An impact evaluation of Bus Rapid Transit on public transportation: The case of Istanbul

Abstract:

Bus Rapid Transit has become popular in the last decade, especially in the urban areas with high density that face severe congestion. Bus Rapid Transit is designed to increase the overall public transportation ridership levels. But the users also consider it as an alternative to other public transport modes. In order to examine the impact of Bus Rapid Transit on other public transportation modes, the monthly ridership levels of Istanbul public transportation systems over the years are analyzed. The results show that Istanbul Bus Rapid Transit system contributes to the ridership levels of the available rail system, however there is no evidence that it has an impact on the bus public transportation in Istanbul.

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1.Introduction

Congestion is one of the most prominent problems faced in the dense urban areas of many cities around the world. The problem can be approached from both demand and supply side. On the demand side, the main driver of increased congestion is the increase in density and private car ownership (Hensher, 2007). On the supply side, inadequate infrastructure and public transport (PT) systems are the main driving forces that aggravate the congestion. It is certain that an increase in the use of PT would lead to less congestion. Having the goal of increasing PT ridership, Bus Rapid Transit (BRT) has become popular over the years especially in cities that face congestion (Levinson et al., 2002).

Istanbul, Turkey is one of those cities facing congestion in its dense urban areas due to the high numbers of car ownership and sub-optimal PT systems. The problem of congestion in Istanbul is addressed through a range of policies and investments on infrastructure and PT systems. BRT is one of those solutions offered to increase PT ridership on these urban areas of Istanbul facing congestion. The implementation of a BRT system in Istanbul is expected to have two major effects on the ridership levels of transport options. The first effect is a shift from private transport options to Istanbul PT services and the second effect is a switch from other PT modes to the newly built BRT system. This thesis aims to analyze the ridership changes within the Istanbul PT modes in order to observe the second effect.

The research question is constructed as follows:

"What is the effect of introducing the BRT system in Istanbul on the ridership of other main public transport modes?"

There is very limited research on BRT in terms of ridership levels. Previous research papers mainly focus on the characteristics of BRT systems and the extent to which it contributes to BRT ridership (Currie & Delbosc, 2011; Hensher & Li, 2012). Up to date there is no research on the impact that the BRT system as a whole has on the ridership levels of other PT modes which are namely, conventional bus transport and rail systems. Hence, this thesis aims to give insight on the ridership changes over the years on different PT systems due to the implementation of a BRT system.

There are two hypotheses made in order to answer the research question: Firstly, it is expected that Istanbul BRT system has a negative impact on the ridership levels of conventional bus transport since it is an improved bus transport option. Secondly, it is expected that Istanbul BRT system contributes to the ridership levels of rail systems since it offers a similar level of service and is integrated with Istanbul rail network.

In order to answer the research question, the dataset on monthly ridership of PT modes in Istanbul for 8 consecutive years between 2006 and 2013 is acquired from IETT, the government body who regulates and controls the public transportation in Istanbul. A vector auto regression model is used to analyze the obtained dataset which will be explained in detail under Methodology.

This thesis is structured as follows: In the second chapter, a discussion on BRT definition and a comparison of BRT with Light Rail Transit (LRT) systems are given along with the history. Then the focus of this thesis Istanbul is qualitatively analyzed in terms of the factors causing congestion problem and solutions of Istanbul including Istanbul BRT system, Metrobus. In the third chapter, a quantitative analysis is conducted. The results are shown in chapter four. The paper ends with the conclusion and discussion.

2. Literature Review

In this section, firstly an explanation of BRT and its strengths and weaknesses in terms of ridership compared to other PT modes, especially LRT, will be given. Then a qualitative analysis will be conducted on the main factors and possible solutions on congestion in Istanbul. Lastly, background information on the main focus of this thesis, Metrobus, will be given followed by a discussion on the effects of Metrobus on congestion in terms of ridership.

2.1 Bus Rapid Transit

This section begins with describing BRT system and its components. Then, a comparison between BRT and LRT is conducted. This section ends with a historical overview on the development of BRT systems.

2.1.1 BRT Definition

BRT systems are a recently developed rapid mode of public transportation. Having the purpose of increasing overall PT usage, there has been many attempts to improve the existing transport modes on road and rail. BRT is an invention that is resulted by combining the road and rail transport service attributes that attract people to public transportation. In this respect, the main objective of a BRT system can be summarized as increasing ridership levels through its ridership deriving attributes (Currie & Delbosc, 2011; Hensher & Li, 2012). This brings the question of what these ridership deriving attributes are that a BRT system consists of. There are various studies that aim to answer this question, yet the findings obtained in many of these studies are somewhat controversial since BRT systems have diverse design characteristics and attributes depending on the region they operate (Currie & Delbosc, 2011). For this reason, an outline of BRT can be given by focusing solemnly on the common attributes that contribute to the ridership levels of the system. In this section, these common attributes, called the components of BRT, will be highlighted by discussing the existing literature.

When the evolution of BRT systems are examined from the existing literature, it is observed that the conventional bus transport services has firstly evolved into road services with a primitive level of traffic priority such as having a right to pass on red traffic light. Then, these services further evolved into operations that have designated lanes. And lastly, this evolution is completed by having bus services that are similar to rail services on completely dedicated lanes with an exclusive right of way (Jarzab, Lightbody, & Maeda, 2002). This shows that the BRT systems are rooted back to conventional bus transportation with a link to rail transportation.

Being originated from the conventional bus services, one of the attributes that is found in every existing literature is the choice of vehicle that is designed to operate on road. Therefore the first common attribute is the vehicle choice (Levinson et al., 2003). There are various studies criticizing that buses are not eligible to derive a high level of ridership compared to rail systems (Loader & Stanley, 2009). Yet, other researchers focus on the operational flexibility capabilities of these vehicles and discuss that buses are able to achieve high levels of ridership in this respect (Polzin & Baltez, 2002). Another common attribute that is mentioned in the evolution process of BRT systems is the dedicated running ways. There is no controversy in the existing literature that dedicated running ways are an important element to improve the overall system performance and therefore increase ridership (Carey, 2002).

The main goal of having dedicated running ways is to allow exclusive right of way to the BRT vehicles. But, there are contradictions in different studies regarding the level of exclusivity and the dedicated running ways. It is seen that the older researches mentions the existence of BRT systems with no dedicated lanes, yet more recent studies refer to the same or similar systems as busways with traffic priorities (RODRÍGUEZ** & Targa, 2004; Goodman, Laube, & Schwenk, 2005). As the name indicates, currently BRT systems are categorized as a rapid mode of transportation. Rapid transit is defined as PT services that are completely separated by other PT modes by having exclusive right of way regardless of its vehicle choice (American Public Transit Association, 1994). Hence, having exclusive right of way on dedicated running ways is essential to the BRT systems. Therefore, the second common attribute is the running ways.

Another common attribute that is discussed in the majority of the existing literature is that BRT systems have rail-like stations that offer higher amount of amenities compared to conventional bus stations (Levinson et al., 2003; Levinson et al.,2002). Stations are the users' meeting points with amenities that increase the service quality. Stations that offer high level of services attract people and therefore increase ridership. Many sources also refer to fee collection methods and IT systems as unique features of the BRT system that increases the ridership levels. But it is seen that the fee collection methods and IT systems are mainly used to help the BRT users as well as to coordinate the operations (Currie & Delbosc, 2011; Hensher & Li, 2012). In this sense, these features are indeed helpful tools, but they can be categorized as one of the amenities offered at the stations.

The last common attribute is dedicated to services. It is stated that the frequent services are crucial to achieve high levels of ridership. Moreover, it is discussed that the ridership increase is observed in BRT systems where non-stop operations are conducted during day and night (Currie & Delbosc, 2011).

In short, the outline of a BRT system consists of vehicles, running ways, stations and services. In this respect, BRT is defined as: "Bus Rapid Transit (BRT) is a public transportation mode which aims to increase ridership by offering frequent bus services with exclusive rights of way on segregated running ways and stations with amenities."

2.1.2 BRT Components

The main attributes listed under the BRT definition in the previous section are the main components of a BRT system. BRT components are important determinants of the system performance because they can contribute to an increase in ridership. The components contribute to the system in terms of improving accessibility, service quality, market orientation and the image of the system (Levinson, Zimmerman, Clinger, & Rutherford, 2002). Each of the components and their contribution to the BRT system are discussed in the following sections.

Vehicles

BRT systems use rubber tired road transport vehicles (Levinson, Zimmerman, Clinger, & Gast, 2003). In many regions of the world, conventional buses are selected as the type of operating vehicles. Standard buses or articulated buses are mainly used in BRT systems. Articulated buses are generally larger in size and can carry more passengers than conventional buses. In order to achieve high levels of ridership, articulated buses are preferred over standard buses (brtdata.org, 2014). BRT buses are generally differentiated by color and name from the bus transportation in the market they serve. The differentiation serves to build a strong positive image and to distance from the negative perception of public on conventional buses (RODRÍGUEZ** & Targa, 2004). Along with the use of conventional buses, there are also various examples on custom design BRT buses. These customized vehicles include features such as easy access units for physically challenged people, fuel efficient vehicles, engines running on alternative fuels (solar energy, bio waste etc.), automatically guided vehicles which do not require a driver and so on (brtdata.org, 2014). The first two features of customized vehicles (easy access units and fuel efficient design) are popular among the BRT systems around the world since they contribute to service quality and image, but the remaining features are not common yet.

Running ways

BRT vehicles operate on segregated running ways, called corridors. Corridors are suitable for the road transport vehicles and therefore they are easier to construct incrementally especially compared to railways. BRT corridors are diverse in design depending on the characteristics of the market they serve, but the common goal of each corridor design is to allow exclusive rights of way to the operating vehicles. The corridor designs determine the service quality in terms of travel speeds, reliability and identity of BRT systems; therefore increase ridership (Chang, et al., 2004).

