and not rather worsen the situation.

It was realised that with an additional connection, global integration measure for the first bridge (Bogazici bridge) increased from 0.4699 (existing situation) to 0.4837 (option 1b). This value further increased to 0.4878 in option 2a. The reason for such improvements might be as a result of the location of the additional connections close to the Bogazici Bridge.

	Option 1a		**Option 1b**		**Option 2a**		**Option 3a**	
	GI	LI	GI	LI	GI	LI	GI	LI
1st Bridge	**0.4699**	**2.9139**	**0.4837**	**2.9139**	**0.4878**	**2.9139**	**0.4870**	**2.9139**
2nd bridge	0.5340	4.0343	0.5341	4.0343	0.5341	4.0343	0.5341	4.0343
Marmaray crossing	-	-	0.4722	3.2085	**0.4726**	3.2085	0.4722	3.2085
Highway option 2	-	-	-	-	0.4155	4.4030	-	-
Highway option 3	-	-	-	-	-	-	0.3617	2.6888

Table 6-4: Global and local integration values for specific connections in the network

It is however interesting to note that both GI and LI values for the second bridge (Fatih Sultan Mehmet Bridge) remained the same even after network improvements. The reason could be as stated earlier location of the new connection with respect to this bridge.

These new connections have not been built, so the results shown are the expected outcomes if network improvements are carried out. These network improvements contribute to the performance of a particular segment within that region. Highway option 2 recorded a GI of 0.41 and highway option 3 had a value of 0.3617.

Another aspect of this analysis considered the minimum, maximum, sum of all segments and mean values of both global in local integration values in the network as a whole. The idea is that all things being equal the minimum, maximum, sum and means of the various network options should increase with the addition of a new connection. The sum of all global and local integration values for each option analysed shows the aggregate gain in terms of accessibility values for that particular option. These are presented in table 6-5 below.

	Option 1a		**Option 1b**		**Option 2a**		**Option 3a**	
	GI	LI	GI	LI	GI	LI	GI	LI
Minimum	0.2263	0.2109	0.2324	0.2109	0.2324	0.2109	0.2324	0.2109
Maximum	0.5588	4.9401	0.5588	4.9401	**0.5589**	4.9401	**0.5589**	4.9401
Sum of all segments	5388.85	37736.55	5581.24	37744.36	**5583.87**	**37757.66**	5582.86	37749.07
Mean	0.3703	2.5929	0.3835	2.5932	**0.3836**	**2.5940**	0.3835	2.5934

Table 6-5: Syntax values of minimum, maximum, sum and mean for network options

It was realised that the minimum value for global integration increased from the existing situation (option 1a) by 0.0061 for options 1b, 2a and 3a.

If we consider the sum of all segments for each of the options, it was realised that with option 1a, sum of global and local integration amounted to 5388.85 and 37736.55 respectively. With an additional segment in the network, the total accessibility measure in terms of global and local integration increases. This indicator measures the aggregate gain in terms of accessibility for the option being considered. It was realised that the best performing option in terms of sum of global and local integration is option 2a.

The same trend is also realised for the mean of all the network options considered. Average accessibility values of global and local integration for option 1a are 0.3703 and 2.5929. However comparing the other network improvement options the best performing option in terms of mean accessibility is option 2a, with mean global and local integration values of 0.3836 and 2.5940 respectively.

6.7.4. Conclusion – space syntax results

Space syntax parameters of local and global integration gave interesting results. Space syntax uses the concept of adjacency to determine connectivity. The results show that the position of a segment adds to indicator performance not only for the segment concerned but also neighbouring segments. The space syntax results analysed for the various network options gave rather interesting results. These are summarised below;

- With the addition of a new segment in the network, the indicator values increase marginally.
- The best performing segments of global integration occurred along the Sultan Mehmet Bridge (2nd bridge). This shows how accessible the second bridge highway is to the whole network.
- In terms of local accessibility (3 steps) best performing segments are evenly spread in the network.
- However, option 2a performed best in terms of segment with highest global and local integration (accessibility, connectivity) values; system wide accessibility (sum of all segments) and also the highest in terms of mean values for global and local integration. These results show that as far as accessibility and connectivity are concerned, the best performing option is 2a.

It should be noted that option 2a performs probably well because it appeals intuitively considering the case of Istanbul. This option has the 3rd bridge location in-between existing 2 bridges; this area is the urban area where demand is expected to be. The results also suggest that in terms of the aggregate measure of accessibility and connectivity for the mean and sum of all the segments, this option 2a is the best. The results from the space syntax will be compared with traditional traffic performance indicators (like the v/c ratios and system-wide travel time) and analyse if there are any correlations.

The next section, which sets the stage for traffic performance indicators, discusses the existing capacity in each TAZ as a function of length of segments in each TAZ and also TAZ area.

6.8. Capacity indicators

The next set of indicators utilised are the capacity (number of people per hour) of each segment in the study area. The total capacity in each of the TAZs was computed and then divided by the area of the TAZ or the total length of segments within each TAZ. The two indicators measured are, the Total capacity per hour per square area and the Total capacity per hour per length.

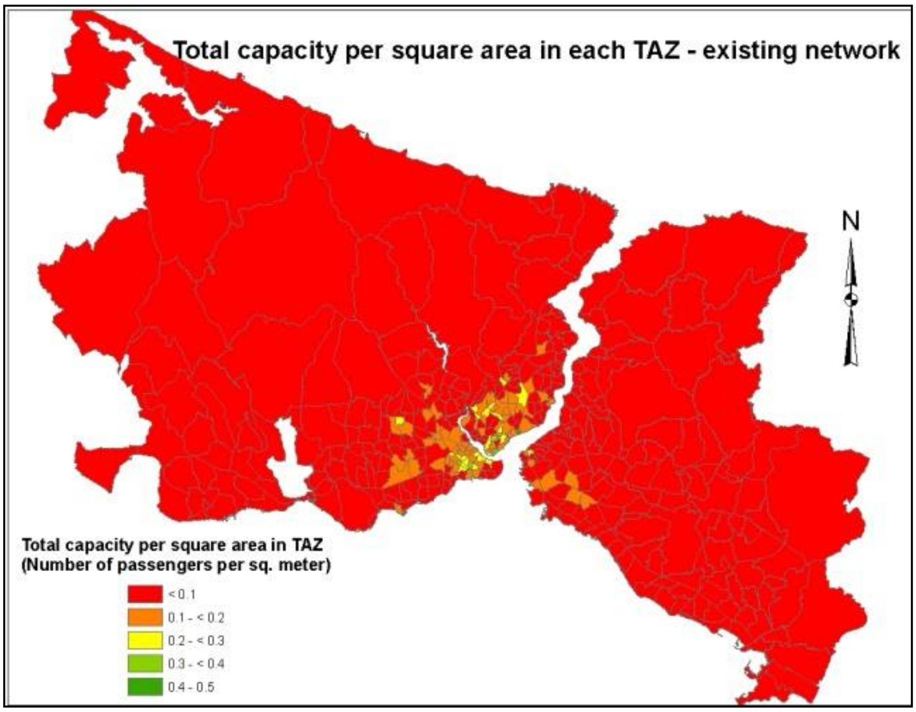


Figure 6-41: Total capacity per hour per square area – existing network (1a)

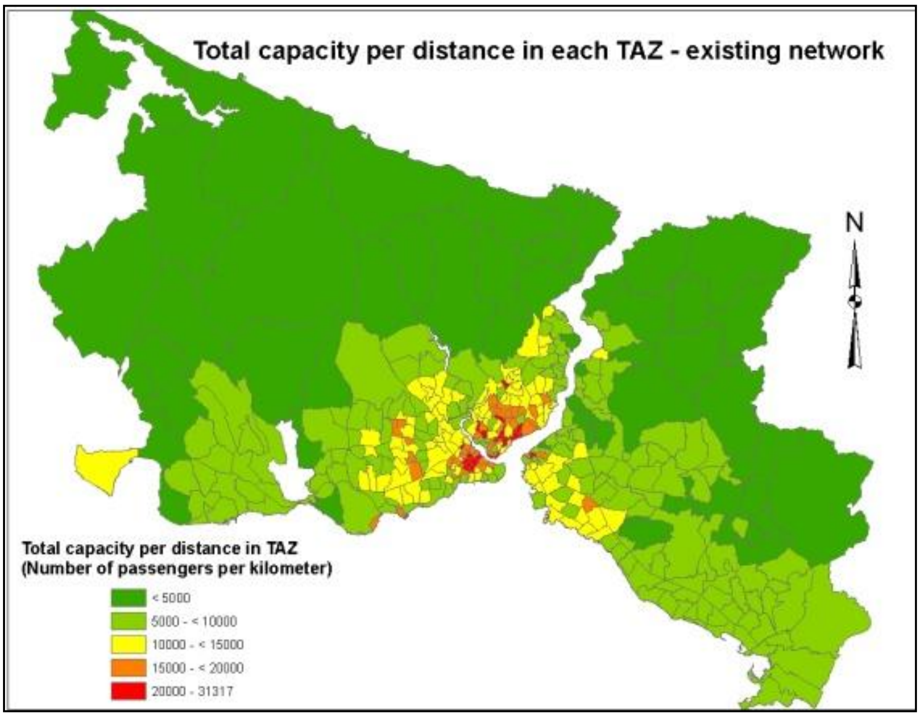


Figure 6-42: Total capacity per hour per length – existing network (1a)

These two indicators reflect the capacity per area or length in each TAZ of the central area of the city. Especially with the capacity per hour per length, it actually equates the capacity to the length of the segment and is a better indicator than just computing average capacity or total capacity in each TAZ. The results show that areas around the historical peninsula and northwards around Beyoglu district record high total capacity per hour. This actually reflect the existing situation and also if things do not change in future a similar trend.

This next section explains the 4-step model as used in the Flowmap 7.3 software and the model parameters it used. The main reason for this step is to assign flows to the various network options to compute traffic performance indicators. In order to set up the model there was the need to convert the files to flowmap format and then compute model parameters. The Flows assigned to the network and the capacity of each link was then used to compute the V/C. This is done to forecast impact of traffic conditions in terms of travel demand patterns, resulting flows and congestion levels in the network and proposed new options for network improvement.

6.9. 4-step transport model and V/C ratio

This section followed the sequential Urban Transport Planning (UTP) procedure also known as the 4-step transport model. This is depicted in figure 6-42 for reference. Network options used in this part of the analysis is same as explained in section 5.3. The extent is the old municipal boundaries of Istanbul. The assumption is that if network improvements that are proposed for the future were completed, what will be the corresponding result in the traffic situation of the city. In the subsequent paragraphs, we explain the various models used in the transport model and the assumptions. [3]

[3] The software used for the transport modelling is Flowmap 7.3, further information can be obtained from http://flowmap.geo.uu.nl and Flowmap 7 manual Van der Zwan, J., R. Van der Wel, et al. (2003). Manual Flowmap 7, Faculty of Geosciences, University of Utrecht, Utrecht.

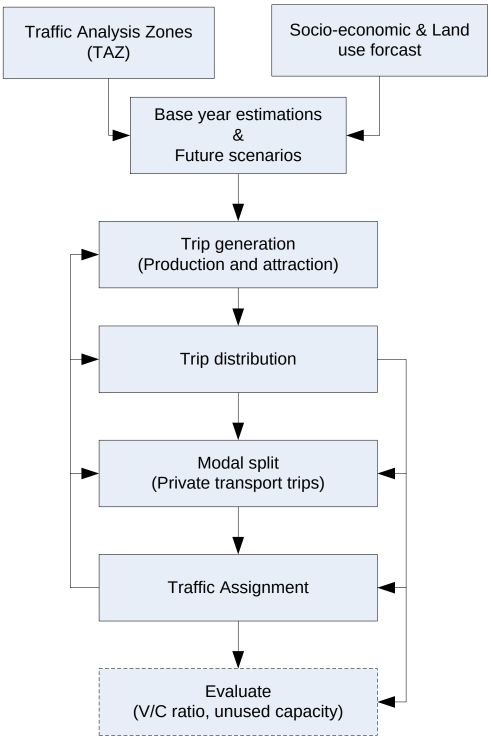


Figure 6-43: 4-Step transport model

6.9.1. Discussion - Traffic flow (car trips assigned) and V/C

In order to set the Flowmap model, there was the need to convert shape files of the road layer and the traffic analysis zones to flowmap format. The conversion involves three steps;

- Converting from ArcMap shape file to plain file in BNA format
- Converting BNA file to Flowmap file set
- Copying data fields in ArcMap table that is relevant for the analysis.

To set up the model the following steps were performed in flowmap. This was the general procedure to get the results required in each of the scenarios developed.

a. A project file (project1a, depending on option being considered) was activated to store all data and results in flow map.
b. Map file activated was the roads layer, origin and destination files used are the TAZ.
c. Distance matrix is created with impedance unit set to the field travel time (MAX_TIME). No distinction was made between directions.
d. Initial intrazonal distances were overwritten using Bonzall's formula.
e. Doubly constrained gravity model was computed using a fixed beta value of 0.00001, this was to maximize the mean trip length. The result is a flow file, like number of trips between each O-D pair.
f. These trips are converted to private car trips (30% of all trips divided by vehicle occupancy ratio of 1.57).
g. These private car trips are assigned to the network using the all-or-nothing assignment.

h. Then lastly the volume-to-capacity ratios are computed for each segment within the network.

Extent of analysis

The extent of this analysis only covered old municipal boundaries of the city of Istanbul. This was as a result of data availability reasons. The traffic analysis zones were 395 (out of 451 for the whole city). The extent is shown in figure 6-43 below.

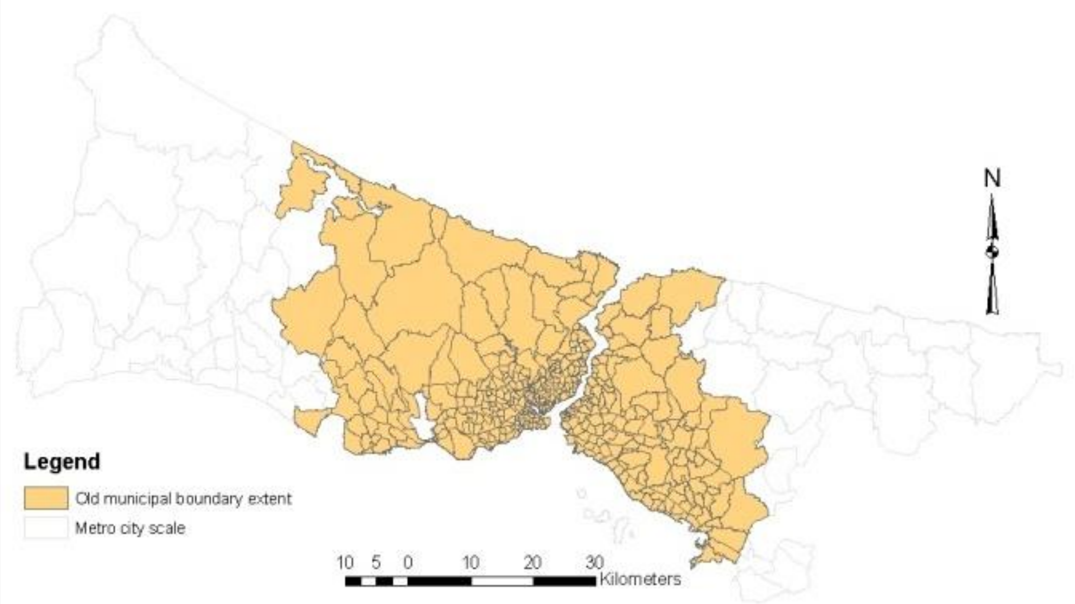


Figure 6-44: Extent of analysis

The next subsections explain in detail the parameters and models used at each stage.

Trip generation model

Trip production and attraction was forecast zone by zone by relying on data from the household survey carried out in 2005. Trip production by purpose was estimated zone by zone and used for analysis. These are for Home Based School (HBS), Home Based Work (HBW), Home Based Others (HBO) and Non Home Based (NHB).

Trip production and attraction models used were adopted from the Transport Master Plan report of Istanbul (Istanbul Metropolitan Municipality and JICA 2008). The table 6-6 below shows the variables employed in the production and attraction models.

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

Table 6-6: Variables used for trip production and attraction
Source: (Istanbul Metropolitan Municipality and JICA 2008)

Trip production and attraction models for HBW and HBS were forecast using trip rates, while HBO and NHB were developed by linear regression. The production and attraction models for the various trip ends are shown below from formulas (13) to (20).

$$\begin{aligned} HBW\ Production &= Net\ trip\ rate\ (1.94) \times Working\ ratio\ (0.88) \\ &\times Number\ of\ workers\ (Home\ place)\ \ by\ zone \end{aligned} \tag{13}$$

$$\begin{aligned} HBW\ Attraction &= Net\ trip\ rate\ (1.94) \times Working\ ratio\ (0.88) \\ &\times Number\ of\ employment\ (working\ place) by\ zone \end{aligned} \tag{14}$$

$$\begin{aligned} HBS\ Production &= Net\ trip\ rate\ (2.02) \times Studying\ ratio\ (0.87) \\ &\times Number\ of\ students\ (Home\ place)\ by\ zone \end{aligned} \tag{15}$$

$$\begin{aligned} HBS\ Attraction &= Net\ trip\ rate\ (2.02)\ \times Studying\ ratio\ (0.87) \\ &\times Number\ of\ students\ (School\ place) by\ zone \end{aligned} \tag{16}$$

$$\begin{aligned} HBO\ Production &= \ -748943 + (0.425737\ \times Population) +\ (1163230\ \times Average\ income) \\ &+\ (0.558952\ \times Workers) \end{aligned} \tag{17}$$

$$\begin{aligned} HBO\ Attraction &= 1063040 + (0.44342\ \times Population) +\ (0.290994\ \times Students\ at\ school) \\ &+\ (0.257524\ \times Employment) \end{aligned} \tag{18}$$

$$\begin{aligned} NHB\ Production &= 511731 + (0.089921\ \times Students\ at\ school) +\ (0.296634\ \times Employment) \end{aligned} \tag{19}$$

$$\begin{aligned} NHB\ Attraction &= 464118 + (0.015623\ \times Population) +\ (0.03754\ \times Students\ at\ school) \\ &+\ (0.286727\ \times Employment) \end{aligned} \tag{20}$$

This model determines the frequency of origins or destination of trips in each zone by trip purpose. A full list of variables for the trip generation model per zone is provided in appendix 2.

Trip distribution

This matches origins and destinations often using a gravity model. Total production and attraction for each trip purpose per zone was computed. Total number of trips produced and attracted for all zones amounted to 19,229,051 and 18,750,602 respectively. Number of productions exceeded attractions and therefore trip attractions were adjusted or fitted to trip productions, by multiplying attractions by 1.0255.

A distance matrix was computed based on travel time in minutes. Attribute fields in the road network used as impedance unit for the distance matrix is, MAX_TIME. This is the maximum time to travel from segment AB and BA. Origins and destinations are usually depicted as centroids of zones. Intrazonal distances (average distance from centroid to network) were computed based on Bonsall's formula as shown in formula (21). This parameter sets average distance from centroid to the network.

$$Ci = 0.667 \times \sqrt{\left(\frac{TAZ\ area}{3.1412 \times travel\ speed}\right)} \tag{21}$$

Where Ci is the intrazonal distance of TAZ area and an off road travel speed of $36 kmh^{-1}$ was assumed.

The gravity model is run after computing a network distance matrix. Parameters used are explained below.

The doubly constrained gravity model was set up using an exponential decay function and the model, calibrated using a beta value of 0.00001. The gravity model estimated the most probable distribution of flows in a matrix of origins and destinations. The model consists of three formulas as computed using flowmap;

$$Tij = Ai.Bj.Oi.Dj.\exp(-\beta.Cij) \tag{22}$$

$$Ai = \frac{1}{\Sigma j Bj.Dj.\ \exp(-\beta.Cij)} \tag{23}$$

$$Bj = \frac{1}{\Sigma i Ai.Oi.\ \exp(-\beta.Cij)} \tag{24}$$

Where:

Tij = the estimated number of trips between origin i and destination j

Ai = balancing factor for origin i

Bj = balancing factor for destination j

Oi = constraint value for origin i

Dj = constraint value for destination j

β= distance decay parameter

Cij = distance between origin i and destination j

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.

Formula (22) calculates the actual trips in the origin destination matrix.

Formula (23) takes care of equating the total number of trips from origins in the matrix to the set number (the "origin constraint").

Formula (24) takes care of equating the total number of trips to the destinations in the matrix to the set number (the "destination constraint").

To actually perform the gravity model the origin constraint was set to the production field of the TAZ layer, and attraction set to attraction field also of the TAZ layer. For further explanation as to how the model works please refer to the Flowmap 7.3 Manual (Van der Zwan, Van der Wel et al. 2003).

The output of this model is the total number of person trips (flows) per origin-destination.

Modal split

The output from the trip distribution model was person trips which were then converted to private vehicle trips by assigning them to private vehicles only for a twenty four hour period. This constituted 30 percent (30%) of all trips divided by car occupancy rate of 1.57 as depicted in formula (25). In Flowmap the flow field is stored as SCORE (this field is saved as a string).

$$CARTRIPS = \frac{SCORE \times 0.30}{1.57\ (occupancy\ \ ratio\ )} \tag{25}$$

This process converts all daily trip volumes produced between each origin-destination pair to private vehicle flows. The unit of measurement being number of vehicles produced per day

Traffic assignment

In assigning the daily flows (private vehicle trips) to the network, Flowmap uses the all-or-nothing assignment based on travel cost. The model assigned all flows to about half the number of segments in the network in each of the network improvement options considered.

And finally in calculating the volume to capacity ratio for each segment, flows (24 hour flow) were divided by the capacity of each segment (daily capacity). The output gives the volume to capacity ratio for each of the segments.

6.9.2. Results from transport model – number of vehicles per day (flows)

The maps below show the results of flow assignment to the network. The output maps was visualised in flowmap using gradient drawing and set to proportional width of 5.

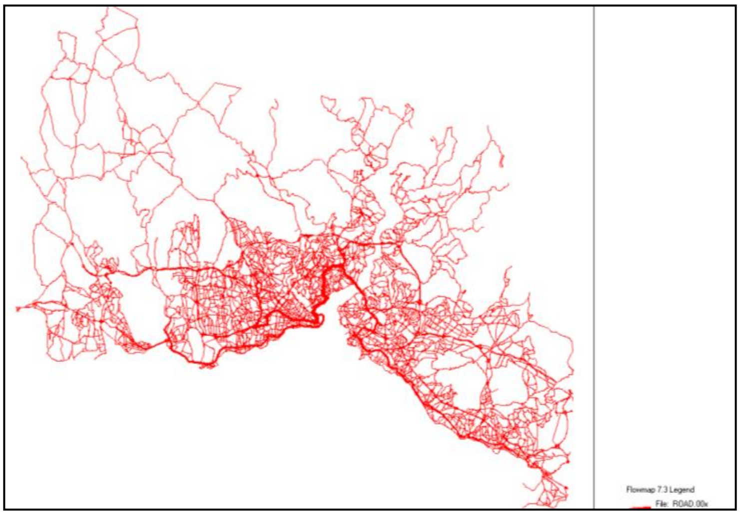


Figure 6-45: Flow assignment to network, existing situation (option 1a)

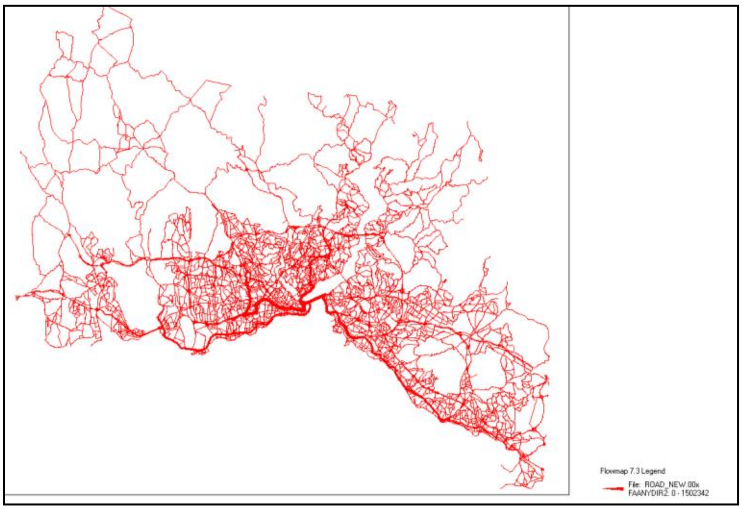


Figure 6-46: Flow assignment to network, option 1b

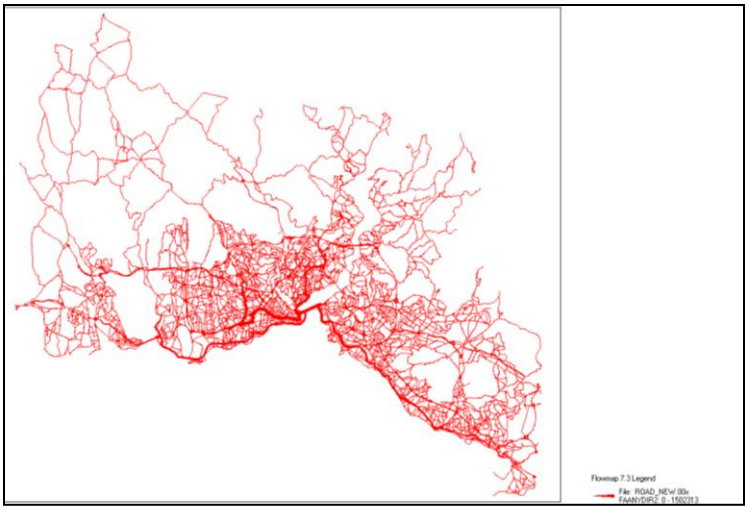


Figure 6-47: Flow assignment to network, option 2a

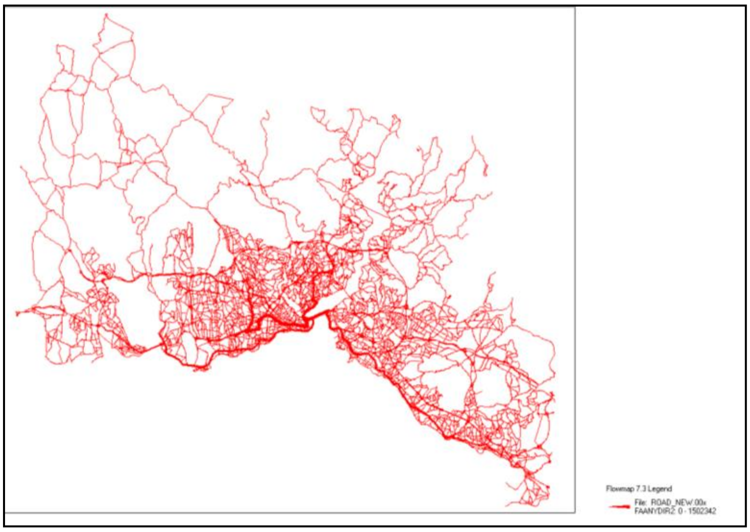


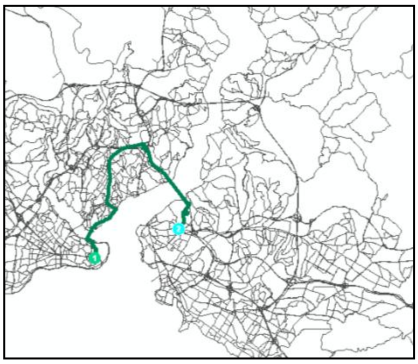
Figure 6-48: Flow assignment to network, option 3a

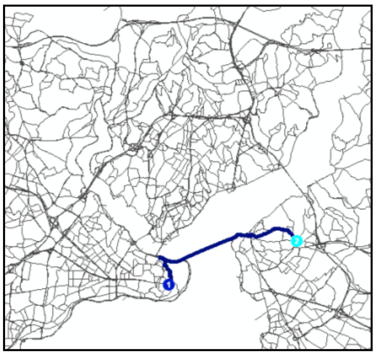
With the existing situation (as shown in figure 6-44) it was realised that the high flows are recorded on the Bogazici Bridge and its corresponding highway and also at locations along the Marmara Sea on the

European side. The historical peninsula also records a large number of flows. However with the introduction of new connections in the segment (as shown in figures 6-45, 6-46 and 6-47), trips are seen to be redistributed. The Marmaray connection now accommodates the high flows on both sides of the Marmaray Sea. This relieves the Bogazici Bridge from receiving high flows.