The variety of corridor designs can be categorized as features related to construction and features related to operation. Construction wise, the first prominent feature is whether the corridor is connected to the mixed traffic at any point or not. These bottlenecks negatively affect the service quality in terms of travel speed and reliability yet, in many BRT systems such bottlenecks exist due to the regional characteristics. In order to eliminate or minimize the undesirable effects of such bottlenecks, grade separation method, a construction method to align and link the lanes at different heights, is widely used (Miller M. A., 2009). Another feature regarding construction is the positioning of the corridor; whether it is constructed on mid-lane or on the sideway. The positioning contributes to the overall infrastructure in terms of efficient use of available space and affects the service quality of BRT operations which will be discussed as the corridor features related to operation. Operation wise, positioning of corridors determines the station positioning and this leads to undesirable consequences such as counter flow operations, accidents and insufficient station capacity (Miller M. A., 2009).

In short, corridor designs affect the service quality and moreover, the highest percentage of the BRT investment costs is derived from the implementation of the corridors. Thus, corridors are an essential part of a BRT system.

Stations

Stations are the meeting nodes of customers with the required service and amenities. The features of BRT stations highly change in different cities, but one common feature is that BRT stations offer a higher level of services in terms of station capacity and amenities compared to bus transport stations. The amenities offered at BRT stations have an impact on the service quality in terms of easy access for physically challenged users (i.e. elevators, security and help staff), reliability (i.e. route and timetable information systems, pre-boarding fare collection methods and credit installment), accessibility (i.e. number of BRT stations, high user capacity, integration to other PT modes) and the image of the BRT system since the variety and the quality of amenities at the station have an overall effect on the customer satisfaction (Chang, et al., 2004). BRT stations are essential not only in terms of increasing the BRT ridership level but also the overall PT ridership. This is mainly because BRT stations can also serve as a main public transport integration point to another transit mode.

Service Patterns

The services offered in the BRT are very important because they can alter the customer perception of the system. Service plans that are designed based on the customer needs often attract ridership and maximize system benefits. In order to have a higher customer perceived value, the BRT service needs to be frequent, direct, easy to understand, comfortable, reliable and rapid (Chang, et al., 2004; Levinson, Zimmerman, Clinger, & Gast, 2003). The most important determinants of the service plan when it comes to increasing ridership are: route structure, span of service and the frequency of service. The appropriate route structure optimizes the service offered. An advantage of BRT systems is that they can accommodate different vehicles serving different routes and therefore can provide point-to-point service and reduce travel time by limiting transfers (Chang, et al., 2004). This integrated route structure can attract new customers (such as choice riders) and increase ridership, so it is often the preferred route structure. Service span and frequency of service are also very important because ridership increases as the time span gets longer and when there is more frequent service in peak hours.

2.1.3 A Comparison of BRT and LRT

There are many similarities regarding the system components of both BRT and LRT such as operating on dedicated running ways with an exclusive right of way. These components are the main factors that derive high ridership levels. In this section a comparison between BRT and LRT is conducted in terms of the common system components. These similarities and differences are listed in the table below. The comparison analysis shows that, an advantage of one system over the other is balanced by a disadvantage: i.e. the low-cost, incremental implementation of BRT running way is overcome by the concreteness and permanence of the LRT running way. This behavior is observed almost in every advantage and disadvantage between the two systems, resulting that there is no absolute proof that one system is better than the other in terms of system performance and system quality.

Factors that derive ridership	Comparison of BRT and LRT	List of articles
Vehicles		
Capacity	1. LRT vehicles have higher capacity compared to BRT vehicles. - LRT vehicle has a passenger capacity between 150 and 250+ on average. - BRT standard bus has passenger capacity of 80 - BRT articulated bus has passenger capacity of 170 on average.	(Currie & Delbosc, 2013; brtdata.org, 2014; Vuchic, 2002)
Operation Flexibility	2. Buses have higher operational flexibility than LRT vehicles (i.e. by-pass roads allow easy access)	(Polzin & Baltez, 2002; Vuchic, 2002; Carey, 2002)
Speed	3. Same level of commercial speed can be achieved.	(brtdata.org, 2014)
Environmental impact	4. LRT vehicles run on electricity whereas BRT vehicles run on fuel (mostly diesel fuel). Hence, LRT vehicles are more environmentally friendly compared to BRT buses.	(Polzin & Baltez, 2002)
Ease of access	5. Custom design BRT vehicles that have low floor platform have same ease of access with LRT. But, this feature is more common in LRT vehicles.	(Vuchic, 2002)
Running ways		
Ease of mixed traffic connection	6. BRT corridors can be connected to mixed traffic more easily compared to LRT systems since, BRT vehicles are designed to operate on road.	(Jarzab, Lightbody, & Maeda, 2002)
Ease of implementation	7. BRT system can be implemented incrementally since the vehicle used is designed for road transport and run on fuel. LRT system can only operate on a fully completed railway.	(Carey, 2002)
Costs	8. LRT running ways are more costly compared to BRT corridors due to having more elements on the LRT infrastructure.	(Polzin & Baltez, 2002)

Factors that derive ridership	Comparison of BRT and LRT	List of articles
Stations		
Capacity	9. Both LRT and BRT stations can achieve same level of capacity.	(Polzin & Baltez, 2002)
Amenities	10. Both LRT and BRT stations can offer same amenities.	(Polzin & Baltez, 2002)
Services		
Service flexibility	11. Higher service flexibility can be achieved in BRT systems compared to LRT as a result of operation flexibility.	(Vuchic, 2002; Carey, 2002; Jarzab, Lightbody, & Maeda, 2002; Currie & Delbosc, 2013)
Service quality	12. Higher service quality can be achieved in LRT systems compared to BRT as a result of vehicle capacity, reliability and environmental impact.	(Polzin & Baltez, 2002); Currie & Delbosc, 2013; Currie & Delbosc, 2011)

2.1.4 BRT History and Overview

Transport demand has been growing over the years due to increase in population and private car ownership. Inadequate infrastructure and suboptimal PT systems fail to fulfill the transport demand especially in urbanized dense areas, causing congestion. With a goal of managing the congestion problem, authorities implemented various policies and investments that regulate the transport demand, improve infrastructure capacity, and increase PT ridership. Having the ability of increasing ridership levels, BRT systems have become popular in the last decade in many regions of the world where congestion is a major problem (Levinson, Zimmerman, Clinger, & Rutherford, 2002).

Even though the rapid growth in the number of BRT projects around the world occurred mostly in the 21st century, the concept of BRT is rooted back to 1930s. According to an overview of Levinson et al. (2002) about BRT systems and the first proposals for the implementation of these systems, the idea of BRT which dates as early as 1937 was first suggested in the "Chicago Plan", and was considered as a plan of converting rail rapid transit lines to express bus operations. In 1963 the concept of BRT was explained as a system that combines the best features of rail rapid transit and conventional buses (Miller & Buckley, 2000).

Currently, fully operational BRT systems are used in 186 cities in the world. Anyhow, the first steps towards the implementation of BRT were the early busways. *Liège (Belgium)* was the first city which began implementing the concept of BRT system in 1968 with the first unidirectional busway, and it was followed by other major projects in different cities including *Lima (Peru)* and *Curitiba (Brazil)*. In Lima the implementation also started with a busway in 1972 (Embarq, 2014). These initiatives mainly focused on developing busways with a traffic priority, but could not achieve a BRT system that fully includes each BRT component that brings high service and ridership levels. Curitiba was actually the first city that fully implemented a BRT system that fits into the definition of BRT and was fully operational in 1974. Curitiba was a rapidly growing city, and BRT was considered as a cost effective solution to the traffic congestion problems that would arise with the increase in population (Goodman, Laube, & Schwenk, 2005). Construction and operation of BRT systems in various regions, such as in the Curitiba case, allowed these regions to gain experience in BRT implementation. The successful implementation and the benefits that followed this new mode of transportation, not only incentivized the current implementing cities to look for ways of improving their current BRT systems, but also motivated other cities in the world to use the available "know-how" to decrease the externalities related to congestion. Therefore, over the years an exponential growth in the number of BRT projects is observed globally.

In the end of the 20th century there were not so many cities in the world that started implementing or fully implemented the concept of BRT. Until 2001, only 39 cities had already implemented a total of 1125 km of BRT systems in the world. Between 2001 and 2010, a higher increase in the number of BRT projects in many regions is recognized: 103 new cities have implemented a total of 2775 km of BRT systems (Embarq, 2014). During this period BRT projects truly emerged in cities that face congestion in their dense urban areas. Below table lists some of those cities that face high rates of congestion and gives some insight into the ridership levels of their BRT systems.

Table 2

Rank	City	Congestion Rate	Population	BRT ridership per day
1	Moscow	74%	BRT system	not available
2	Istanbul	62%	13.624.240	750.000
3	Tianjin	56%	BRT system	not available
4	Rio de Janeiro	55%	6.429.923	3.253.600
5	Mexico City	54%	8.851.080	855.000
6	Hangzhou	47%	3.410.000	260.000
7	Sao Paulo	46%	11.376.685	3.164.000
8	Los Angeles	36%	3.792.621	26.883
9	Vancouver	35%	578.041	100.000
10	San Francisco	32%	BRT system	not available

(TomTom, 2013; brtdata.org, 2014)

The ranking of top congested cities in the world is done by compiling the 2013 traffic reports of TomTom, 2013. The population and the BRT ridership levels are gathered from brtdata.org, 2014. Note that even though Istanbul population and ridership levels are currently higher, brtdata.org, 2014 is preferred to make an appropriate comparison.