The total numbers of private vehicles per day assigned to the network are as follows (table 6-7);
Option 1a – 222,305,040 private vehicles per day,
Option 1b – 211,348,941 private vehicles per day,
Option 2a – 211,329,637 private vehicles per day and
Option 3a – 211,348,941 private vehicles per day
The difference in total flows between the options is as a result of how flowmap assigns the flows to the network, by using shortest path algorithm (route choice) for each origin-destination pair, with the all-or-nothing assignment. Without any of the network improvement options total flows (total vehicles per day) is high when compared with the situation when network improvements are introduced. As mentioned earlier this is a bug in Flowmap and as such results should be interpreted with some level of caution. However, the 3 improvement options show the same range of results that are comparable.

For example computing shortest route from point 1 and 2 before and after new connections in the network, in this case reduces the number of segments involved to move from point 1 to 2 as shown in the example below.





Before network improvement After network improvement (Marmaray crossing)

This is the probable reason why the number of flows differs between the existing situation and when a new crossing is introduced in the network. It becomes shorter using the new crossing (Marmaray in this case) than to use the Bogazici Bridge.

The next sections discuss the results from the transport modelling process. We measure the v/c ratio, system-wide travel time and unused capacity within the network for the 3 network improvement options/ scenarios. We compute these indicators with the notion of estimating the overall change in the performance of the indicators as a result of introducing new connection(s) within the network. The traditional way to measure link importance is to calculate the overall change of some performance measure (in this case change in v/c ratios, system-wide travel time and unused capacity) (Jenelius 2010).

6.9.3. Results from transport model – volume to capacity ratio (V/C)

The V/C for each of the segments was calculated by dividing the capacity for each segment by the total volume. The resulting V/C field was saved in the road network layer in flowmap as V_C2. In visualising the outputs, green on the map represents segments with V/C less than 1 and red, with V/C >=1, still having at the back of our minds that the software used uses the all-or-nothing assgignment. The maps that follow show the existing situation and that of network improvements.

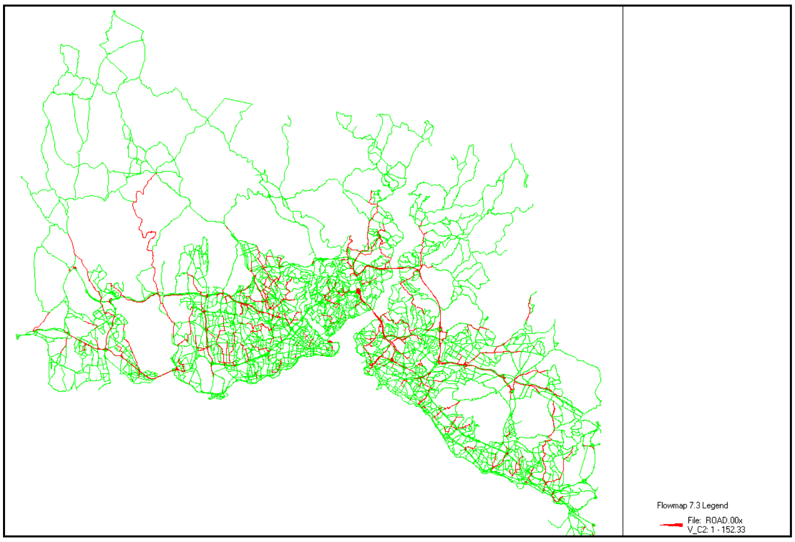


Figure 6-49: Volume-to-capacity ratio, existing situation (option 1a)

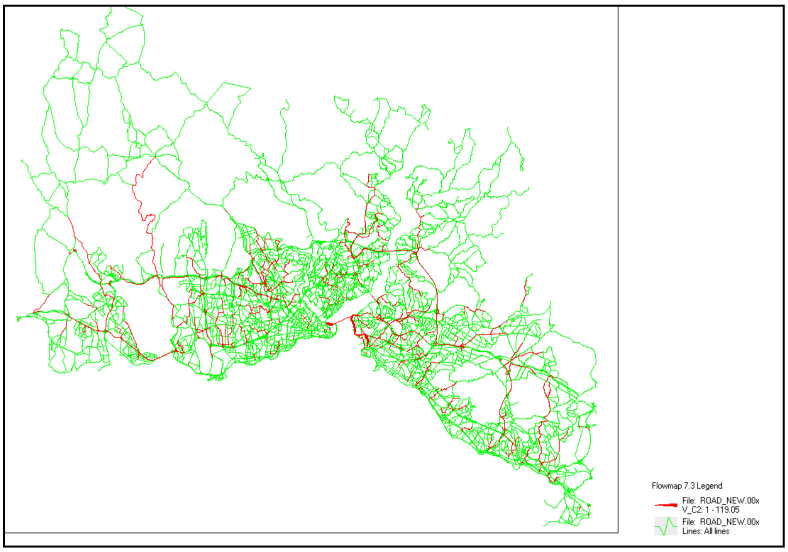


Figure 6-50: Volume-to-capacity ratio, option 1b

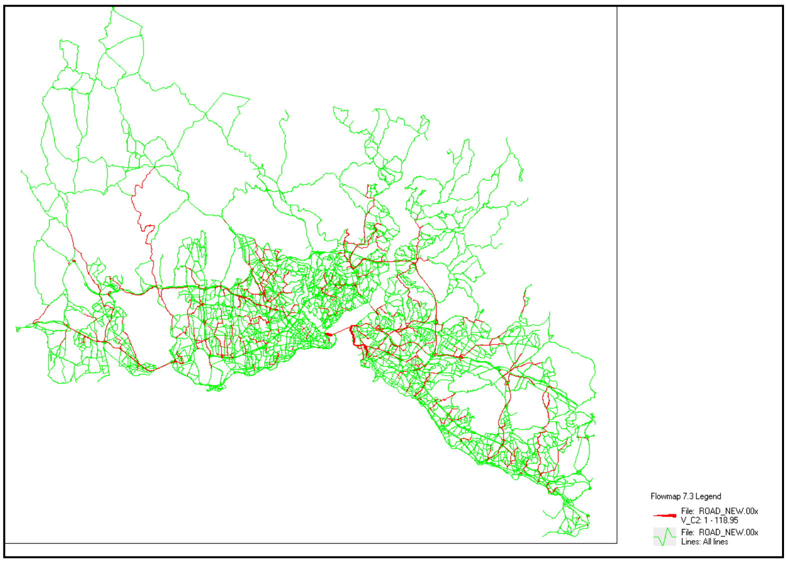


Figure 6-51: Volume-to-capacity ratio, option 2a

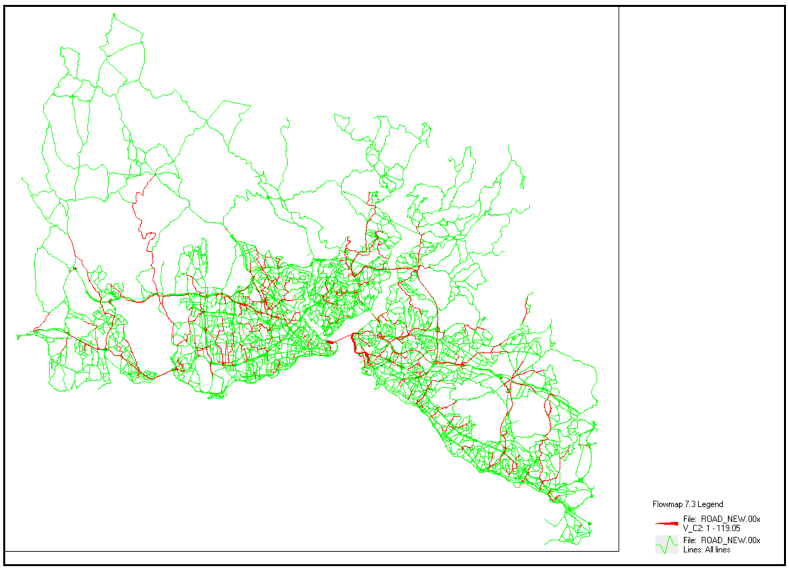


Figure 6-52: Volume-to-capacity ratio, option 3a

Figure 6-49, shows the existing situation without any network improvements. It shows the two existing bridges to be congested. This is what happens daily on the existing bridges. With the introduction of new connection(s) over the Bosphorus especially the Marmaray connection, traffic is re-routed in the network. Figures 6-50 to 6-52 show that with the introduction of new connections across the Bosphorus, the Marmaray crossing gets heavily congested because traffic is routed to the Marmaray crossing and other parts of the network. Interestingly the Sultan Mehment Bridge does not see any significant improvement in terms of congestion levels below 1 (like v/c below 1). However network improvement options relieve the Bogazici Bridge from traffic congestion at the European side at least. The Anatolian side of the bridge still records a v/c ratio greater than 1.

There is the need to analyse ratios for v/c and excess (unused) capacity within the network for the various options. This is provided in table 6-7. This was an attempt to quantify and compare changes in performance of the indicators as a result of new connections in the network.

	Option 1a	Option 1b	Option 2a	Option 3a
Total flows (vehicles per day)	222305040	211348942	211329637	211348942
Total capacity (vehicles per day)	243344760	243544760	243744760	243744760
Volume-to-capacity ratio	0.9135	0.8678	0.8670	0.8671
Unused capacity available (vehicles per day)	21035720	32195819	32415123	32395819
Largest v/c ratio for a segment	152.33	119.05	118.95	119.05
System-wide travel time (minutes)	3094263	2843821	2847885	2843821

Table 6-7: Traffic analysis for the various network options considered

As can be seen from table 6-7, flows assigned to the network are all in excess of 200,000,000 vehicles per day. Comparing these flows to the total capacity in the network (which are also in excess of 240,000,000 vehicles per day), it was realised that with the existing situation (option 1a), the v/c ratio is about 0.91. As new connections are introduced in the network the v/c ratio drops from 0.914 to 0.867 for the 3 options being considered. It must also be noted that traffic does not exceed capacity in all the network options analysed as a whole, although the ratios are all nearing the maximum of 1. Using the v/c ratios as a benchmark, then the best performing option in terms of improving the traffic situation is option 2a which has a ratio of about 0.87.

The unused capacity available in the network is that capacity remaining in the network after subtracting total vehicle flows on the network from the existing capacity. Option 2a in terms of excess or 'unused' capacity leaves the network with a total of about 32,415,000 vehicles per day which is the maximum in terms of all the options being assessed.

The largest v/c ratio assigned to a single segment is found in table 6-7 above. It was realised that with the existing situation the largest v/c for a segment records a value of 152. This figure reduces to 119 for options 1b and 3a, and 118 for option 2a. This shows the improvement in the network as new connections are introduced.

The next section discusses system-wide travel time for all the network options.

6.9.4. System-wide travel analysis

For the next part of the analysis we computed system-wide travel time for the existing situation as well as for the three other network improvement options (table 5-7). This travel time computation was a summation of travel time in minutes for each O-D pair for the network scenarios developed. The main assumption underlining this technique is that as new connections are introduced in a network, travel cost associated with rerouting all traffic in the network will be reduced. This technique is similar to the one developed by Scott et al (2006). However, their focus was in measuring system-wide travel time differences between segments in a network should that segment become unusable or disrupted due to natural (e.g., mudslides, earth quakes) or human induced (e.g., vehicle collision, terrorism) occurrences. Scott et al mention that travel times computed using link performance functions are more realistic to use.

The range of values in absolute terms for the system-wide travel time across the 4 networks considered was between 2,843,821 (for options 1b and 3a) and 3,094,263 minutes (for option 1a – existing situation). Network option 2a recorded a system-wide travel time of 2,847,885 minutes. As expected the existing situation resulted in the highest system-wide travel time in excess of 3,000,000 minutes.

With new connections in the network, we see improvement in system travel time for the 3 options that are being analysed.

As anticipated these results seem to suggest that the Marmaray crossing makes a significant impact in terms of reducing travel time in the network as a whole. For example the difference in travel time between the existing situation (network option 1a) and network option 1b is 250,442 minutes. This is a significant gain in terms of travel time. The reason may be that areas around the historical peninsula can easily cross over to the Anatolian side of the city more easily with a crossing on that side of the city. Initially any trips from the historical peninsula had to use the Bogazici Bridge to get to the other side of the city by the shortest route.