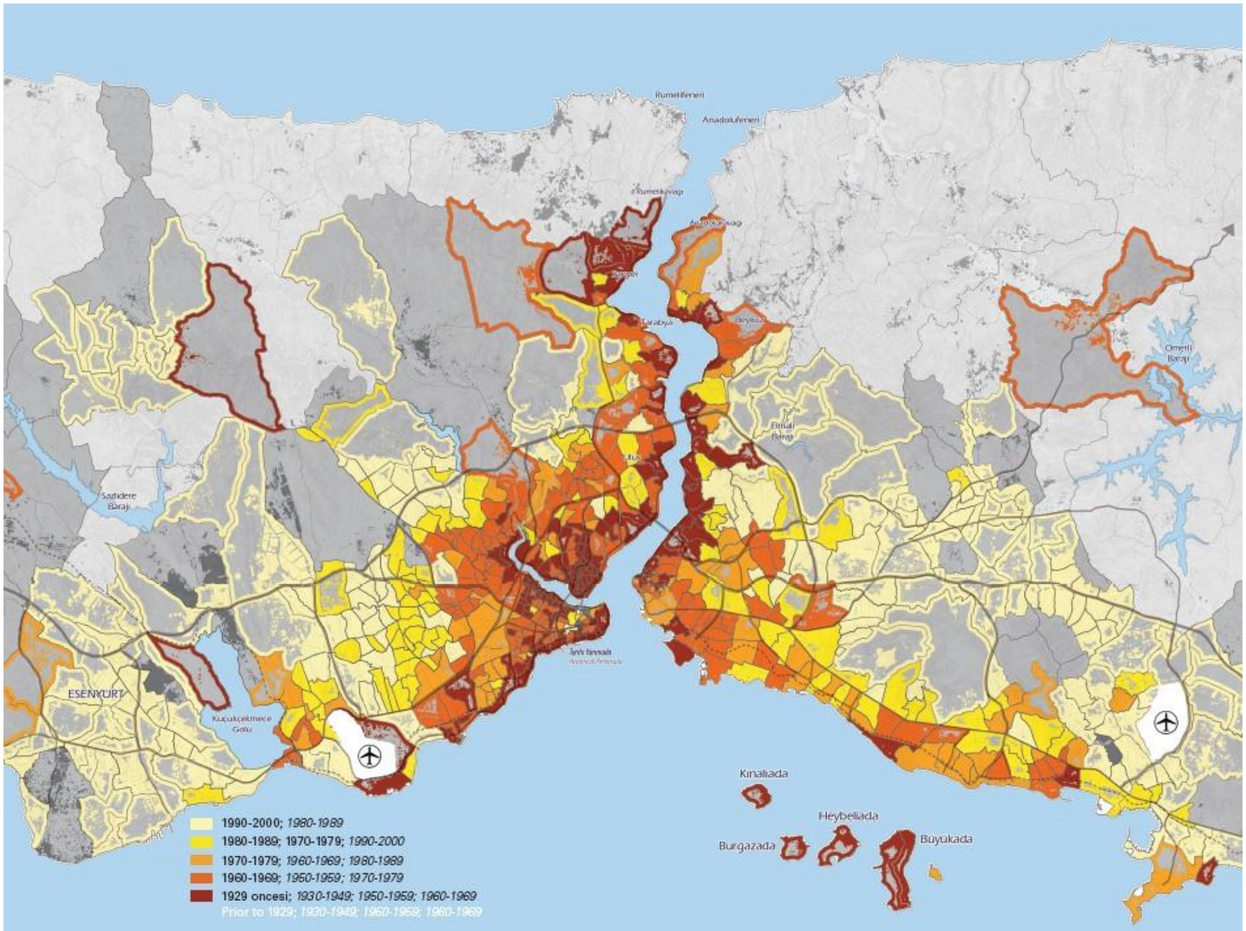
As indicated in the above table, majority of the top congested cities in the world have implemented BRT systems and one of these cities is the focus of this thesis; Istanbul, Turkey. The upcoming section is dedicated to the congestion problems and the solutions addressed in Istanbul.

2.2 Istanbul

Istanbul is located in the north-west of Turkey between; Black Sea in the north, Marmara Sea in the south, the city Tekirdag in the west and Kocaeli province in the east. The city of Istanbul has a total area of 5,343 km^2 (Tuik, 2013). Istanbul is positioned as a bridging city between Asia and Europe which is separated by the Bosphorus strait. For simplicity the European and Asian side of Istanbul will be called Istanbul-west and Istanbul-east, consecutively.

Urbanization majorly occurred in the southern and the middle of Istanbul east and west, aggregating around the Bosphorus strait, leaving the northern parts of the city green. Istanbul has been the historical, cultural and business center of the country throughout the history and it continues to preserve its importance in this respect (Dokmeci V., 2000). Below map gives an overview of the city and its urbanization over the years. The map visualizes the urbanization of Istanbul throughout the history by using a spectrum of colors; lighter colors indicating more recent decades compared to darker colors.

<u>Map 1</u>



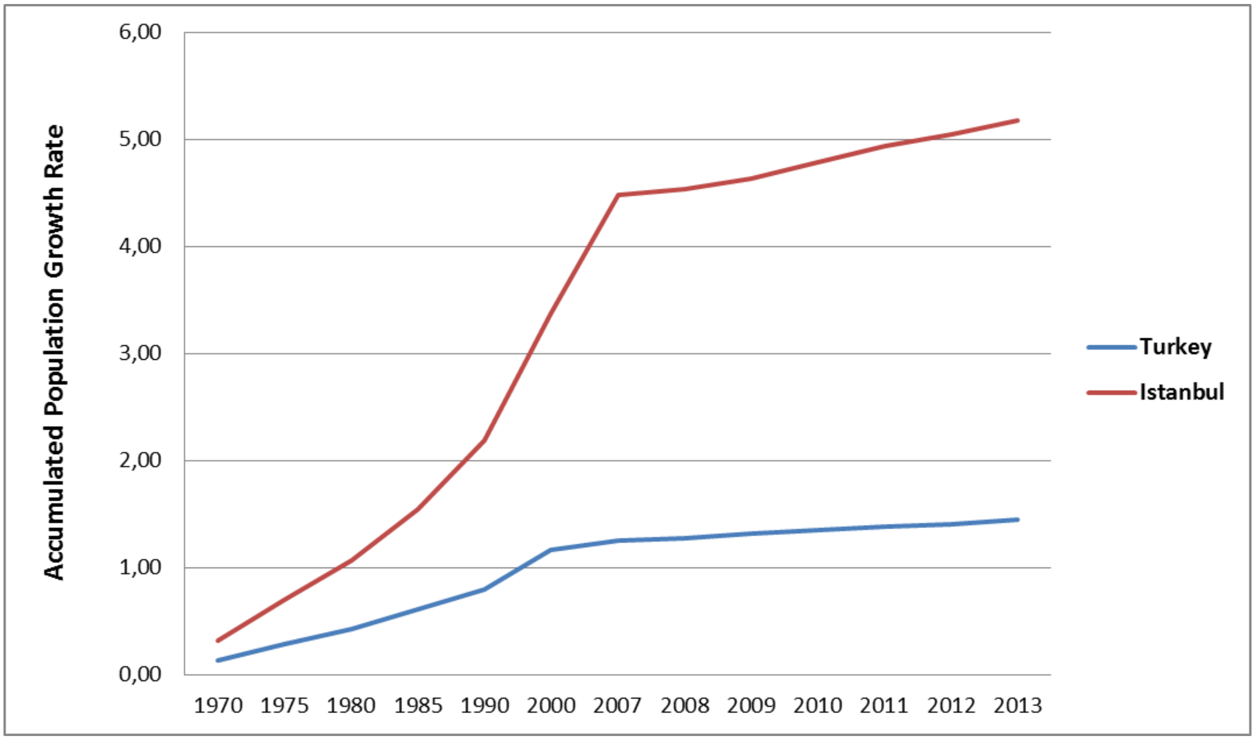
(Guvenc & Unlu-Yucesoy, 2009)

The problem under investigation in this thesis is one of the most prominent problems of Istanbul: Congestion. For this reason, the upcoming section is dedicated to explain the main factors causing congestion in Istanbul. The factors related to the transport demand will be summarized under the section **Demographics of Istanbul** and the factors related to the infrastructure and transport supply will be explained under the section **Transportation in Istanbul**. Later a qualitative analysis on the problem and an overview of the solutions that address congestion will be given.

2.2.1 Demographics of Istanbul

Istanbul is one of the most populated cities in the world with over 14.16 million dwellers living in its 39 districts and expected to grow yearly around 1.62% (Tuik, 2013). Urbanization that occurred in the southern and middle of Istanbul-east and west around the Bosphorus strait evolved as a polycentric characteristic. Since 1970s total population growth as well as density increase in the urban areas are observed (Cakir, Un, Baskent, Kose , Sivrikaya, & Keles, 2008). The graph below demonstrates the accumulated population growth rates of Turkey and Istanbul over the years, indicating that since 1970s urbanization is observed in Istanbul.

Graph 1



(Tuik, 2013)

In order to calculate accumulated population growth rates of Turkey and Istanbul between 1970 and 2013, population of the country and the city in 1965 is selected as the base year. Then, the population growth compared to 1965 for each consecutive year is calculated. The following formula demonstrates the accumulated population growth of Istanbul in 1970:

“(Population of Istanbul in 1970) / (Population of Istanbul in 1965) – 1”

Therefore, the above graph indicates that population of Istanbul is more than five times larger than 1965, whereas Turkey grew around 50% more between 1965 and 2013.

As mentioned earlier, another urbanization feature that is observed in Istanbul is polycentrism. Polycentric urbanization of the city has led various districts to develop faster than others (Kaya & Curran, 2006). One of the main consequences of this urban behavior was the change in location of businesses. This shift can easily be observed with the change in location of Central Business District (CBD) in Istanbul-west. In 1970s, Istanbul CBD was located in Beyoglu district, but in 1990s CBD has moved to the region between Sisli, Besiktas and Sariyer districts (Dokmeci & Berkoz, 1994). Since polycentric urbanization is still continuing in Istanbul especially in the eastern side of the city, another CBD is developing in Istanbul-east in Atasehir district. The following map introduces the districts of Istanbul.

Map 2

(The map from (wikimedia.org) is altered.)

CBDs are important locations to discuss since it is expected that the density levels increase around CBDs and thus, congestion problems are faced majorly around these locations. For the case of Istanbul, since 1970s the density increase occurred around the districts where the old and the current CBDs are located (Tuik, 2013). The below table list these districts that have the highest density levels.