6.10. Summary

Section 6.9 discussed the various models that were used in the four-step urban transport model and the calibration process. The final stage of the assignment model flows were assigned to the network and then the volume to capacity ratio, system-wide travel time and unused capacity within the network.

6.11. Conclusion

In this chapter, we discussed two sets of indicators that were used for the prioritisation problem. These are the graph theory measures on one side and traffic performance measures on the other. It was further mentioned how each of the indicators used was measured and compare some results. The alpha, gamma and beta indices were computed at various network scales. Also the sum and mean was computed for space syntax parameters of local and global integration. In the end we included only the space syntax measures as part of the indicators used to assess the various network options. In terms of traffic performance, the indicators measured for each of the 3 network options were the system-wide volume to capacity ratio (v/c), system-wide travel time and also the unused capacity within the network after all flows have been assigned to the network.

As mentioned earlier in sub-objective 1, various network based indicators were explored at different degrees of aggregation. The extent used was the old municipal boundaries, because the traffic performance indicators were analysed at this scale as a result of data availability. Hence all the other indicators were scaled to the old municipal boundaries in terms of extent.

The indicators that were finally used in the selection of the 'best alternative' are mentioned below. They are grouped in two; graph theory indicators and network performance indicators.

- Graph theory indicators
  - Space syntax indicators (local and global integration)
    1. Sum of accessibility measure for each network option
    2. Mean accessibility measure for each network option
- Traffic performance indicators
  - System-wide volume-to-capacity (v/c) ratio
  - System-wide travel time (minutes)
  - Unused capacity (vehicles/day)

The alpha, gamma and beta indices (graph theory indicators) which provided an overview of network connectivity at various scales was not used in the selection of the best alternative. The reason being, at the various scales of aggregation as discussed earlier, the variations in terms of output values were all similar to each other. There was no variation in terms of output values and as such could not be utilized in the decision process.

The next chapter reflect on the indicators used and their significance to the Istanbul context.

7. Discussion - evaluation of network based indicators used

7.1. Introduction

The previous chapter discussed various network based indicators used for this research. In the end 7 of these indicators as mentioned above are used. This chapter provides an overview of the indicators and then decide on the ‘best alternative’ based on the indicators measured. We then consider policy implications and what transport projects the metropolitan municipality want to implement to achieve set goals.

7.2. Brief overview of indicators measured

Transport infrastructure aids in economic development. As a result building a new infrastructure to improve on existing situation has been a priority for transport planners. For the case of Istanbul, the 2 existing bridges over the bosphorus does not adequately cater for demand hence, congestion on the bridges. There was the need to examine alternatives of a third bridge with the main objectives of improving accessibility and improving traffic performance in the city.

The conventional methods consider a cost benefit analysis (CBA) or traffic performance measures in evaluating transport investments. This research deviated a little from the conventional methods by incorporating structure analysis as part of the evaluation process. Decision makers in our opinion need to know more than just traffic performance; they also need to understand how topological measures of graph theory provide useful information for urban transportation planning. And how these can be incorporated within a multi-criteria decision framework to decide on which bridge alternative will meet the set objectives for the city of Istanbul. The decision tool involved these steps or phases;
1. Identification of projects to be evaluated;
2. Selection and measuring of criteria;
3. Assessing various alternatives based on objectives (evaluation) and;
4. Selection of better alternative or best option (Tsamboulas 2007).

In this research the approach involved using network indicators for the prioritisation process. The first phase involved the identification of the projects to be evaluated. This phase involved identification of highway improvement projects including the Marmaray crossing, over the bosphorus selected by the Istanbul Metropolitan Municipality (IMM). The criteria used was that such improvement alternatives should be located close to demand areas and also not located in forest areas, which are considered environmental sensitive areas. As a result 2 out of the 5 highway improvement options were selected for evaluation.

The second phase involved the selection and measuring of criteria selected. As regards the selection of criteria to use for evaluation, we considered using indicators at network scale. This involved selecting indicators that measure network structure and network performance. As mentioned earlier, the main aim for improving existing network in Istanbul is to improve accessibility and traffic performance. Based on this the space syntax parameters of global and local integration are used to measure accessibility and traffic performance indicators to measure traffic performance. This criteria selected measure the performance (or state of network) after network improvements and this gives an indication whether the particular option meets the set objective.

The third phase involved assessing the various alternatives based on the criteria measured. We take a quick overview of the indicator values for each of the options in the table 7-1 below. It was realised that with respect to the values measured for each of the options, there appeared was a dominant alternative (figures in bold are those that perform best in each option). This meant that there was no need to perform a multi-criteria evaluation of the alternatives. In terms of just considering the output figures we will say that the best performing alternative is option 2a. This option consisted of the Marmaray crossing and highway bridge in-between existing two bridges over the bosphorus. Of course option 1a is not part of the evaluation; this is the existing situation. It is only used as a benchmark to assess the performance of the options.

	units	Option 1a	Option 1b	Option 2a	Option 3a
Graph theory indicators (space syntax)					
Sum global integration	[-]	5388.85	5581.24	**5583.87**	5582.86
Sum local integration		37736.55	37744.36	**37757.66**	37749.07
Mean global integration	[-]	0.3703	0.3835	**0.3836**	0.3835
Mean local integration		2.5929	2.5932	**2.5940**	2.5934
Traffic performance indicators					
System-wide volume to capacity (v/c) ratio	[-]	0.9135	0.8678	**0.8670**	0.8671
System-wide travel time	minutes	3094263	**2843821**	2847885	**2843821**
Unused capacity	vehicles/ day	21,035,720	32,195,819	**32,415,123**	32,395,819

Table 7-1: Overview of indicators used for evaluation

[-] dimensionless

The last phase involved selection of the best option out of the three evaluated. Based on the output figures, we can conclude that option 2a should be selected as best option. A critical look at the output values for options 1b, 2a and 3a show that, the values are all within the same range. For example the v/c ratios for all the 3 options are all in the range of 0.867. Although the indicator performances for each of the proposed options are all different, it is not conclusive to base judgement on them. The same applies to all the other criteria used.

7.3. Policy relevance

Indicators are things that we measure in order to evaluate progress towards goals and objectives. In order to provide useful information to decision makers and also the general public there is the need to carefully select indicators. More so there is the need to understand what they measure and also their limitations (Litman 2007). Hart (1997) as cited by Litman (2007) recommends asking the following questions about potential indicators:

- Is it relevant to the community?
- Is it understandable to the community at large? It further explains that if it is only understood by experts, it is only these experts who will use it.

- Does it provide a long term view of the community?
- Is it based on information that is reliable, accessible, timely and accurate?

These checklist of questions helps to pre-consider which indicators will be used and also ensures that the indicators chosen are relevant. This is to ensure its usage by decision makers and also beneficial for transport goals set by municipal authorities, in this case, the IMM. Aside these questions that should be asked, Hart (1997) and Marsden et al (2006) as cited by Litman (2007) also mention some principles that should be applied when selecting transportation performance indicators. Litman mentions that the indicators should take these aspects of the data into cognition;
High standards in terms of data quality; data sets should be comparable; indicators should be useful to decision makers and understandable to the general public; indicators should be cost effective to collect and lastly indicators selected should reflect set objectives.

These guidelines are general issues to consider in selecting indicators. They are helpful as they keep the researcher focused on what to collect and also at which scale the analysis is going to be made. It is good also to be realistic when selecting indicators, taking into consideration data availability, understandability and usefulness in decision-making. It is also important that users understand the perspectives, assumptions and limitations in different types of indicators and indicator data.

In this research we relied on information that was readily available considering the time availability and resources available. The indicators used are understandable and will make meaning to both the IMM (policy makers) and the general public.

Istanbul's transportation issues are rather a complex one and there is the need for policies that intervene delicately and deliberately to address salient issues of recurring congestion. One of the stepping stones in terms of policy direction for the city is the Transport Master Plan for Istanbul (2006) and the Ministry of Transport Strategic Plan (2009 – 2013).

7.4. Summary

In this chapter we discussed the whole process of this research from identifying alternatives to evaluation through selecting the better alternative. In the end some thoughts are shared on the relevance of indicators and the need to ensure that it makes meaning and understanding to decision makers and the general public. The last chapter discusses the main findings of the research, give conclusions and give directions for future work.

8. Conclusion and recommendation

The objective of this chapter is to summarise the study with respect to achievements, limitations and recommendations for future work. This last chapter outlines a review of the research objectives; give some recommendations and directions for future research.

8.1. Introduction

This research focussed on choosing the 'best option' out of 3 new connections over the bosphorus, based on graph theory indicators and traffic performance indicators. The reason for this was that most approaches to this decision problem did not consider network structure analysis as part of the criteria for the selection process. From literature it was realised that these quantitative indices are not widely used in actual datasets, however they provide easily obtainable and quantitative information that can be utilized in transport planning context. The extent of the study area had to be limited to the old municipal boundaries of the city as a result of data availability.

This chapter gives conclusions on this research based on the main research objective, to develop and operationalise network indicators that can be used to prioritise the location of a new transport connection. Also some limitations are discussed and possible research direction for future work.

8.2. Main findings

The main findings of this research work are as follows;

- Network indicators explored in this research provided quantitative information for urban transport analysis.
- Graph theory measures can easily be utilised in combination with traffic performance measures.
- In a typical multi-criteria evaluation (MCE) framework, option 2a (option that incorporates Marmaray crossing and highway bridge in between existing two bridges) appeared to be the dominant alternative. However, indicator values for each of the options were similar and such a conclusive decision could not be made on the best option.
- The method presented in this research presents an objective approach combining connectivity and traffic performance indicators. The output indicators used in this research can be used as a basis for a more comprehensive transport analysis for network improvement plans.
- The hypothesis was that transport network indicators may be used to prioritise the location of a new transport connection to ensure general improvements in the network structure and performance. Results from the research confirmed this hypothesis.

8.3. Conclusions

The main objective of this research was to develop and operationalise network based indicators to prioritise the location of a new urban transport connection. In view of this some network based indicators were explored at various degrees of aggregation in order to answer the decision problem. To answer these questions, research questions were developed. Sections 8.3.1 to 8.3.3 below is a review of the sub objectives formulated with the purpose of analysing the extent to which they were achieved.

8.3.1. Specific objective 1

To explore the use of network based indicators (NBI) for transport network planning

For this research work both graph theory and traffic performance indicators for transport planning were explored at various degrees of aggregation. One of the reasons for analysing graph theory measures (of alpha, gamma, beta and space syntax) were to compare how topological properties of a network could be utilised for this kind of decision problem. This objective was pursued through an exploratory approach. And in the end it was realised that the alpha, gamma and beta indicators could not be utilised for in this case. This was not as a result of its inappropriateness but with the formula for calculating the indicator. This indicator will be better suited for a decision problem with several new connections for each of the options.

It should however be noted that the space syntax parameters of global and local integration was useful in this sense as it provided meaningful results in terms of accessibility values. It utilises the concept of adjacency in graph theory.

8.3.2. Specific objective 2

To examine effects that additional transport connection(s) have on general structure of the city of Istanbul

The idea behind this objective was to anlayse the network performance as new connections were introduced. The reason is that a new connection in the network has to improve on the existing situation in terms of connectivity, ease of traffic, decrease in travel time and distance among others. And as such if an indicator rather performs worse after improvement in the network, then is should not be built in the first place.

As already discussed in section 6.1 to 6.7, it was realised that the alpha, gamma and beta indicators gave outputs that could not be used to make a decision on the problem at stake. The results gave similar outputs that could not be used. The results however gave some insights to the connectivity levels of the various network scenarios.

8.3.3. Specific objective 3

To use NBIs to prioritise expansion of the transport network of Istanbul

Network based indicators are relevant in measuring the impacts of new connections in any network. They should however be used with caution with respect to the meaning of the indicators. It was realised that though a framework was developed to evaluate the best performing options, a decision could not be arrived at because of similar performance of indicators under the 3 options compared. This framework could be used to inform decision makers and the general public on the effects of a new connection(s) within a network. The researcher presented a sound and replicable process which can be utilised in other cities other than Istanbul for similar decision problems.

8.4. Recommendations

8.4.1. Limitations of the research

The following factors restrict the extent to which findings in this research may not be conclusive enough in choosing the best option for network improvements.

- One of the limitations of this work was that economic, social, environmental indicators were not considered as data required for such comprehensive analysis are huge and not possible to obtain considering the time and resources available to do this research. The idea is that an approach had to be developed which utilised data already available and hence easy to collect, and develop it into a framework for selecting a 'best' option from a number of options.
- This study also excluded other network improvements for the city including but not limited to public transport, rail improvements and sea transportation. The focus was only on road transportation and its impacts on traffic re-distribution and also accessibility as a result of improvements. Information on such network improvements by the modes not considered can be made available by the IMM and IMP for a holistic analysis of accessibility and traffic mitigation measures.
- Data required to perform the 4-step transport model was only available for the old municipal boundaries of the city and not at the whole city scale. Hence although a whole city wide evaluation could have been done, it was not possible because of data availability. Also for traffic assignment on the network, only private vehicle trips were considered using the all-or-nothing assignment. The reason being that for the assignment model rail and public transport routes did not form a 'network' to allow for such analysis to be done. The data required for the 4-step transport model should be made available by the IMM and IMP so that several scenarios of the future can be modelled and assessed.
- Not all network improvement options could be evaluated. This was because data on specific locations of where such developments will take place was not available and have to be digitised by researcher. This brings some uncertainties with respect to the exact location of where improvements will take place, which may bring about distortions in indicator values.

Limitations encountered in this research can be interesting areas to overcome and to consider for future work.