Table 3

HIGHEST DENSITY DISTRICTS				
Rank	**District**	**Land Area (m2)**	**Population**	**Person per m²**
1	GÜNGÖREN	7.210	306.854	42,6
2	GAZİOSMANPAŞA	11.760	495.006	42,1
3	BAHÇELİEVLER	16.620	602.931	36,3
4	BAĞCILAR	22.360	752.250	33,6
5	KAĞITHANE	14.870	428.755	28,8
6	BAYRAMPAŞA	9.610	269.677	28,1
7	BEYOĞLU	8.910	245.219	27,5
8	ESENLER	18.430	461.621	25,0
9	FATİH	15.590	425.875	27,3
10	ŞİŞLİ	10.710	274.420	25,6
11	ZEYTİNBURNU	11.590	292.313	25,2

(Tuik, 2013)

Another demand factor that leads to congestion is the level of private car ownership. Along with the density increase in the urban areas of Istanbul, the number of privately owned motor vehicles also increased in Istanbul. Despite the fact that the rates of private car ownership are not extremely high in Istanbul compared to other cities in the world, increase in the number of personal vehicles in the traffic is observed (Alpkokin, 2005). Table 4 demonstrates this growth in private car ownership for the last decade.

Table 4

Year	Number of Personal Car	Population	Car Ownership Rate
1995	732.969	no data	no data
2000	986.220	10.018.735	9,84%
2007	1.682.414	11.174.257	15,06%
2010	1.788.568	13.120.596	13,63%
2013	2.086.356	14.160.467	14,73%

(Tuik, 2013)

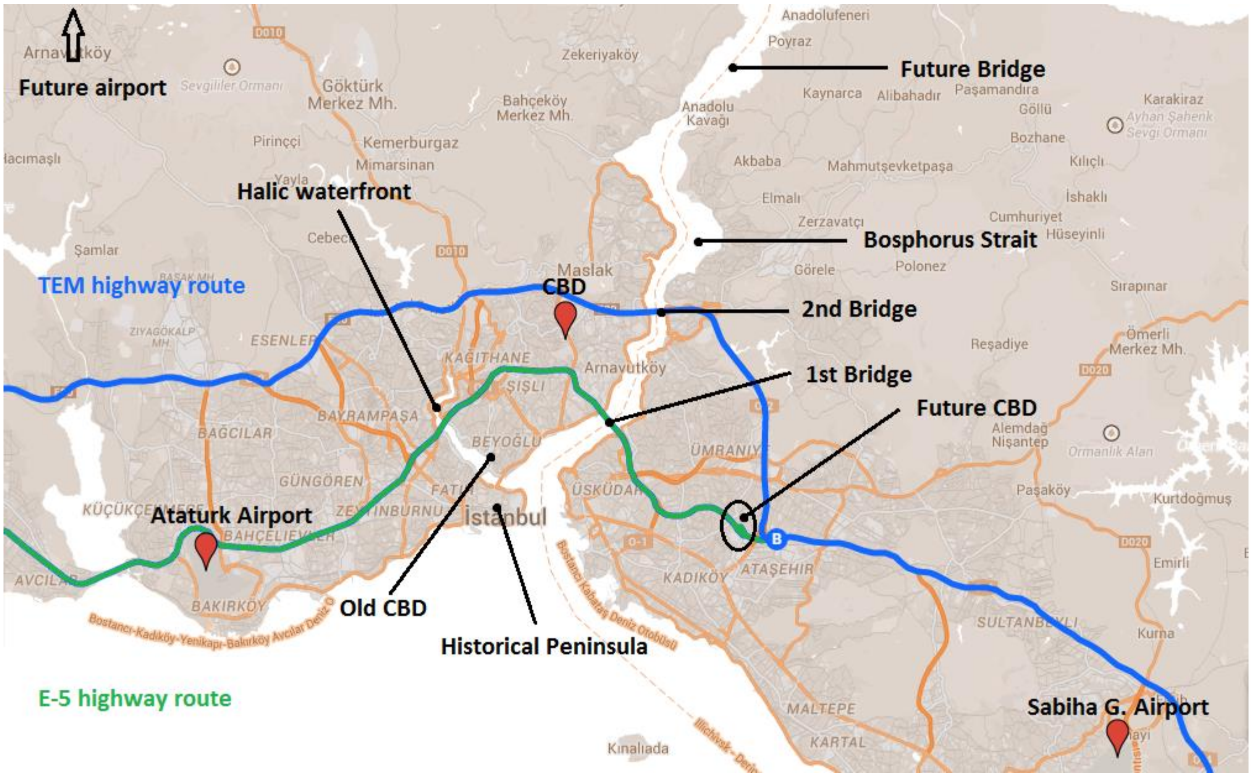
As a result, the increase in both Istanbul urban area density and personal car ownership augmented the transport demand in the city. As explained before, the push effect of these factors has grown over the years and increased the level of congestion problem in the city. It is expected that these demand factors that push the level of congestion will continue to rise due to further urbanization in the near future. Further urbanization in Istanbul is expected to occur on the outskirts of the city (i.e. The third airport in the north west) as well as within the rapidly developing new districts (i.e. new CBD in Atasehir district).

2.2.2 Transportation in Istanbul

This section is dedicated to the transport supply in Istanbul. Firstly, an overview on the infrastructure will be given, followed by the Istanbul transport services that are categorized as road, rail and sea.

Before proceeding with the section, the three main topographical features that are relevant to the infrastructure and transport system developments in Istanbul must be given. These are, namely: 1. Bosphorus strait preventing land access between east and west, 2. Golden Horn waterfront interrupting land access on Istanbul-west, and 3. Ground irregularities such as steep elevations (Hennig , 2011). The map presented below points out these interruptions as well as the main infrastructure elements.

Map 3



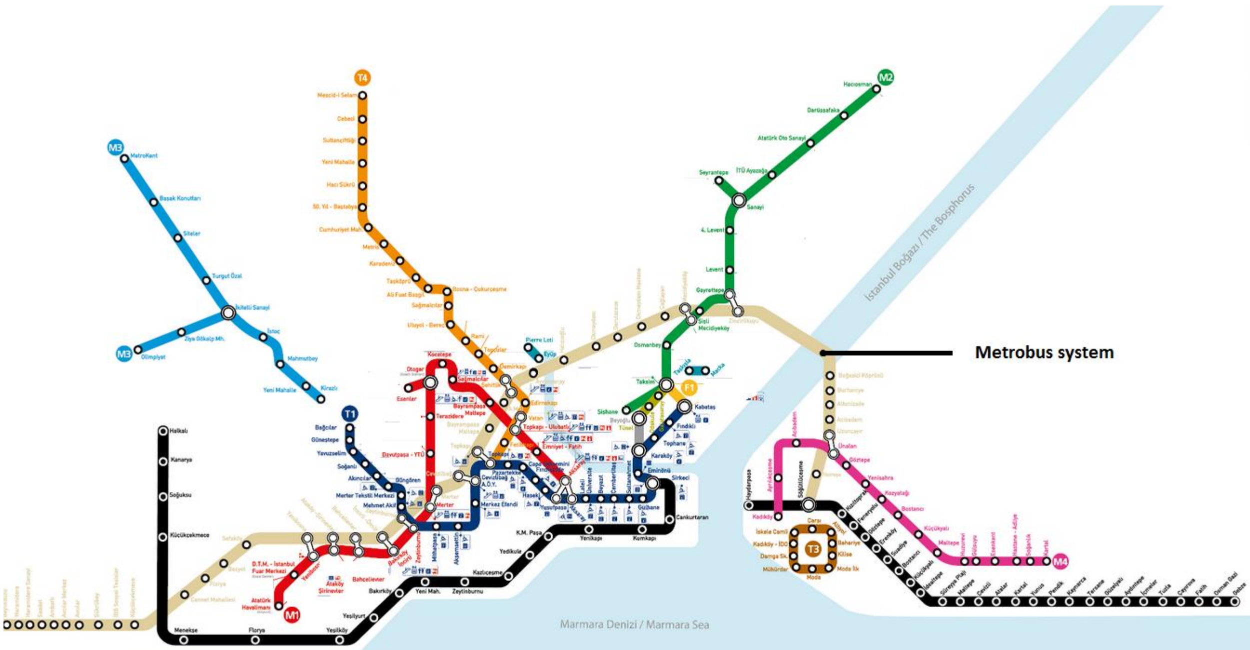
(The map from (Google Maps Engine) is altered.)

Infrastructure

The topography of Istanbul has an impact on the transport infrastructure of the city. The most prominent interruptions regarding land access are the Bosphorus strait and the Golden Horn waterfront. These interruptions are overcome by the construction of appropriate bridges: Istanbul-east and west connection was achieved by two bridges and the Historical peninsula was connected to Istanbul-west by three bridges namely, Halic, Ataturk and Galata. Regarding road infrastructure, there are two main highways: E-5 and TEM. The E-5 links the Ataturk Airport in Istanbul-west to Sabiha Gokcen Airport in Istanbul-east through Halic bridge and the First Bosphorus bridge. The TEM highway is located in the north of E-5 allowing east-west connection through the Second Bosphorus bridge (Ekenyazici-Guney, 2012).

Similar to the road infrastructure, the railway network is also mainly developed in the dense urban areas of the city (Gercek, Karpak, & Kilincaslan, 2004). The map below shows the railway network of Istanbul.

Map 4



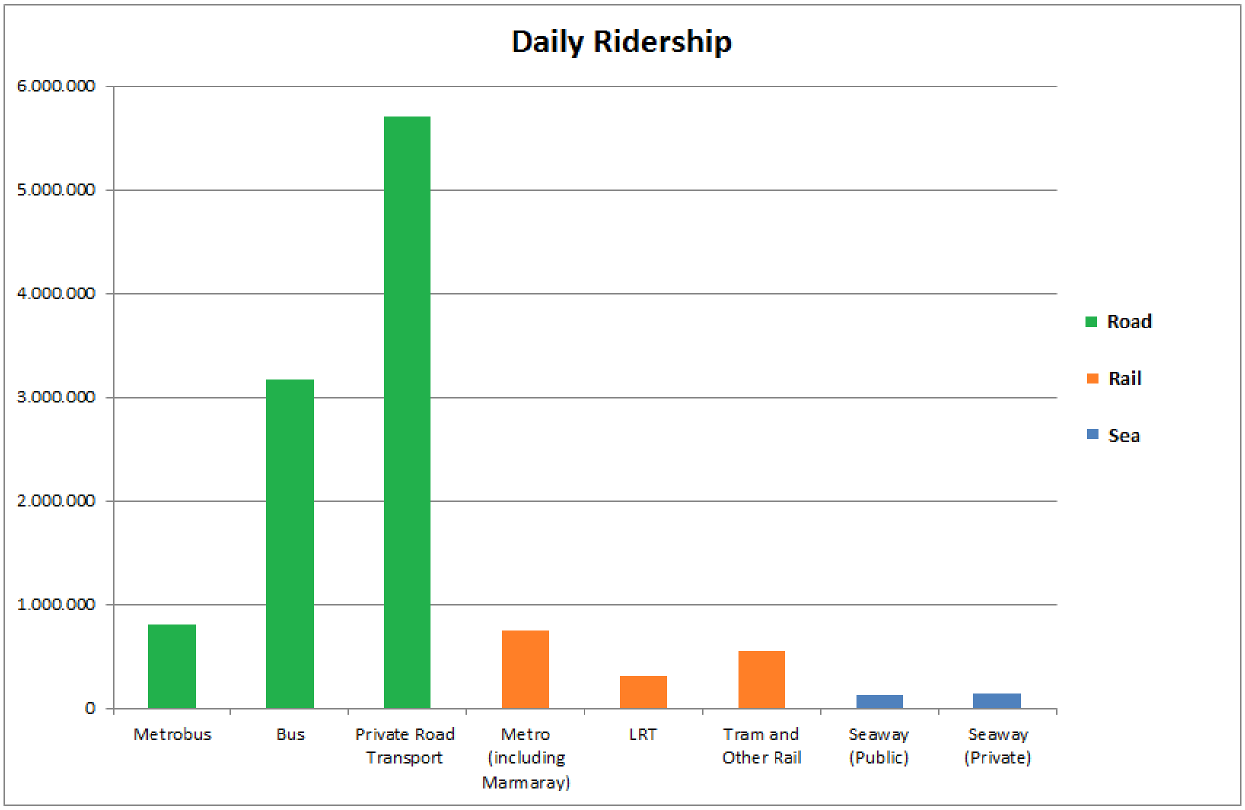
(IETT, 2014)

Note that the gray line indicates the Metrobus system.

Transport Services

Transport services in Istanbul are regulated by the government body IETT. The market share in terms of ridership is almost equally distributed between private operators and the PT operator IETT. The graph below gives an overview on the ridership levels of the public and private transport services by categorizing these services as road, rail and sea.

Graph 2



(IETT, 2014)

IETT reports that total daily ridership on all modes is estimated on average 11,544,029 in which the ridership of road, rail and sea are distributed around 85%, 13% and 2%, consecutively as it can be observed in the graph (IETT, 2014). This suggests that sea transportation lacks behind the other modes in terms of ridership. Moreover, the high share in ridership levels indicates that private road transport services are an important factor in Istanbul transportation.

Overview on Private transport services

There are a large number of privately owned commercial vehicles that offer transport services to public. These private road transport services consist of minibuses, shared taxis, taxis and shuttles. In this respect, the private transport services do not refer to commuting by personal car in this thesis.

Minibuses and shared taxis are common para-transit modes in Istanbul. Both services operate on a predetermined route that does not include a designated stop. This implies the following: Minibuses operate on a schedule and are allowed to pick up and drop passengers at any point on the route, whereas shared taxis have approximately ten passenger capacity, thus shared taxis operate on a flexible timetable that allows operators to wait until the vehicle is filled up, and then a service similar to minibuses is offered. Another private road transport service is shuttles. Shuttles are extensively used by employers and schools to make sure employees and students have reliable transportation during morning and evening peak hours on weekdays. Shuttles majorly operate on a door-to-door service mentality (Yazici, Levinson, Ilicali , Camkesen , & Kamga, 2013).

2.2.3 An analysis on Istanbul congestion

The previous sections, **2.2.1** and **2.2.2** outlined the factors causing Istanbul congestion in terms of ridership demand and supply. Combining the findings from these two sections allows highlighting the set of problems that need to be addressed in order to decrease the externalities created by the congestion.

First of all, it is discussed that the topographical characteristics of the city have an impact on the transport infrastructure in terms of creating bottlenecks at the access points; in the case of Istanbul these bottlenecks occur around the bridges on Bosphorus strait and Golden Horn waterfront. The effects of these bottlenecks are experienced by the commuters majorly around the two Bosphorus bridges where the speed of traffic can be as slow as 7km/hour (Istanbul Metropolitan Municipality Traffic Control Center, 2014). The map below represents the congestion level in terms of speed, highlighting these bottlenecks.

Map 5

(Istanbul Metropolitan Municipality Traffic Control Center, 2014)
(Access time: at 20:20 (Turkish time zone) on December 2, 2014)
(Red: 7-25 km/hour Yellow: 35-60 km/hour Green: 70-100 km/hour)

Therefore the first problem that needs to be addressed is overcoming these bottlenecks and thus;

"Problem 1: Limited infrastructure connectivity between Istanbul-east and west as well as on the Golden Horn."

Secondly, the population growth, density increase and private car ownership increase have caused high transport demand and with the urban expansion transport demand will be pushed further in the future. Suitable improvements and adjustments are required in the transport supply. Therefore the problem needs to be addressed is;

"Problem 2: Currently high transport demand and further increase in the future."

Another concern regarding PT is that the private road transport services have a high ridership share compared to other modes of transportation. These private services are able to achieve such high market shares due to the inadequacy of the PT services in terms of accessibility and reliability. Having door-to-door service mentality, shuttles operate on main arterial roads as well as within small neighborhoods. Moreover, private paratransit services, especially minibuses, also seek opportunities between districts where PT supply is not enough, which leads to an increase in the number of minibuses on the arterial roads (Hennig , 2011). Private road transport services offer sub-optimal solutions to the users regarding operational features and vehicle capacity. This brings that;

“Problem 3: High rate of suboptimal road transport services on arterial roads.”

2.2.4 Solutions that address congestion

An overview of the major problems in Istanbul regarding congestion is given in the previous section. In this section the measures that the authorities take in order to overcome these problems and the lessons learnt from these solutions will be explained.

The first problem addressed in that section is the limited infrastructure connectivity between Istanbul-east and west as well as on the Golden Horn. There have been new infrastructure projects recently carried out regarding *Problem 1*. In order to increase connectivity on the Golden Horn, the Golden Horn Metro bridge has been implemented. For the case of Bosphorus strait following projects are have or being implemented; Marmaray, Eurasia Tunnel and the Third Bosphorus bridge.

Golden Horn Metro bridge: This is the fourth bridge on the Golden Horn between Ataturk and Galata bridges which is completed on February 15, 2014. The bridge does not allow road access and is designed for rail (metro) service (Railway Gazette, 2014).

Marmaray: Marmaray is a 76.3 km of railway in which 13.6 km of it is a underground rail tunnel passing under the Bosphorus strait, making the third physical connection between Istanbul-east and west. Marmaray project is completed on October 29, 2013. Some archeological findings during the tunnel construction delayed the project and also raised some public resistance against Marmaray (Railway Gazette, 2014).

Euroasia Tunnel: An undersea road tunnel project in the southern direction of Marmaray is in progress. This tunnel will be the fourth connection between the two sides of Istanbul. The project is estimated to be finished on October 2016 (ERM Group, Germany and UK ELC-Group, Istanbul , 2011).

The Third Bosphorus Bridge: In the north of Istanbul, The Third Bosphorus Bridge is under construction (estimated to be completed on May 29, 2015). The bridge will not only allow road transportation but it will also have a high-speed rail system. Recalling from the previous sections, having started the construction in the northern side of Istanbul which is a green area raised some concerns by the public. Thus, the bridge project includes a three year tree plantation period after completion (ICA, 2014).

One of the lessons learnt from these projects is that public opinion can affect the progress of transport projects and therefore that should be taken into account in the planning process. Having a strong historical background, many archeological findings rest under the ground and thus, surface transport options are more feasible regarding progress planning.

These projects also contribute to the solution of *Problem 2* by increasing the overall infrastructure ridership capacity. The improvements in the infrastructure raise the concern on the configuration of PT services. It is suggested that the PT options to address this concern are; 1. Status quo, 2. Rail (excluding rapid rail), 3. Rapid Rail (Underground or surface) and 4. BRT (Wright, 2003). By taking into account *Problem 2* and *Problem 3*, Istanbul Metropolitan Municipality decided that the current configuration of PT systems is insufficient and therefore status quo is not a viable option. Hence, IETT began to extend the rail network along with the implementation of rapid rail and BRT systems in order to increase PT ridership levels and thereof decrease the private road transport usage. Some of the major PT projects are; Marmaray rapid rail, Golden Horn rapid rail, Istanbul BRT system: Metrobus and the high speed train on the Third Bosphorus bridge (expected).

2.3 Metrobus

This section is dedicated to the main focus of this thesis. The section begins with an overview on the Metrobus investment in terms of the process of implementation and its main features that increase its level of ridership. This is followed by a qualitative analysis on the effects of Metrobus on congestion during the implementation period as well as after its completion.