8.4.2. Future research direction

Findings from this research work can be used as a stepping stone to analyse other network based indicators that were not explored in this research work. The problem of congestion is a growing concern in most cities and government efforts to improve network performance by additional connections to ease congestion will always be with us. Provided in the paragraphs below are some directions for future research work. This can enhance the understanding of network based indicators in these kinds of decision problems. More so, the limitations outlined in this research are all potential areas to consider in subsequent work to improve on the concept.

In further research it would be interesting to consider exploring inter-relationships that might exist between graph theory measures, volume-to-capacity (v/c) ratio and system wide travel time at various levels of aggregation. For example it was realised that with the addition of a new connection over the bosphorus, the accessibility measure (sum and mean of global and local integration) increased, volume-to-capacity ration decreased as well as system wide travel time reduced. Although indicator values for each option gave similar results, this can be explored further to find correlations.

In assigning traffic on the network, Flowmap 7 uses the all-or-nothing assignment; however subsequent work should consider using an equilibrium assignment model.

References

Alpkokin, P. and Y. Hayashi (2003). Istanbul transportation master plan study towards more integrated transportation and more sustainable city. Proceedings of the Eastern Asia Society for Transportation Studies, Fukuoka, Eastern Asia Society for Transportation Studies.

Batty, M. (2004). "A new theory of space syntax." WP75, Centre for Advanced Spatial Analysis, University College London, http://www. casa. ucl. ac. uk/publications.

Batty, M. (2005). "Network geography: Relations, interactions, scaling and spatial processes in GIS." Re-presenting GIS: 149-170.

Black, J. (1981). Urban transport planning: theory and practice, Croom Helm Ltd.

Buhl, J., J. Gautrais, et al. (2006). "Topological patterns in street networks of self-organized urban settlements." The European Physical Journal B-Condensed Matter **49**(4): 513-522.

Button, K. and D. Hensher, Eds. (2001). Handbooks in transport 3 Handbook of transport systems and traffic control

Elsevier Science Ltd.

Desyllas, J. (1999). The relationship between urban street configuration and office rent patterns in Berlin. The Bartlett, University College London, Gower Street, London. **PhD Thesis**.

Dill, J. (2003). Measuring network connectivity for bicycling and walking. Joint Congresss of ACSP-AESOP, Leuven, Belgium.

Fullerton, B. (1975). The development of British transport networks, Oxford University Press.

Gastner, M. and M. Newman (2006). "The spatial structure of networks." The European Physical Journal B-Condensed Matter and Complex Systems **49**(2): 247-252.

Greene, D. and M. Wegener (1997). "Sustainable transport." Journal of Transport Geography **5**(3): 177-190.

Haggett, P. and R. Chorley (1969). Network analysis in geography. London, Edward Arnold.

Hart, M. (1997). "Evaluating indicators: A checklist for Communities." Johnson Foundation.

Hillier, B. (1996). Space is the Machine. Cambridge, UK, Cambridge University Press.

Hillier, B. (1999). "The Hidden Geometry of Deformed Grids." Environment and Planning B **26**: 169-191.

Hillier, B. and J. Hanson (1984). The social logic of space. Cambridge, UK, Cambridge University Press Cambridge.

Hillier, B. and S. Iida (2005). "Network and psychological effects in urban movement." Lecture Notes in Computer Science **3693**: 475.

Istanbul Metropolitan Municipality and JICA (2008). The study on Integrated Transportation Master Plan for Istanbul Metropolitan Area in the republic of Turkey, Final Draft Report (2008). Istanbul, Istanbul Metropolitan Municpality and Japan International Coorporation Agency.

Jenelius, E. (2010). "User inequity implications of road network vulnerability." Journal of Transport and Land Use 2 **3/4**: 57 - 73.

Jiang, B. (2005). Axwoman 4.0 Extension for ArcGIS 9.2 User's Guide. Kowloon, Hong Kong, Department of Land Surveying and Geo-informatics, Hung Hom.

Jiang, B., C. Claramunt, et al. (2000). "An integration of space syntax into GIS for modelling urban spaces." International Journal of Applied Earth Observations and Geoinformation **2**(3-4): 161-171.

Kansky, K. (1963). Structure of transportation networks: relationships between network geometry and regional characteristics. Chicago, IL, Department of Geography, University of Chicago.

Kruger, M. J. T. (1989). On node and axial grid maps: distance measures and related topics. Paper presented at European Conference on the Representation and Management of Urban Change, Cambridge, 28-29 September 1999. Cambridge.

Kubat, A., H. Kaya, et al. (2007). The effects of proposed bridges on urban macroform of Istanbul: a syntactic evaluation. 6th International Space Syntax Symposium, Istanbul, Turkey.

Litman, T. (2007). "Well measured: Developing indicators for comprehensive and sustainable transport planning." Transportation Research Record: Journal of the Transportation Research Board **2017**(1): 1 - 45.

Lowe, J. C. and S. Moryadas (1975). The geography of movement, Houghton Mifflin Harcourt (HMH).
Marsden, G., C. Kelly, et al. (2006). "Selecting indicators for strategic performance management." Transportation Research Record: Journal of the Transportation Research Board **1956**(1): 21-29.
Marshall, S. (2005). Streets and Patterns. New York, Spon Press.
Miller, H. and S. Shaw (2001). Geographic information systems for transportation: Principles and applications, Oxford University Press, USA.
Morlock, E. K. (1967). An analysis of transport technology and network structure. Evanston, Illinois, The Transportation Center Northwestern University.
Nagar, A. and H. Tawfik (2007). "A Multi-Criteria Based Approach to Prototyping Urban Road Networks." Issues in Informing Science and Information Technology **4**.
Nystuen, J. and M. Dacey (1961). "A graph theory interpretation of nodal regions." Papers in Regional Science **7**(1): 29-42.
Porta, S., P. Crucitti, et al. (2008). "Multiple centrality assessment in Parma: a network analysis of paths and open spaces." Urban Design International **13**(1): 41-50.
Raford, N. and D. Ragland (2004). "Space Syntax: Innovative Pedestrian Volume Modeling Tool for Pedestrian Safety." Transportation Research Record: Journal of the Transportation Research Board **1878**(-1): 66-74.
Rodrigue, J., C. Comtois, et al. (2009). The geography of transport systems. New York, Routledge.
Samaniego, H. and M. Moses (2008). "Cities as organisms: Allometric scaling of urban road networks." Journal of Transport and Land Use **1**(1): 21-39.
Scheurer, J. and C. Curtis (2008). "Spatial Network Analysis of Multimodal Transport Systems: Developing a Strategic Planning Tool to Assess the Congruence of Movement and Urban Structure. A case study of Perth-to-Mandurah railway." Research Monograph, Curtin University of Technology, Perth (WA).
Scheurer, J. and S. Porta (2006). Centrality and connectivity in public transport networks and their significance for transport sustainability in cities. World Planning Schools Congress, Mexico City.
Scott, D., D. Novak, et al. (2006). "Network robustness index: A new method for identifying critical links and evaluating the performance of transportation networks." Journal of Transport Geography **14**(3): 215-227.
Taaffe, E. and H. Gauthier (1973). Geography of Transportation, Engelwood Cliffs, New Jersey: Prentice Hall.
Tsamboulas, D. (2007). "A tool for prioritizing multinational transport infrastructure investments." Transport Policy **14**(1): 11-26.
Turner, A. (2007). "From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis." Environment and Planning B and Planning Design **34**(3): 539.
Ulengin, F. (1994). "Easing the traffic in Istanbul: at what price?" Journal of the Operational Research Society: 771-785.
Van der Zwan, J., R. Van der Wel, et al. (2003). Manual Flowmap 7, Faculty of Geosciences, University of Utrecht, Utrecht.
van Nes, A. (2009). Analysing larger metropolitan areas on identification criteria for middle scale networks. 7th International Space Syntax Symposium, Stokhom, KTH.
Vickerman, R. (2001). The concept of optimal transport systems. Hanbooks in transport 3, Handbook of transport systems and traffic control. K. Button and D. Hensher. Oxford, Pergamon. **3:** 13.
Vuchic, V. (2007). Urban Transit Systems and Technology: systems and technology, Wiley.
Wegener, M. and D. Greene (2002). Sustainable Transport. Social change and sustainable transport. W. R. Black and P. Nijkamp. Bloomington, Indiana USA, Indiana University Press**:** 35.
Xie, F. and D. Levinson (2006). "Measuring the structure of road networks." Geographical Analysis **39**(3): 336-356.
Yang, H. and M. Bell (1998). "A capacity paradox in network design and how to avoid it." Transportation Research Part A **32**(7): 539-545.

Appendix 1

The network categories used are explained below. The network options that are explored are same as outlined in section 5.3

1	Highways and highway junctions for option 1a
2	Highways and highway junctions for option 1b
3	Highways and highway junctions for option 2a
4	Highways and highway junctions for option 3a
5	Highways, highway junctions and 1st arterials for option 1a
6	Highways, highway junctions, 1st arterials and proposed rails for option 1b
7	Highways, highway junctions, 1st arterials and proposed rails for option 2a
8	Highways, highway junctions, 1st arterials and proposed rails for option 3a
9	Highways, highway junctions and 1st 2nd arterials for option 1a
10	Highways, highway junctions and 1st 2nd arterials for option 1b
11	Highways, highway junctions and 1st 2nd arterials for option 2a
12	Highways, highway junctions and 1st 2nd arterials for option 3a
13	Highways, highway junctions and 1st 2nd 3rd arterials for option 1a
14	Highways, highway junctions and 1st 2nd 3rd arterials for option 1b
15	Highways, highway junctions and 1st 2nd 3rd arterials for option 2a
16	Highways, highway junctions and 1st 2nd 3rd arterials for option 3a
17	Highways, highway junctions,1st 2nd 3rd arterials and pedestrian walkways for option 1a
18	Highways, highway junctions,1st 2nd 3rd arterials, pedestrian walkways and existing rails for option 1a
19	Highways, highway junctions,1st 2nd 3rd arterials, pedestrian walkways, existing and proposed rails for option 1b
20	Highways, highway junctions,1st 2nd 3rd arterials, pedestrian walkways, existing and proposed rails for option 2a
21	Highways, highway junctions,1st 2nd 3rd arterials, pedestrian walkways, existing and proposed rails for option 3a

Appendix 2

Variables used for the trip generation model for each zone (2006 household survey).
Source: Fieldwork 2009, IMP

Zone ID	Area (sq. m)	Employment	Worker	Population	Student at home	Student at school	Number of vehicles	HH size	HH income	Personal income	Worker (home based)
920267	74100000	974	422.51	1837	394	51	165.33	3.70	726.33	196.31	422.51
920270	95400000	1400	631.03	2141	459	145	135.22	3.52	556.30	158.04	631.03
925349	108000000	2191	3411.93	10318	1432	687	822.15	3.14	861.00	274.20	3411.93
925350	171000000	20145	35487.11	121347	23068	16641	8726.93	4.23	767.20	181.37	35487.11
919254	15100000	10042	14845.26	46528	9350	6477	7262.05	3.31	1374.16	415.16	14845.26
919258	22600000	9920	17399.54	55163	9998	12395	7475.42	3.24	1141.80	352.41	17399.54
919251	9128280	4686	5215.44	13839	2875	634	1445.88	3.67	1048.78	285.77	5215.44
919242	1553236	548	317.46	962	206	9995	100.98	3.62	599.44	165.59	317.46
919244	5134322	3400	4777.52	14275	2111	2877	2302.39	3.49	1320.94	378.49	4777.52
919248	6715727	5721	4525.49	11671	1963	1582	1667.29	3.70	1389.64	375.58	4525.49
912158	4275214	30012	42882.15	118028	25275	17904	15791.62	3.24	1230.84	379.89	42882.15
912156	3971564	9555	16098.04	47325	9604	25785	5976.13	3.60	1152.70	320.19	16098.04
923306	87800000	2495	1107.37	3906	838	280	483.22	3.80	698.84	183.91	1107.37
929406	36200000	2860	1973.38	5065	1224	987	690.68	3.76	1166.22	310.16	1973.38
929398	3010998	913	760.93	2443	524	337	256.45	3.62	1301.53	359.54	760.93
929401	10900000	365	282.81	857	184	17	89.96	3.62	750.00	207.18	282.81
929403	16800000	1217	1068.63	3008	645	3381	158.32	3.45	822.86	238.51	1068.63
929400	4489868	548	1471.53	4693	1006	565	517.03	3.69	1593.84	431.94	1471.53
929404	19300000	10164	20919.65	64946	13380	9737	8034.96	3.43	1144.39	333.64	20919.65
929391	1145248	1156	3580.17	12102	2572	2598	1008.50	3.81	1007.10	264.33	3580.17
929385	622277	304	2785.76	7456	1599	325	1474.83	3.14	1576.00	501.91	2785.76
929399	3707110	6999	12329.09	31650	6880	4161	6458.14	3.17	1717.65	541.85	12329.09
929396	2021526	2739	5522.85	16331	2962	2468	3384.95	3.02	2018.15	668.26	5522.85
929395	1787898	6695	6147.20	18080	4467	2475	2996.15	3.61	1349.00	373.68	6147.20
929392	1255154	1217	3252.82	9238	1297	1191	1626.41	2.84	2793.66	983.68	3252.82
929387	792196	974	2549.18	7373	2070	1412	627.48	4.09	867.04	211.99	2549.18
929389	1064937	2313	3862.08	11408	2738	3777	2614.34	2.78	1975.55	710.63	3862.08
917213	1224001	3408	1984.62	6014	1290	10018	3546.78	1.77	2477.64	1399.79	1984.62
917199	405301	2860	1841.25	4910	1053	597	1010.87	2.43	2286.36	940.89	1841.25
917209	1011540	791	1068.83	3498	750	1153	476.99	3.14	895.33	285.14	1068.83
917208	769992	6512	3191.78	8574	977	1912	1816.55	2.88	1964.12	681.99	3191.78
917201	564806	730	3585.41	11855	1924	2875	1474.20	2.41	1453.63	603.16	3585.41
917214	1402776	14789	4398.19	10529	1928	30687	1978.62	2.40	2055.06	856.28	4398.19
917197	167786	7973	565.23	2672	573	0	53.44	2.27	1027.73	452.74	565.23
917203	592625	4443	3328.44	7256	1882	607	1007.78	2.40	1773.22	738.84	3328.44
918225	236094	2739	669.24	2028	435	2718	212.88	3.62	1443.00	398.62	669.24
918229	348743	4869	1526.67	4580	983	4548	480.77	3.62	1500.00	414.36	1526.67
918219	141375	11076	142.56	432	93	0	45.35	3.62	1566.60	432.76	142.56
918221	155397	5660	41.58	126	27	0	13.23	3.62	1589.44	439.07	41.58
918236	526400	5843	3459.81	10963	2342	4392	393.09	3.44	991.95	288.36	3459.81
918238	553540	1948	3703.37	11249	1802	2673	813.75	3.31	1109.38	335.16	3703.37
918231	375381	2921	4086.79	12507	3111	0	975.99	3.43	895.25	261.01	4086.79
918241	894323	4504	7276.55	23551	5431	5736	1357.17	3.71	931.53	251.09	7276.55
918240	719582	2921	2549.38	8734	1976	1496	1079.48	3.42	911.98	266.66	2549.38
918237	538043	2008	3259.68	9925	2651	893	744.38	4.35	1055.61	242.67	3259.68
923303	10200000	1826	9270.62	28078	5325	3662	1693.60	3.56	960.71	269.86	9270.62
923295	1172161	3165	8097.34	25081	6224	2263	2026.72	3.88	1037.84	267.48	8097.34
923299	1428641	7181	6402.92	22373	3978	8132	1858.07	3.78	921.50	243.78	6402.92