2.3.1 An overview

Congestion problem in the dense areas of Istanbul, especially on the main arterial roads around the bridges (the bottlenecks), created the need for a new PT system to increase ridership levels. After considering various options, the authorities decided that the appropriate mode would be a BRT system. The main factors that derived the decision of a BRT system in Istanbul are;

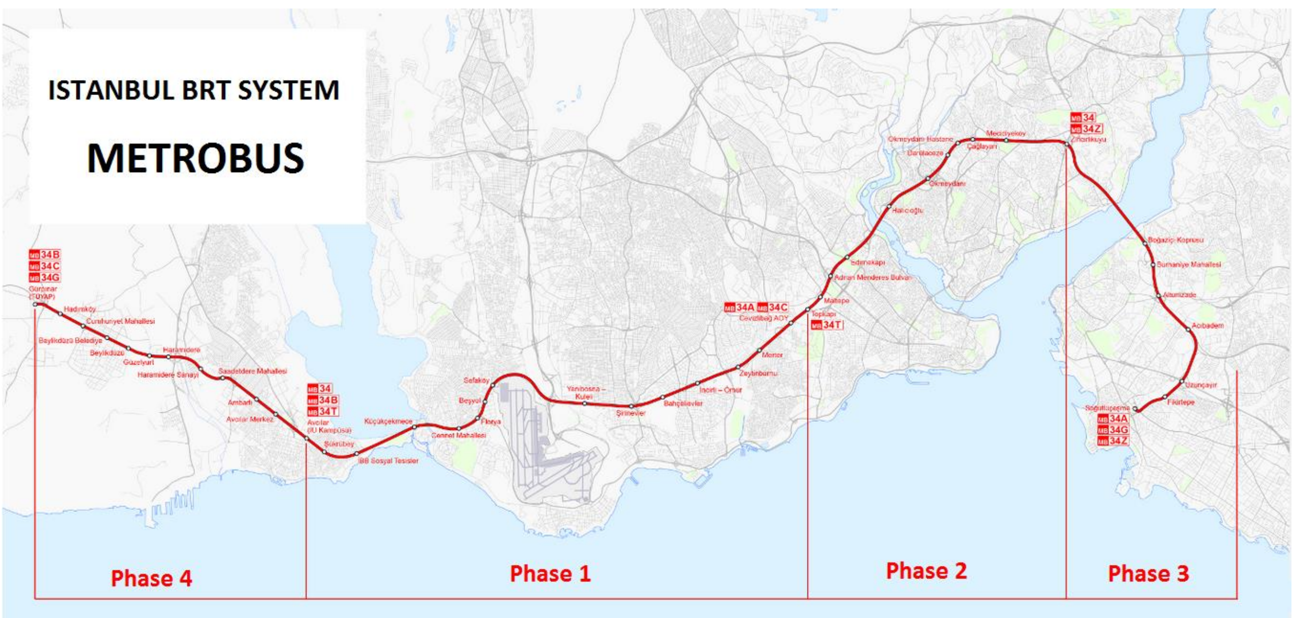
1. A rapid mode of transportation should be considered in order to achieve high levels of ridership.
2. Lessons learnt from the underground projects that the chances of interruptions are high in an underground project and therefore surface transport options should be considered.
3. During the implementation process, the negative externalities of constructing a new PT system on congestion should be minimized. Therefore the project is required to be implemented incrementally and in a short period of time especially at the CBD.

4. Having the desire to operate in the dense areas (around E-5 highway route) and allow access between Istanbul-east and west, the First Bosphorus bridge must be used. But the construction of a rail system is not feasible on this bridge.

(Yazici, Levinson, Ilicali , Camkesen , & Kamga, 2013)

Taking into consideration the above listed factors, a BRT system on the E-5 route is found eligible. Istanbul's bus rapid transit system operates under the commercial name: Metrobus. Briefly, the Metrobus system is a 52 km segregated mid-lane corridor running on the E-5 highway passing through the Halic and the First Bosphorus bridge. The corridor contains a total of *45* stations and *7 lines* operate on the corridor. The implementation of the whole system cost around 466 million dollars and it has been implemented incrementally in four stages over the years between 2007 and 2012 (Buran, 2013). The map below shows the Metrobus system.

Map 6



The map from (IETT, 2014) is altered.

The four stages are summarized below:

Phase 1: The first corridor was opened on September 17, 2007 between Avcilar and Topkapi area which had a population around 3.2 million. Another important thing to notice is that Ataturk Airport belongs to this area. The corridor is 18.5 km long and contains 15 stations. This corridor is important in terms of operating on the densest area on its route and it increases the level of accessibility to the airport. (completion period: 8 months)

Phase 2: The second phase was built as a 12 km extension to the east-end of the corridor between Topkapi-Zincirlikuyu. It began operating on September 8, 2008 reaching to a new region with a population of 2.7 million with its 11 new stations. In this phase the Metrobus system could reach to the current CBD of Istanbul. (completion period: 77 days)

Phase 3: Metrobus corridor reached to the Asian side in the third phase. On March 3, 2009, 11.5 km of extension was built between Zincirlikuyu-Sogutlucesme. This extension passes through the First Bosphorus bridge by linking to the mixed traffic at the bridge. Therefore Metrobus started to serve to the Zincirlikuyu-Sogutlucesme area which has a population of around 1.7 million with its 8 stations.(completion period: 5 months)

Phase 4: The last phase was a 10 km extension on the west-end of the corridor between Beylikduzu-Avcilar. The fourth phase has 11 stations and it was completed on July 19, 2012. (began on March 15th, 2011)

(Buran, 2013; IETT Metrobus , 2014)

The components of Metrobus

Vehicles

Metrobus system uses articulated buses that run on diesel. The vehicles are distinguished from other PT buses regarding color and design features. IETT reports that the Metrobus fleet consists of 535 buses with passenger doors at the right side. The table below gives an overview of the fleet (IETT Metrobus , 2014).

Table 4

Brand	Number of Vehicle	Easy access	Passenger Capacity
Capacity	250	Low floor	165
Phileas	50	Low floor	258
Citaro	100	Low floor	160
Conecto	85	Low floor	160
Karsan	50	Low floor	155

(IETT Metrobus , 2014)

Running ways

The 52 km long Metrobus corridor is built on the median lanes of the E-5 highway and it is segregated from the mixed traffic. This means that the Metrobus system removed two road lanes from the highway. The corridor is linked to the mixed traffic only at the First Bosphorus bridge by using grade separation.

Stations

There are 45 approximately equally distant stations on the corridor. The stations are located in the mid-lane similar to a railway system. Having vehicle doors at the right side and mid-lane stations, the Metrobus operations are conducted as counter-flow and also the bridge grade separation is built accordingly to correct the counter-flow movement at the connection points with the mixed traffic (Yazici, Levinson, Ilicali , Camkesen , & Kamga, 2013).

On average, each Metrobus station has similar capacity and amenities regardless of the differences in usage levels. These amenities are: 1. Announcement system, 2. Information screens, 3. Kiosk, 4. Ticket sale/refund installations, 5. Security/Help staff, 6. Elevator and 7. Easy access platforms (IETT Metrobus , 2014).

Ten stations in the system are selected as the integration points to the rail modes and each integration point includes park and ride (P+R) facilities. It is reported that these facilities will be further expanded in terms of capacity and number in order to promote a shift from commuting by car to BRT. The below table lists the P+R facilities offered at the Metrobus stations.

Table 5

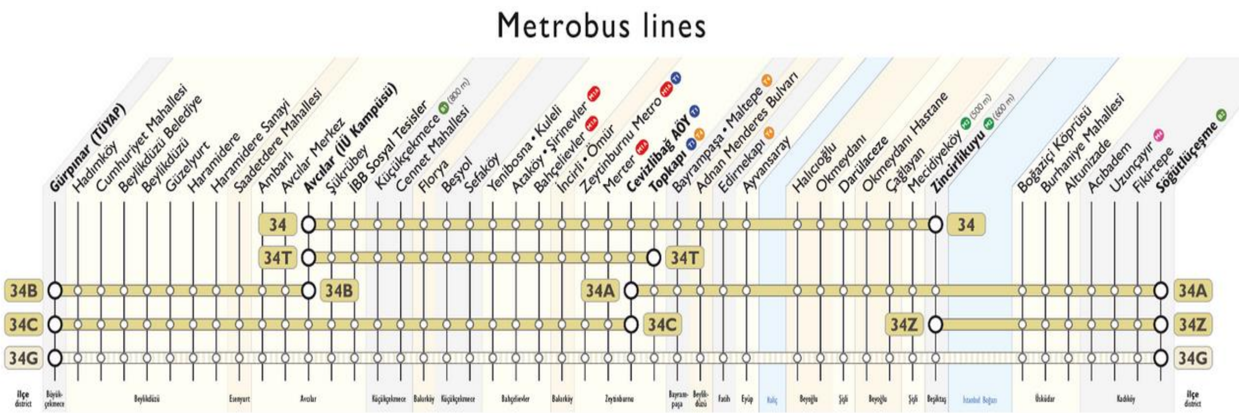
P+R Station	District
Zincirlikuyu	Beşiktaş
Zeytinburnu	Zeytinburnu
Merter	Güngören
Acıbadem	Üsküdar
Florya	Bakırköy
Mecidiyeköy	Şişli
Söğütlüçeşme	Kadıköy
Okmeydanı	Kağıthane
Şirinevler	Bakırköy
Tüyap	Büyük Çekmece

(IETT Metrobus , 2014)

Service patterns

There are seven Metrobus line services offered in which the vehicles stop at each designated station on their route. These services are namely; 34, 34A, 34B, 34C, 34G, 34T and 34Z.

Map 7



(IETT, 2014)

The overall system frequency at the peak hours is 15-20 seconds, off the peak hours the frequency drops to 45-60 seconds and at night, the system frequency is around 30 minutes (Yazici, Levinson, Ilicali , Camkesen , & Kamga, 2013).

2.3.2 An analysis of Metrobus on congestion

Being built on the one of the two main arterial roads (E-5) that faces severe congestion, the Metrobus system has dropped the road capacity in order to increase overall ridership levels on E-5 (Ekenyazici-Guney, 2012). In this respect, the first hypothesis is that;

“Hypothesis 1: Metrobus system is a substitute to road transportation (commuting by personal car, private road services and road PT mode: Bus.”

The Metrobus stations that are chosen as the main integration points to the rail mode increase accessibility and therefore promote railway usage and vice versa. Hence, the integration between Metrobus and Rail should have a positive effect on the ridership levels of each other. So;

"Hypothesis 2: Metrobus system is a complementary service to Rail."

For the case of Hypothesis 1, IETT reports that the implementation of Metrobus system has led to a need for re-organization of their bus transport services. In this respect, IETT removed a number of bus transport service lines (18 lines in 2011) as well as shortened the routes of various bus services (11 lines in 2011) (Yazici, Levinson, Ilicali , Camkesen , & Kamga, 2013). Regarding the private road transportation, IETT reports that every year 3.500.000 commuters by personal car use the P+R services indicating the shift from private car usage towards the Metrobus and Rail systems (IETT Metrobus , 2014). Moreover, around 1.296 minibuses have been removed from the main arterial road with the implementation of the Metrobus. As a result of a decrease in the vehicles in traffic, negative externalities of congestion such as accidents, time loss at the cues and pollution levels have decreased (Buran, 2013).