923300	1597461	6573	6323.15	21627	4868	9113	1763.58	3.61	950.95	263.42	6323.15
924327	422237	1521	2274.22	8580	1393	1389	397.75	3.97	846.42	213.20	2274.22
924325	368774	2374	2703.25	11017	1976	2200	641.77	3.49	830.93	238.09	2703.25
924314	250895	1704	3850.61	13641	2694	1959	1049.32	3.32	1074.11	323.53	3850.61
924317	275179	2921	1961.25	8304	1632	3933	856.08	3.73	1249.87	335.08	1961.25
921277	430002	5599	1612.76	5861	1226	1223	79.74	4.90	776.73	158.52	1612.76
921276	351648	31160	121.77	369	79	751	38.73	3.62	759.29	209.75	121.77
921283	1304374	18319	1925.87	5153	971	859	318.75	3.23	1095.03	339.02	1925.87
921282	670136	19536	2542.03	8078	1265	2877	406.80	3.09	997.84	322.93	2542.03
921278	454474	7121	2460.72	6842	1261	6307	244.35	2.95	985.03	333.91	2460.72
921281	594664	7181	4464.61	11514	1179	1108	412.69	3.77	978.59	259.57	4464.61
924333	519806	11076	1190.27	4421	948	0	709.33	2.37	986.89	416.41	1190.27
924335	618427	7425	3976.69	13748	2423	7018	1368.57	3.11	1052.08	338.29	3976.69
924331	497010	6025	6233.98	20274	3639	5017	1382.32	2.82	1013.74	359.48	6233.98
924336	927138	1095	5279.89	16010	3402	2240	1014.40	3.49	915.47	262.31	5279.89
932448	2429866	18623	11822.30	33778	6450	5847	2888.59	3.70	1051.57	284.21	11822.30
915181	1072391	18197	7274.33	20989	3777	5618	3521.37	2.70	1407.92	521.45	7274.33
915178	555606	4321	601.26	1822	391	0	191.26	3.62	2650.00	732.04	601.26
915182	1211571	2434	2549.67	7649	1634	813	2658.15	2.47	2304.49	932.99	2549.67
915188	13000000	34873	9071.73	24253	3810	5287	6340.96	2.82	1770.24	627.75	9071.73
915180	681020	1643	2311.32	7004	1503	632	2429.96	2.45	1653.25	674.80	2311.32
915187	5038971	13511	8741.21	23964	7037	9510	7195.21	3.36	1951.93	580.93	8741.21
928372	1430432	1521	3443.92	15115	1631	1577	1738.23	3.13	991.23	316.69	3443.92
912160	11200000	8155	7565.32	20450	3504	3101	1300.28	3.60	876.28	243.41	7565.32
928384	66700000	20205	22930.01	80618	15882	23029	6602.39	3.98	784.03	196.99	22930.01
928376	2250064	1400	2101.19	8526	2059	1125	877.67	4.43	845.24	190.80	2101.19
928380	6227009	2434	9629.46	26310	3815	3622	5283.79	3.22	1523.13	473.02	9629.46
928377	2395979	17528	30700.63	97325	20233	19373	6184.58	3.97	892.40	224.79	30700.63
920265	46300000	28543	4464.13	13655	3573	2393	1271.79	3.89	1088.89	279.92	4464.13
928383	22900000	79886	5762.69	21060	4516	6797	3008.59	3.96	1189.49	300.38	5762.69
922293	34400000	3773	5481.82	19047	4305	7694	3662.93	3.68	1644.44	446.86	5481.82
925348	38300000	7912	6047.08	24317	5246	4426	1175.06	4.69	746.88	159.25	6047.08
923304	29100000	4686	2923.14	8858	1900	2380	929.84	3.62	2245.55	620.32	2923.14
923305	63600000	1217	1988.02	6770	1452	1986	715.52	3.84	857.34	223.27	1988.02
929405	28500000	2008	2698.33	6931	1490	3578	1534.33	3.45	1888.18	547.30	2698.33
929402	11600000	1765	3992.04	8282	2467	640	3592.96	2.83	2812.83	993.93	3992.04
931442	16100000	9555	9080.06	24712	5702	7024	2721.92	3.58	1270.64	354.93	9080.06
931441	5030343	31890	1584.79	4034	865	7745	423.46	3.62	1348.57	372.53	1584.79
929394	1423840	548	3593.00	10779	2472	918	1046.50	3.86	990.33	256.56	3593.00
929393	1281899	244	3714.48	11256	2415	1761	1181.57	3.62	1561.56	431.37	3714.48
929397	2787574	6695	5886.38	16459	2833	17795	2914.65	3.35	1308.28	390.53	5886.38
929390	1071036	669	4795.09	14893	4000	1370	1861.64	3.77	991.37	262.96	4795.09
917212	1220992	14485	3969.27	11199	681	4540	3870.29	2.47	2575.71	1042.80	3969.27
917206	737772	2739	1498.20	4540	974	2659	476.57	3.62	3933.50	1086.60	1498.20
917202	588338	3408	2079.00	6237	1254	1552	896.82	3.48	1412.93	406.01	2079.00
917207	761656	609	2590.49	5321	1141	232	2176.82	2.36	2501.93	1060.14	2590.49
917200	559603	6816	896.61	2717	583	1845	285.21	3.62	1328.13	366.89	896.61
917205	635070	4138	5863.64	15996	4434	2302	2873.58	2.90	1696.36	584.95	5863.64
917198	350921	2191	5747.43	16264	3045	713	1898.54	2.45	1331.24	543.36	5747.43
931431	562164	14971	6372.77	17280	2485	8522	3323.10	2.55	1691.65	663.39	6372.77
931436	838178	12598	1729.20	5240	1124	9600	550.05	3.62	1662.09	459.14	1729.20
918234	469180	25744	3190.14	7256	1708	1930	1276.53	2.35	2339.85	995.68	3190.14
918227	295108	5782	2783.05	8813	1632	4358	890.21	2.41	1498.37	621.73	2783.05
918223	164369	2617	912.12	2764	593	1013	290.15	3.62	1633.19	451.16	912.12

918218	135921	5295	262.35	795	171	1369	83.45	3.62	2166.00	598.34	262.35
918230	372996	10590	1994.23	6100	1321	1509	414.56	3.32	1059.26	319.05	1994.23
918224	225676	4990	949.19	4390	1334	0	460.83	3.62	735.61	203.21	949.19
918217	100781	1095	2741.28	8746	1780	0	98.64	4.67	759.02	162.53	2741.28
918222	156560	1156	1564.65	7481	2042	1485	101.78	4.45	644.76	144.89	1564.65
918239	697353	7121	6975.30	24760	3978	1876	710.14	3.66	859.20	234.75	6975.30
918233	450532	2130	4213.12	16505	3203	3155	1415.96	3.33	878.88	263.93	4213.12
918232	410528	1948	4995.47	16016	3680	2099	1640.67	3.57	898.04	251.55	4995.47
918228	344893	1095	4093.19	13732	3681	0	990.49	4.01	1102.89	275.04	4093.19
918235	493036	5417	6933.22	21233	4811	4882	1758.44	3.77	913.16	242.22	6933.22
927361	556352	1765	3608.31	11727	2426	4400	1162.99	3.78	960.20	254.02	3608.31
927370	2221754	12233	6498.91	19930	5478	6077	2179.82	3.56	1123.33	315.54	6498.91
927365	853713	3104	5456.96	16163	2974	2023	2172.72	3.39	1313.96	387.60	5456.96
927371	4068193	8216	8766.18	26838	4601	7142	2697.72	3.75	994.22	265.13	8766.18
923298	1410279	1582	11357.80	31320	6172	6908	2599.01	3.70	1162.35	314.15	11357.80
923302	1963610	8338	8914.66	30098	6641	3214	3000.83	3.82	938.68	245.73	8914.66
923294	1100064	669	7393.92	21224	4387	7270	1719.80	3.88	1026.31	264.51	7393.92
925342	1631106	6329	21655.84	71204	13357	7943	5728.52	3.51	963.38	274.47	21655.84
925339	1253096	4382	17956.46	58835	10981	5199	5977.01	3.46	1093.53	316.05	17956.46
923296	1216587	10407	12443.67	40865	8328	5569	4248.31	3.19	977.04	306.28	12443.67
923301	1656023	23674	1680.76	4418	551	625	194.20	3.64	990.00	271.98	1680.76
924310	212433	1765	1865.61	6981	1556	1908	587.18	3.57	915.73	256.51	1865.61
924320	301430	1278	4740.34	17047	3335	4793	799.85	3.75	868.08	231.49	4740.34
924313	250040	1887	3741.66	11833	2643	2281	1704.36	3.16	1364.53	431.81	3741.66
924321	302534	2008	4900.31	17377	3439	2684	1371.87	3.77	960.63	254.81	4900.31
924330	482339	6816	5544.33	16633	3141	4564	1370.32	3.63	1016.78	280.11	5544.33
921280	509533	7181	719.67	3048	654	21241	319.96	3.62	565.40	156.19	719.67
921279	457149	62625	244.53	741	159	1877	77.79	3.62	600.00	165.75	244.53
921275	293544	12476	1332.00	3552	762	5806	512.90	2.63	947.47	360.26	1332.00
924322	303519	4443	3166.40	8494	1577	3044	967.67	3.16	972.56	307.77	3166.40
924319	296964	7303	3109.08	9929	2542	0	727.79	2.69	1110.44	412.80	3109.08
924318	286787	5599	4041.47	12798	2197	1505	1633.78	2.65	1055.61	398.34	4041.47
924332	518104	1521	8098.09	23363	5017	2132	2138.89	3.28	955.13	291.20	8098.09
932446	1242609	10164	7623.96	25084	3958	1837	1384.52	3.78	903.06	238.91	7623.96
932444	1124346	23066	21590.47	66175	11463	14727	4995.93	3.70	958.55	259.07	21590.47
932445	1225503	21423	27547.67	82933	16092	14669	8161.43	3.65	1101.17	301.69	27547.67
932443	785217	16554	19734.30	57972	12140	6194	3770.19	3.83	996.22	260.11	19734.30
915186	2386427	5721	6434.87	17011	3760	4382	2421.03	3.36	1313.78	391.01	6434.87
915183	1339716	6877	10424.59	29723	6012	10725	5470.74	2.91	1589.78	546.31	10424.59
915184	1842171	13876	6644.13	17617	4138	2569	3724.70	2.73	1791.93	656.38	6644.13
915179	643308	1643	2207.86	6182	1215	3208	1159.10	2.60	1569.44	603.63	2207.86
915185	2045500	4564	8030.64	18444	2637	6208	7501.22	2.46	2215.36	900.55	8030.64
914177	4380195	57756	10613.90	27832	6513	8802	4198.39	3.69	1328.40	360.00	10613.90
928379	3503349	19536	28073.26	89270	16340	14373	6066.97	3.71	950.32	256.15	28073.26
928374	2027343	16250	31594.55	95859	19804	18864	10621.55	3.32	1046.04	315.07	31594.55
928375	2030704	8155	25373.55	80390	15784	8898	8278.32	3.49	1064.42	304.99	25373.55
928373	1861893	8703	21129.63	64565	12861	11068	4700.10	4.09	948.21	231.84	21129.63
928381	12900000	26657	27178.91	79351	16185	21720	12981.27	3.45	1268.13	367.58	27178.91
928378	2811556	56478	27452.44	84179	18358	13492	5453.18	4.00	901.20	225.30	27452.44
913170	4542790	27265	8088.60	24417	4829	3505	907.13	4.34	787.13	181.37	8088.60
913169	3231019	24466	40472.63	132645	30679	25147	8008.19	4.25	858.54	202.01	40472.63
913162	1128952	16615	15415.01	51330	11263	9439	2482.40	4.56	860.19	188.64	15415.01
922292	2374011	11989	27862.63	90922	22442	14484	5356.75	4.21	860.45	204.38	27862.63
922285	552625	7973	10450.54	34741	8192	8892	2527.26	4.15	855.76	206.21	10450.54