This thesis aims to analyze the ridership effects of the PT modes. In this respect, Hypothesis 1 must be narrowed down to "Metrobus system is a substitute to Bus transport services." In the next section, these hypotheses will be analyzed quantitatively.

3. Methodology

3.1 Method and Scope of study

This thesis aims to analyze the impact of Metrobus system on the ridership of other public transport modes in Istanbul. In order to achieve this goal, Istanbul PT systems are categorized under four main modes (Metrobus, Bus transport, Rail systems and Seaway) and ridership levels of the four main modes over the years are utilized by using the appropriate tests and an econometric model under Multivariate Time Series Analysis. The statistical tests and the model are conducted by using the statistical analysis software: STATA.

The limited number of variables due to aggregating the PT modes under four main categories and the unavailability of other measures except ridership levels (i.e. distance travelled by the users, number of transits made by the users etc.) is the main limitation of this research. This limitation restricted the use of various econometric models in order to analyze the level of ridership “take over” between PT modes. This limitation is handled by the appropriate model selection.

3.2 Focus and Control areas

Istanbul transportation market consists of public and private transport services on road, rail and sea. The focus of this study is solemnly on the ridership levels of public transportation services in Istanbul. Hence, the private transport services are not included in this study. As mentioned previously, in order to observe the impact of Metrobus system on the ridership levels of other PT modes which are namely; Bus transport and Rail systems, the road public transport services are differentiated into two separate categories as Metrobus ridership levels and Bus ridership levels.

3.3 Data

In order to answer the research question, secondary data on the ridership of four main public transport modes which are namely; Metrobus, Bus, Rail and Sea was collected from IETT. The dataset contains the monthly ridership levels for 96 consecutive months between January 2006 and December 2013. The selected time interval captures 21 months before the completion of the first phase and 17 months after the completion of the last phase of the Metrobus system. There are no missing observations in the acquired dataset. Also, because all variables have the measures of previous years, there are no estimated values or forecasts in the dataset. Screening the dataset shows that the monthly ridership levels of the four main modes are generally large values (in millions) and continuously grow over the years. For this reason, variable transformation is conducted which will be explained in the upcoming section.

3.4 Variable specification

The table below gives an overview on the values of obtained and transformed variables.

Table 6

Variable	Obs	Mean	Std. Dev.	Min	Max
Metrobus	96	1.01e+07	7155291	0	2.20e+07
Bus	96	5.64e+07	1.28e+07	2.94e+07	8.31e+07
Rail	96	2.51e+07	8274906	8483623	4.25e+07
lnMetrobus	96	12.67402	6.767719	0	16.90593
lnBus	96	17.8228	.2305924	17.19732	18.23542
lnRail	96	16.97197	.3956643	15.95365	17.56562

The summary table shows that monthly ridership levels of *Metrobus*, *Bus* and *Rail* are acquired for 96 consecutive months. The values for ridership levels of *Metrobus*, *Bus* and *Rail* are in tens of millions which are relatively higher compared to the variable *Sea*.

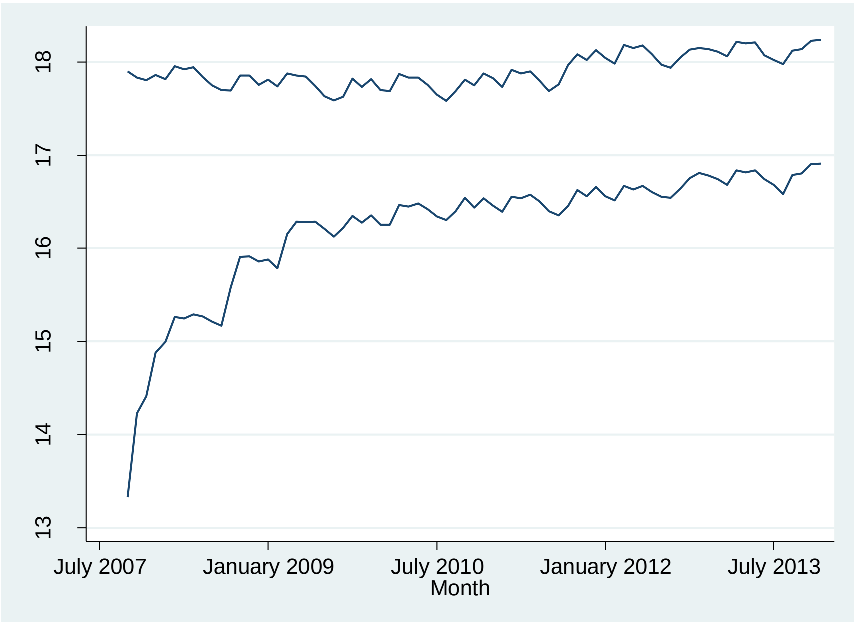
For this reason, the variable *Sea* is excluded from the analysis. The high ridership values and the continuous growth in these values over the years that is observed by screening the dataset indicate that there is a need for a logarithmic transformation in the variables. Thus new variables *lnMetrobus, lnBus* and *lnRail* are generated by taking the logarithm of the value of ridership plus one as shown in the example equation below for the variable bus:

“*lnbus* = log(*Bus*+1)”

The first 21 observations under the variable *Metrobus* have a value of zero because the Metrobus system was not implemented at that period of time. Hence, adding the value one to every observation prevents having undefined values under the variable *lnMetrobus* without distorting the observations largely.

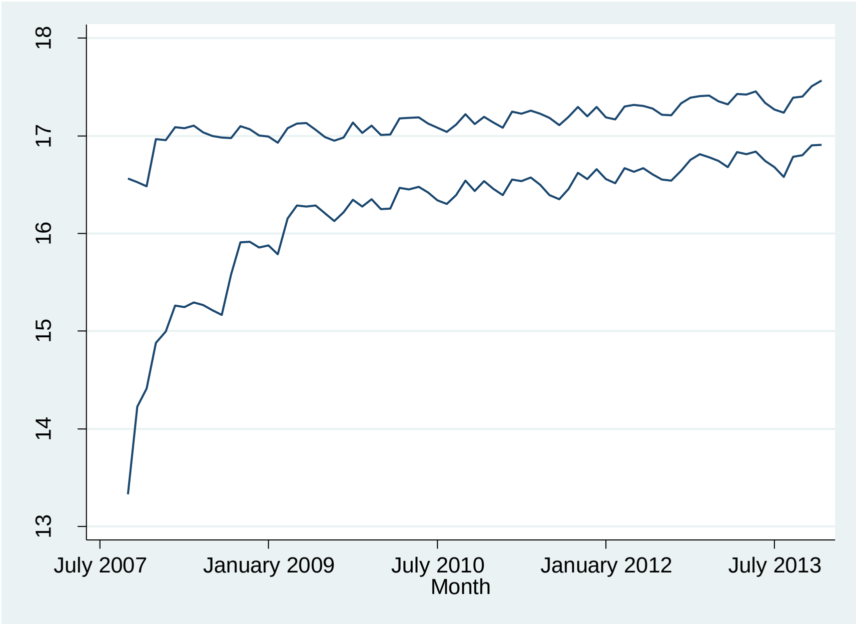
Graph 3 represents the monthly ridership levels of Metrobus (*line below*) and Bus (*line above*) in logarithmic scale.

Graph 3



Graph 4 represents the monthly ridership levels of Metrobus (*line below*) and Rail (*line above*) in logarithmic scale.

<u>Graph 4</u>



Both graphs show that until January 2009, Metrobus system gains ridership levels rapidly. In both graphs after this period, the monthly ridership levels of Metrobus seem to move together with Bus and Rail which suggests that there may be serial correlation between the variables. Also, a continuous increase in ridership levels in all variables over the years is observed. This increase shows a roughly linear trend on the logarithmic variables which indicates that the ridership levels have increased exponentially over the years. Continuous growth shows non-stationarity.

The selected model utilizes all the variables as dependent variables and the selected lags of each variable are utilized as the independent variables. The upcoming section is dedicated to elaborating the econometric model used.

3.5 Model specification

Having the ridership levels of four PT modes over the years and the goal of analyzing the effect of one variable on the others, Multivariate Time Series Analysis is selected as the appropriate econometric tool. The model used under this econometric analysis is the Vector Auto Regression (VAR) model. VAR model is an easy to use, efficient econometric tool to achieve a successful time series analysis with limited number of variables (Zivot & Wang, 2006). But, there are various conditions that the variables must meet in order to be able to use the VAR model. These conditions are summarized below:

*"Condition 1**:** Variables at level 1 must be stationary on the selected optimum lags to be able to run an Unrestricted VAR model."*

If condition 1 is not met, the analysis can be continued if the variables meet condition 2. However, before checking for condition 2 the precondition regarding cointegration must be met.

*"Precondition**:** Variables that are non-stationary at level 1 but become stationary when transformed into differenced variable (Integrated of same order), are eligible for Johansen Cointegration Test."*

*"Condition 2**:** Variables that meet Precondition are eligible to run:*

1. *Restricted VAR (Vector Error Correction) Model if there is cointegration.*
2. *Unrestricted VAR Model if there is no cointegration."*

(Wooldridge, 2009)

In order to check for the above mentioned conditions, the necessary steps are taken. First of all, optimum lags must be selected in order to check for Condition 1. The rule-of-thumb for the maximum lag selection for monthly data is 12, as various researches also utilize maximum lag of 12 for monthly data (Karfakis & Moschos, 1990). Akaike's information criterion (AIC) and Schwarz's Bayesian information criterion (SBIC) tests with maximum lag of 12, are used to select the optimum lag.