922287	723331	4747	6052.29	20828	4159	5481	1301.74	4.44	817.99	184.23	6052.29
916196	2074208	17649	19121.10	61630	12854	11451	6686.57	3.70	1050.40	283.89	19121.10
916195	1771685	15154	5668.49	17872	4895	3384	1334.85	3.74	991.60	265.13	5668.49
925344	2301823	18014	38815.29	125627	27919	20193	9845.04	4.11	946.01	230.17	38815.29
925346	5604312	48323	47837.18	155336	33443	32124	12881.45	4.28	981.02	229.21	47837.18
925347	14400000	20814	29887.31	96992	19544	19438	6521.15	4.18	931.02	222.73	29887.31
925345	3899166	13815	31092.45	93794	17175	18916	4696.84	3.92	823.96	210.19	31092.45
925343	2128660	6999	20733.07	64813	14675	10043	5172.50	4.12	995.55	241.64	20733.07
923297	1358567	5234	5059.83	16585	4480	6526	1674.84	4.02	980.48	243.90	5059.83
925340	1426658	10833	24897.71	80141	17811	8760	8305.61	3.76	1002.02	266.49	24897.71
925337	848883	21544	10238.73	29801	4766	19906	3174.05	3.45	1028.18	298.02	10238.73
916194	1309568	19658	15790.44	50799	10577	12459	3688.03	3.69	1047.05	283.75	15790.44
916192	826197	17528	5433.23	16677	3409	10211	1579.13	3.61	971.58	269.14	5433.23
916190	773022	18988	5513.19	15520	3332	2065	1047.59	3.45	903.28	261.82	5513.19
932449	3229588	41445	341.55	1035	222	0	108.65	3.62	951.93	262.96	341.55
924308	174059	2130	1527.20	4058	1182	101	308.76	3.29	976.86	296.92	1527.20
924324	354010	2678	3967.08	11815	2349	869	653.96	3.15	1084.51	344.29	3967.08
924315	257061	2617	4471.85	15547	3432	3557	1064.86	3.32	955.26	287.73	4471.85
924311	242917	3773	2699.61	9304	1767	0	650.28	3.10	1076.82	347.36	2699.61
924323	315777	7303	3979.70	14310	4159	1321	1594.92	3.08	1087.83	353.19	3979.70
924316	268437	3834	2697.39	8974	2421	1720	961.49	2.85	1086.19	381.12	2697.39
924334	530185	6634	7176.05	22741	4595	11609	2907.57	2.86	1225.80	428.60	7176.05
924307	129613	1339	2150.42	6511	1600	624	1034.45	2.82	1286.95	456.36	2150.42
932447	1256932	14606	6036.08	20844	3647	8095	1197.42	3.64	843.65	231.77	6036.08
926356	1688048	47897	13885.74	35436	7828	4602	6469.98	3.14	1414.71	450.55	13885.74
914176	3177226	16797	22363.06	66737	13758	43675	15671.93	3.02	1546.57	512.11	22363.06
914174	1903039	28421	47831.20	143868	32427	11557	15772.20	3.49	1118.15	320.39	47831.20
914171	1656597	13085	41693.64	124959	25939	20789	8005.42	3.94	984.39	249.85	41693.64
914173	1800462	14059	20769.43	58216	12557	12722	5236.38	3.63	970.46	267.34	20769.43
914175	1969513	10529	15074.57	45785	11015	13908	3888.90	3.97	1134.43	285.75	15074.57
913163	1373434	4564	4932.02	13046	1726	3554	1219.74	3.51	856.53	244.03	4932.02
913166	1892572	14850	15569.24	45808	9531	9947	2855.65	4.29	898.37	209.41	15569.24
913168	2962925	59886	37481.19	116599	26521	20522	8063.94	4.05	905.46	223.57	37481.19
913167	2341093	19719	38125.95	115993	27520	25209	7693.24	4.14	896.26	216.49	38125.95
922290	1186033	12415	24912.87	76389	13941	12503	4306.44	4.04	892.03	220.80	24912.87
922286	587656	4443	8840.04	26927	6236	1637	1757.75	4.14	963.18	232.65	8840.04
922291	1440373	22396	31618.41	98263	20373	20019	6534.20	4.16	906.87	218.00	31618.41
916193	1267990	15154	8915.14	26707	4706	4935	2161.28	3.62	902.33	249.26	8915.14
916191	799790	8216	13096.91	40616	8671	7682	4013.87	3.41	922.29	270.47	13096.91
925338	883527	8825	11599.47	34019	8206	4949	2641.81	3.80	1009.71	265.71	11599.47
925341	1554055	7547	9572.65	30854	4717	5360	1995.72	4.49	902.14	200.92	9572.65
916189	718787	18623	8328.29	25329	5217	2866	1646.57	3.97	954.83	240.51	8328.29
922289	1095777	1278	1202.14	3366	722	3615	353.34	3.62	961.17	265.52	1202.14
922288	954521	15093	16313.16	48044	9793	7540	2662.48	3.80	963.03	253.43	16313.16
926352	728456	13998	8411.07	23551	5551	5192	2489.71	3.63	1116.37	307.54	8411.07
926351	698874	15397	4976.59	14095	2597	1474	1091.63	4.18	969.36	231.90	4976.59
926354	1291683	17102	33601.31	98303	19803	9178	10528.18	3.57	1093.67	306.35	33601.31
914172	1666930	11502	35717.48	106673	24349	15060	9348.79	3.67	1056.20	287.79	35717.48
913165	1853783	16919	37967.65	116466	23710	20758	7515.42	4.14	922.11	222.73	37967.65
913161	1024520	5903	14588.62	42249	8973	11549	2498.33	3.93	935.66	238.08	14588.62
913164	1405243	20145	18506.69	62520	14201	8147	6232.84	3.78	1010.41	267.31	18506.69
926353	1251562	10103	10260.95	30818	7622	9723	3338.34	4.24	1074.20	253.35	10260.95
922284	503777	7121	14798.03	43779	8438	4889	3009.13	4.09	962.75	235.39	14798.03
926355	1542206	23431	32571.13	93942	20415	19855	8468.57	3.93	1051.54	267.57	32571.13

924326	383767	3652	3813.14	11897	1519	1408	906.95	3.05	907.03	297.39	3813.14
924329	447101	8581	2106.40	6490	1189	7512	741.71	2.63	1049.58	399.08	2106.40
924309	177790	2739	2066.64	6068	1867	2179	351.77	3.45	1081.43	313.46	2066.64
924312	245842	2130	3675.91	12191	3313	2805	1068.52	3.35	1036.91	309.52	3675.91
931440	2432749	2008	3891.64	8685	1843	1675	3275.43	2.87	2597.89	905.19	3891.64
927369	1117272	11076	5856.00	16848	4140	4037	1729.27	3.97	1041.72	262.40	5856.00
929388	894313	4320	1952.87	5518	1433	4310	635.81	3.74	1135.20	303.53	1952.87
917216	2611618	9068	6154.76	16500	2820	4142	5956.50	2.56	2628.37	1026.71	6154.76
917215	1507677	3043	5178.75	16572	1974	3837	4999.33	2.11	2006.95	951.16	5178.75
917210	1035005	1217	4295.19	12423	2261	746	4436.79	2.40	2907.56	1211.48	4295.19
931439	1530456	18623	2509.86	6932	757	3361	953.96	2.60	1389.24	534.32	2509.86
917204	598540	10955	5176.82	12974	2196	1764	3459.75	2.79	1990.06	713.28	5176.82
931434	674193	7060	6917.02	17496	3458	1771	3474.84	2.76	2011.85	728.93	6917.02
931429	435573	10224	3180.23	9308	1188	3328	1878.67	2.22	1834.27	826.25	3180.23
931428	399963	19962	3136.98	8610	1010	496	1707.80	2.37	1876.76	791.88	3136.98
931423	287208	2130	2104.52	7132	1308	1464	806.24	2.61	1069.43	409.74	2104.52
918220	151040	3408	1312.74	3978	853	136	718.02	2.11	954.05	452.16	1312.74
931426	363942	3286	7855.36	21995	3603	0	2089.27	2.69	1216.71	452.31	7855.36
931433	621829	7790	10007.78	28221	5148	6434	2666.96	3.23	1228.72	380.41	10007.78
931435	753455	1948	4799.73	12908	2604	2087	1143.16	3.04	975.34	320.83	4799.73
931424	333854	2860	4584.83	13296	3358	1843	895.84	3.44	1057.07	307.29	4584.83
931430	483292	7364	824.06	2637	566	1762	540.92	3.90	1402.50	359.62	824.06
927367	1038891	3408	10163.53	31533	5884	4962	2503.43	3.50	900.16	257.19	10163.53
927366	884988	6025	8848.07	24063	4966	5020	1623.30	3.50	1108.31	316.66	8848.07
927363	742922	25013	7739.73	22142	4352	1993	1259.47	4.04	1014.57	251.13	7739.73
927357	338791	2556	6210.81	17381	3219	2445	1416.92	3.23	988.91	306.16	6210.81
927358	376094	1704	6078.74	19316	3997	3727	1179.31	3.83	1030.06	268.95	6078.74
927364	757249	11685	9819.11	31152	6185	6112	2846.11	3.60	1108.06	307.79	9819.11
927359	393861	2008	3451.94	10042	2357	0	794.02	3.52	983.72	279.47	3451.94
917211	1075454	27995	1101.02	3248	697	1847	418.76	2.95	4487.11	1521.05	1101.02
927362	709393	7607	13863.04	39920	9304	9365	4600.60	3.54	1144.28	323.24	13863.04
927368	1098608	7912	25677.07	68342	14410	8252	4874.45	3.39	1044.40	308.08	25677.07
931437	871039	41750	12323.45	32061	7901	6816	4341.06	2.89	1522.57	526.84	12323.45
931438	1128291	19901	5624.16	12963	2123	5352	2336.31	2.49	1819.35	730.66	5624.16
931425	363587	7060	1895.66	4816	1033	2916	703.47	2.62	1194.65	455.97	1895.66
931427	364242	2921	4195.09	12200	2795	2539	1399.28	3.49	1191.31	341.35	4195.09
931422	274996	16189	1487.25	3966	1004	0	724.55	3.85	1970.30	511.77	1487.25
927360	443132	3834	7541.09	19493	4054	4101	1665.23	3.26	1168.80	358.53	7541.09
931432	586050	5964	6804.11	23387	6978	19918	1487.63	3.69	865.63	234.59	6804.11
919257	21900000	11746	19483.09	54255	14039	16922	12244.46	3.75	2163.93	577.05	19483.09
912159	4888979	3347	18118.69	53502	10729	11469	4270.45	4.28	867.58	202.70	18118.69
919246	5270824	15763	31483.71	91450	19509	11630	6172.18	3.88	890.79	229.59	31483.71
912157	4195392	6573	16860.03	43809	10671	7029	5349.19	3.54	1027.87	290.36	16860.03
919247	5731177	19049	15614.33	40440	7152	5705	3706.97	3.73	1093.67	293.21	15614.33
919243	4858545	24002	21198.47	55829	10948	12739	11840.48	2.99	1636.08	547.18	21198.47
919245	5145958	2374	1300.88	4967	1066	0	1419.15	3.11	1806.74	580.95	1300.88
919249	7852850	2678	7184.34	17793	4372	4825	4297.24	3.12	1751.86	561.49	7184.34
919250	9021477	16797	13744.13	37823	7218	5042	1971.05	3.97	868.65	218.80	13744.13
919255	18000000	13146	3647.10	9082	976	4450	1215.70	3.85	1136.70	295.25	3647.10
919256	20800000	609	640.86	1942	417	498	203.85	3.62	1188.64	328.35	640.86
920271	103000000	2860	975.22	2856	613	232	185.75	4.39	847.71	193.10	975.22
919252	9673933	22701	24563.81	76785	17773	16631	4709.59	4.31	831.07	192.82	24563.81
311128	183457	4564	1083.28	3441	738	518	318.62	2.45	1365.45	557.33	1083.28
311134	575979	5112	5425.05	14063	2743	1959	2686.16	2.93	1636.70	558.60	5425.05

311130	310344	8825	4031.39	12620	2205	4546	1402.21	3.10	1306.46	421.44	4031.39
311137	931439	2069	10115.46	27463	7370	5353	4989.04	3.12	1536.76	492.55	10115.46
311136	617015	1035	1984.57	5330	1143	275	1134.05	2.69	1897.49	705.39	1984.57
311138	1104329	669	950.07	2879	618	2342	302.21	3.62	1181.91	326.49	950.07
311139	1293246	3895	3443.86	9380	2531	2230	1948.51	3.29	1811.84	550.71	3443.86
311142	1651843	1217	3647.35	10421	1434	1343	2340.57	3.02	1741.66	576.71	3647.35
311147	1969620	1826	3165.06	8270	1118	1505	1550.63	3.20	1625.44	507.95	3165.06
302002	732798	669	950.62	3052	655	1589	600.38	2.90	1101.67	379.89	950.62
302003	990992	1765	909.15	2755	591	2963	289.20	3.62	1597.13	441.19	909.15
302004	1316823	1095	1278.75	4650	998	809	1162.49	2.67	1020.37	382.16	1278.75
302006	2125805	2252	6208.76	18878	4698	2396	3272.21	3.57	1362.28	381.59	6208.76
302005	1446669	3773	6516.31	18765	4504	3103	1763.83	3.30	995.65	301.71	6516.31
302011	6507074	3591	10253.48	34372	6952	7089	3196.40	3.49	893.62	256.05	10253.48
302008	3342136	4382	5601.31	20357	4229	6666	1797.43	3.41	936.64	274.68	5601.31
302013	9731083	3469	7423.71	24285	5344	2536	2448.25	3.66	937.40	256.12	7423.71
302018	31100000	426	648.90	2781	597	1591	339.90	3.46	774.92	223.97	648.90
302021	60400000	1035	909.43	3542	760	129	358.99	3.89	764.47	196.52	909.43
309105	36600000	20717	8836.58	29923	7597	8457	2237.59	3.94	713.06	180.98	8836.58
309102	15200000	20753	7612.67	24100	5103	6995	2365.11	3.40	865.28	254.49	7612.67
309101	9772182	13937	11654.87	32233	7503	6379	5766.76	3.16	1514.29	479.21	11654.87
309100	7300395	4138	4725.69	16906	3956	6495	3109.15	3.00	1300.00	433.33	4725.69
306067	2145643	8338	9394.83	28364	7314	7647	3051.83	3.54	909.43	256.90	9394.83
306074	3153049	13389	14483.96	42167	10011	4659	4730.64	3.34	1002.56	300.17	14483.96
306068	2356546	13024	8722.39	34288	5972	7556	6215.88	2.63	1201.02	456.66	8722.39
304044	2795486	17102	17166.19	45214	9799	6258	6767.41	3.14	1232.04	392.37	17166.19
304046	2971305	6269	19337.42	53352	11050	10896	6615.59	3.27	1535.76	469.65	19337.42
304045	2895794	2495	10404.19	29607	6624	5707	3275.36	3.11	1046.64	336.54	10404.19
305063	5428654	20388	28214.66	85581	22490	16010	13274.61	3.31	1168.57	353.04	28214.66
305058	1935362	2982	13767.38	41024	8456	4126	7648.60	2.94	1423.38	484.14	13767.38
305059	2050052	13754	21634.16	60969	12172	10336	12722.28	2.82	1627.49	577.12	21634.16
303032	1829677	21605	11272.57	33398	5681	6090	8214.53	2.65	1871.19	706.11	11272.57
303025	1426213	8581	8704.00	25364	4317	4292	6527.94	2.42	1658.25	685.23	8704.00
303026	1661514	5356	5273.37	19366	4215	4951	5455.11	2.27	1717.56	756.64	5273.37
303028	1678242	6938	7778.45	20879	3956	1358	6072.67	2.49	1581.37	635.09	7778.45
303027	1677460	8338	12273.11	33179	4600	3443	7956.66	2.60	1777.98	683.84	12273.11
303030	1766924	40106	12429.53	30016	5531	7418	6427.29	2.48	1662.17	670.23	12429.53
303022	832215	9494	5149.55	13958	3018	1611	1264.81	2.86	1412.25	493.79	5149.55
311143	1666009	8764	4748.08	12345	3337	14447	1843.39	2.87	1494.25	520.64	4748.08
311132	404749	1643	5845.01	15632	3404	1587	1676.48	3.11	1268.68	407.94	5845.01
311131	328824	1095	4530.40	13814	2904	2073	1114.02	3.35	1082.56	323.15	4530.40
311133	448034	1521	7043.93	19733	5045	1023	3397.03	3.04	1257.04	413.50	7043.93
311135	585738	5173	5851.99	16199	3913	6019	1762.59	3.11	1290.58	414.98	5851.99
311151	2239993	17954	4311.91	13172	2354	6050	2244.57	3.10	1434.74	462.82	4311.91
311148	2037756	3104	6280.64	18378	4640	4153	2248.16	3.68	1168.91	317.64	6280.64
311145	1791974	2800	9609.10	30211	7460	3592	3228.65	3.67	1186.77	323.37	9609.10
311140	1469607	2860	7604.28	22548	5561	4597	2686.11	3.75	1105.25	294.73	7604.28
311154	2999560	3834	10260.68	30269	6703	6589	4735.22	3.60	1321.38	367.05	10260.68
302007	2446589	1461	5300.50	18211	4533	1616	1628.02	3.76	823.91	219.13	5300.50
302009	4228645	13389	8112.01	23351	5632	2082	4519.49	3.39	1444.76	426.18	8112.01
302010	5706475	1704	3125.23	9303	2143	1312	690.46	3.82	829.36	217.11	3125.23
302012	7650772	3530	3855.68	11745	2993	2112	889.76	4.21	963.13	228.77	3855.68
302015	24800000	2556	2560.79	10170	2339	2418	987.72	3.76	776.80	206.60	2560.79
302014	16100000	123	551.10	1670	358	185	175.31	3.62	1161.22	320.78	551.10
302017	29500000	487	278.85	845	181	0	88.70	3.62	1218.75	336.67	278.85

310126	41100000	5721	9076.93	28664	6749	5762	2589.74	3.75	1001.42	267.04	9076.93
304055	15100000	1765	1153.47	3978	971	168	443.65	4.01	739.70	184.46	1153.47
306082	87300000	1461	1207.43	3856	827	269	740.04	3.81	803.12	210.79	1207.43
310121	6129830	2617	6038.14	20285	4062	4201	1362.72	4.20	810.60	193.00	6038.14
310122	6897618	9616	11367.43	36924	8233	14874	2784.44	4.24	814.56	192.11	11367.43
302020	42100000	4199	4820.22	17285	3251	2573	2213.07	4.16	976.90	234.83	4820.22
310118	4761586	13450	9568.06	31420	8302	14264	2528.53	4.21	946.90	224.92	9568.06
310116	4404758	7425	20675.54	66507	15883	11904	5857.48	4.12	972.03	235.93	20675.54
310109	1454154	1521	3278.06	10027	2663	1755	694.18	4.19	873.29	208.42	3278.06
311144	1739216	3104	9783.49	28046	5656	3760	3605.34	3.71	1071.99	288.95	9783.49
311149	2205744	6269	7712.05	24736	5472	5825	3918.58	3.65	1355.75	371.44	7712.05
311146	1812970	2191	7873.43	21530	5259	3314	4877.34	2.92	1949.53	667.65	7873.43
311152	2329110	20145	17678.76	47051	9557	12308	6982.96	2.64	1488.96	564.00	17678.76
303033	2257163	12841	19308.96	58459	12192	36080	4941.30	3.53	1080.29	306.03	19308.96
303029	1686939	4321	13423.85	39680	8350	4742	7599.25	3.14	1441.08	458.94	13423.85
303023	1365357	9494	12396.22	32160	6146	2487	8946.47	2.59	1841.68	711.07	12396.22
303031	1780324	19049	14317.85	40078	7445	8855	11681.82	2.57	1642.62	639.15	14317.85
303034	2775174	21179	24101.37	67084	15063	6798	19214.53	2.78	1938.42	697.27	24101.37
303037	3600689	18075	23757.17	64433	13925	10249	11101.61	3.35	1322.66	394.82	23757.17
305057	1417045	2008	5405.17	18895	3730	3547	2078.91	3.75	1005.18	268.05	5405.17
305062	4016138	8581	17030.35	50704	10597	10137	5321.97	3.68	1092.38	296.84	17030.35
305065	21700000	1948	561.99	1703	365	19111	178.77	3.62	1390.91	384.23	561.99
305061	3011401	6025	19359.87	57787	11432	6251	6193.24	3.52	963.73	273.79	19359.87
304040	1689852	13267	9978.72	29116	8077	7054	2160.05	3.66	916.32	250.36	9978.72
306080	13600000	2617	1384.10	4063	872	0	357.19	3.96	827.43	208.95	1384.10
306071	2864257	2860	15874.05	48798	9666	7891	3233.59	3.69	749.19	203.03	15874.05
306077	4009418	8338	26050.17	82685	16952	13134	6852.04	3.87	843.92	218.07	26050.17
306073	2894506	4504	13947.81	45773	10553	11990	4447.73	3.75	884.98	235.99	13947.81
306072	2875687	5417	14533.77	47324	8656	7720	3767.79	3.54	800.47	226.12	14533.77
306069	2413764	5538	14292.97	44070	8235	8790	4883.42	3.29	1116.73	339.43	14292.97
304042	2663782	7303	11368.64	35576	8153	5366	2793.19	3.51	842.14	239.93	11368.64
304039	1371760	4138	4500.75	13280	3059	2994	1611.40	3.32	1067.19	321.44	4500.75
304041	2546532	8946	9945.02	23512	5430	5634	4604.21	3.11	1499.47	482.15	9945.02
305060	2165687	9372	14819.81	46879	10274	4919	7216.89	3.17	1228.20	387.45	14819.81
311150	2219083	11259	12255.88	33252	7961	6719	7226.68	2.99	1638.22	547.90	12255.88
307086	7948740	5660	10804.28	35426	8303	9597	2797.91	4.20	732.01	174.29	10804.28
307085	5962223	7425	15608.94	55173	13727	15274	3814.73	4.35	892.31	205.13	15608.94
306079	9099146	1765	6950.26	18206	4072	5801	2890.81	3.22	1297.92	403.08	6950.26
306066	1956350	20814	4856.52	16231	4182	4884	1261.47	4.29	713.06	166.21	4856.52
306076	3557328	5477	4771.94	15308	3954	1461	1842.65	3.56	1143.15	321.11	4771.94
306070	2716093	3652	5833.62	18425	4662	7296	1877.69	3.65	793.34	217.35	5833.62
306075	3397712	4078	8010.39	23459	6002	4436	2340.68	3.67	898.23	244.75	8010.39
304050	4054548	7242	17179.48	52782	11044	9508	5546.23	3.68	873.03	237.24	17179.48
304048	3964351	12111	17042.08	52671	10889	10225	5531.17	3.55	1011.43	284.91	17042.08
304043	2698153	3530	12936.21	39922	7335	9498	5566.74	3.33	1179.30	354.14	12936.21
304047	3775589	4808	4726.61	13537	2480	3498	1134.40	4.11	773.09	188.10	4726.61
304053	6900314	304	0.00	0	0	0	0.00	3.62	871.90	240.86	0.00
304054	11200000	15884	10461.14	38168	9268	10185	3051.93	4.26	812.48	190.72	10461.14
304052	4825625	5964	3919.68	12446	2127	5292	1333.50	4.00	793.79	198.45	3919.68
310112	2860306	5721	21529.07	57608	11062	11072	10823.76	3.31	1515.48	457.85	21529.07
303035	3078360	12659	10813.95	31128	7700	5667	3537.25	3.68	947.19	257.39	10813.95
305064	10200000	3712	4764.94	16998	4549	2789	1420.32	4.03	840.64	208.60	4764.94
305056	1151835	1704	6892.16	20311	3852	2018	2558.43	3.70	940.91	254.30	6892.16
303038	6097492	17162	12257.56	33421	8258	10482	8618.57	3.22	1881.00	584.16	12257.56

303024	1371183	3956	12020.79	32244	7003	3200	9097.99	3.17	2096.37	661.31	12020.79
303036	3359146	6025	8156.24	23059	5085	6633	2651.65	3.69	887.59	240.54	8156.24
311153	2361463	7607	16669.09	49768	14762	11132	6061.43	3.43	1054.85	307.54	16669.09
311141	1626515	5964	10380.66	30913	6742	5171	4121.76	3.68	1151.08	312.79	10380.66
311155	3494067	10590	18637.37	54826	12670	11878	9762.44	3.64	1459.65	401.00	18637.37
310115	3516331	18014	36536.43	103637	24181	17683	13099.09	3.39	1196.86	353.06	36536.43
310108	1349788	15154	11373.90	33825	7310	6738	4306.75	3.46	1283.95	371.08	11373.90
310117	4538262	14850	17734.85	51234	11138	8193	5336.83	3.63	1072.19	295.37	17734.85
310114	3453020	11442	17656.15	50606	11471	9423	3845.05	3.90	942.62	241.70	17656.15
310125	9762019	4869	4710.24	16161	4458	6752	1624.23	4.15	1131.19	272.58	4710.24
310124	9707042	6269	12576.23	33245	6515	3838	3319.09	3.70	1110.16	300.04	12576.23
310119	4920764	7364	7688.02	21584	4020	1984	1521.16	3.83	852.81	222.67	7688.02
310111	2345713	4321	10473.89	32193	7362	3940	2395.21	4.09	898.79	219.75	10473.89
310110	2003923	3469	5849.74	17433	3894	4083	1588.33	4.41	864.56	196.05	5849.74
307083	2198512	5721	12456.50	41983	9098	5232	2642.31	4.17	994.53	238.50	12456.50
307084	2759877	10894	11181.01	43062	12510	16187	2417.52	4.52	759.14	167.95	11181.01
307087	9971535	7486	16907.32	63587	16231	8841	2778.43	4.95	746.30	150.77	16907.32
306078	5984795	1704	9679.14	32707	8759	2920	2450.35	4.23	758.23	179.25	9679.14
304049	3971406	4625	3156.01	11021	1792	4712	1502.86	3.24	1027.62	317.17	3156.01
304051	4317277	3165	5910.50	19247	5090	4123	1024.98	4.19	746.88	178.25	5910.50
310106	1205993	2739	3015.38	9800	2495	1357	548.25	4.09	785.33	192.01	3015.38
310123	7747051	25840	13118.56	41722	10087	6512	3196.64	4.10	895.69	218.46	13118.56
310120	5950168	58364	20217.53	56086	14511	12437	5203.06	3.86	947.63	245.50	20217.53
310107	1238262	4138	12944.72	33454	6305	4294	2265.35	3.96	1059.45	267.54	12944.72
310113	3292850	6999	13891.19	41323	8317	1615	3485.06	3.88	875.58	225.66	13891.19