Table 7

```
. varsoc lnMetrobus lnBus lnRail, maxlag(12)

   Selection-order criteria
   Sample:  January 2007 - December 2013          Number of obs      =        84
```

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-160.368				.009814	3.8897	3.9246	3.97652
1	65.825	452.38	9	0.000	.000056	-1.28155	-1.14195	-.934287*
2	72.5314	13.413	9	0.145	.000059	-1.22694	-.982647	-.619234
3	85.7984	26.534	9	0.002	.000053	-1.32853	-.979545	-.460385
4	112.008	52.419	9	0.000	.000036	-1.73829	-1.2846	-.609695
5	128.317	32.618	9	0.000	.00003	-1.91231	-1.35393	-.523272
6	136.034	15.434	9	0.080	.000031	-1.88176	-1.21868	-.232278
7	145.181	18.294	9	0.032	.000032	-1.88526	-1.11748	.02467
8	160.772	31.183	9	0.000	.000028	-2.0422	-1.16973	.128174
9	188.43	55.315	9	0.000	.000018	-2.48643	-1.50926	-.055612
10	203.34	29.819	9	0.000	.000016*	-2.62714	-1.54527*	.064126
11	210.135	13.591	9	0.138	.000018	-2.57464	-1.38808	.377062
12	224.147	28.024*	9	0.001	.000016	-2.69398*	-1.40272	.51817

```
   Endogenous:  lnMetrobus lnBus lnRail
    Exogenous:  _cons
```

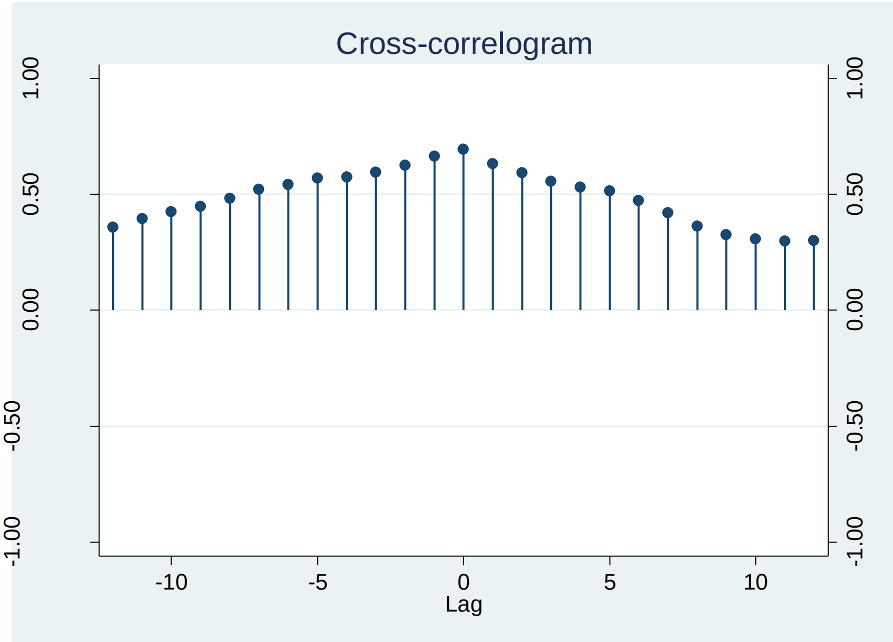
The lowest values of AIC and SBIC tests indicate the most appropriate lags for the model (Wooldridge, 2009). The results show that AIC test has the lowest value on Lag 12 and SBIC test has the lowest value on Lag 1. As mentioned previously, the econometric model under consideration generates independent variables for each lag selected. In this respect, having 12 lags would lead to too many independent variables which causes complexity. For this reason, Lag 1 is selected as the optimum lag that will be used.

Examining Graph 3 and Graph 4 suggested that there might be serial correlation and non-stationarity on the variables. To observe serial correlation as well as looking for indications of non-stationarity, correlograms are used on the level 1 variables (lnMetrobus, lnBus, lnRail) **(see appendix).**

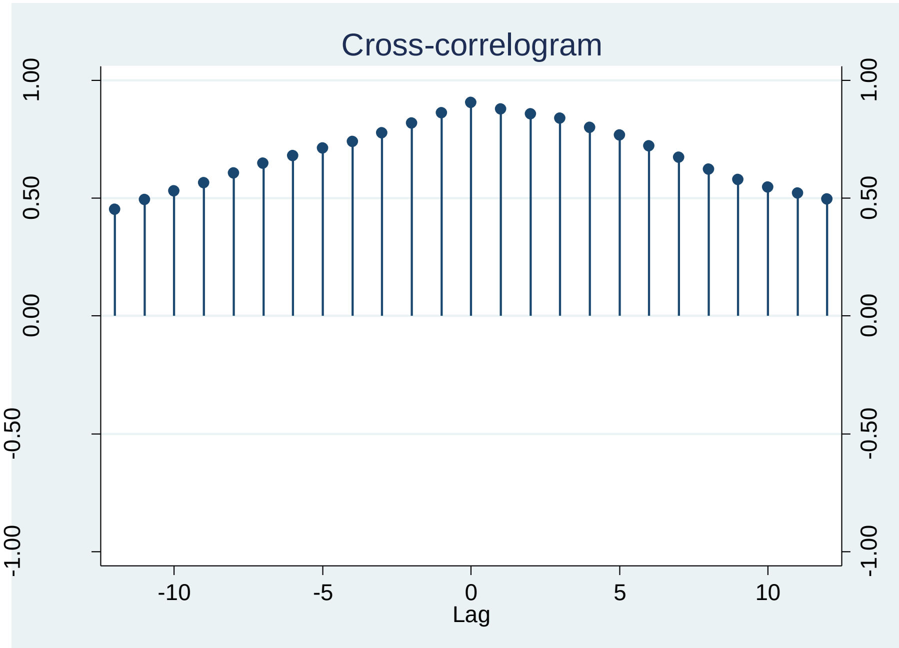
First of all, the descending order of autocorrelation levels indicates serial correlation. Serial correlation is observed in all level 1 variables. Second of all, the null hypothesis is the variable is stationary. For all variables at every lag, the Null hypothesis is rejected (p-value: 0.000), suggesting that the variables are non-stationary on every lag including the selected lags; Lag 1 and Lag 12 (Dehkordi-Vakil , 2007).

Having observed the indications of serial correlation within each variable, the correlation between the variables are also taken into consideration to have an insight about the relationships between the variables. For this reason, the cross correlation between the variable of interest *lnMetrobus* versus the other variables; *lnBus* and *lnRail* are performed.

Graph 5



Graph 6



Graph 5 represents the cross correlation between the variables *lnMetrobus* and *lnBus.* It shows that there is positive correlation between these two variables at all lags. The highest level of correlation between these variables are observed at lag zero with above 0,50 and the level of correlation descends as it is moved further from lag zero. At the selected lag for the model, lag 1, the cross correlation between these variables are still above 0,50 and it indicates that these two variables are positively affecting each other. Therefore this graph shows that the Hypothesis 1 may be falsified in the model since Metrobus ridership levels do not negatively correlate with the Bus ridership levels, ceteris paribus.

Graph 6, on the other hand visualizes the cross correlation between the variables *lnMetrobus* and *lnRail.* Similar to Graph 5, there is also positive correlation between these variables at all lags, yet at a higher level. At lag zero, the correlation between the two variables are very high (close to 1,00). Same with the previous graph, the correlation levels also decrease as it is moved away from lag zero. At lag 1, the correlation between rail and metrobus ridership levels is around 0,75 which is higher than the correlation between Metrobus and Bus at lag 1. This indicates that the Hypothesis 2 may be found correct in the model.

Moreover, in order to confirm that the level 1 variables are non-stationary, Dickey-Fuller Test is used. Dickey-Fuller test is a common statistical test to check for unit root in time varying variables at one specific lag, in this case lag 1 (Wooldridge, 2009). The Null Hypothesis for the Dickey-Fuller Test is that there is a unit root, indicating non-stationarity. The results show that Z(t) values are above 5% significance level for all level 1 variables, indicating that there is unit root. By using Dickey-Fuller Test, it is confirmed that the level 1 variables are non-stationary therefore Condition 1 cannot be met.

The next step is to proceed with Condition 2. But first it should be checked whether the level 1 variables meet the precondition or not. For this, the differenced variables are generated for every level 1 variable. This is done by subtracting each observation from its predecessor. Differenced variables that are generated are namely; *dlnmetrobus, dlnbus* and *dlnrail*. Then, Dickey-Fuller Test is used for each differenced variable to check for unit root. Generating differenced variables by subtracting every observation at time (t) from the predecessor observation at time (t-1) leads to obtain number of observation for every variable minus one. Therefore, the selected lag to test for unit root on the differenced variables is Lag 0 **(see appendix)**.

The results show that the Null hypothesis of having a Unit Root (non-stationarity) can be rejected for all differenced variables at lag zero (Z(t) value: 0.000 for all differenced variables). Therefore, the level 1 variables meet the Precondition to test for cointegration.

Johansen Test is used to test the level 1 variables on cointegration. The Null Hypothesis is represented on the maximum rank 0, that is there is no cointegration (Johansen, 1988). Johansen Cointegration Test results show that the trace statistic value is lower than 5% critical value on the maximum rank 0. This means that there is no cointegration between the level 1 variables. Thus, the selected model is Unrestricted VAR with optimum lag of 1.

3.6 Model

The results under Model specification concluded that a VAR model with a lag selection of 1 shall be used. VAR model is used to observe the linear relationships between a set of dependent variables over time. This means that VAR model differs from other linear regression models by setting up each variable as the dependent variable and obtaining the linear relationships between each selected dependent variable and the selected lags of every variable including the dependent variable itself (Zivot & Wang, 2006). In short, the linear relationships between variables over time captured by the VAR model can be summarized as the below equation.

The VAR(p) linear equation for the number of set of dependent variables (k), observed for the same period of time (t=1,…, t-1, t) on (p)th order in which (p) refers to the number of selected lags is:

$$\mathbf{Y}_{\mathrm{t}} = \mathbf{c} + \mathbf{A}_1\mathbf{Y}_{\mathrm{t}-1} + \mathbf{A}_2\mathbf{Y}_{\mathrm{t}-2} + \ldots + \mathbf{A}_{\mathrm{p}}\mathbf{Y}_{\mathrm{t}-\mathrm{p}} + \mathbf{e}_{\mathrm{t}}$$

(Kunst, 2011)

In this equation “c” is the constant term for “k” variables that is a vector of (k x 1). “A_i” represents the coefficient for each lag for “k” variables. Therefore “A” is represented as (k x k) in the matrix form. The **“$\boldsymbol{e_t}$”** represents the error term which is a vector of (k x 1). The error term must suffice the following conditions in order to have results that are reliable in the VAR model.

1. The error term has zero mean, indicating unbiasedness: $\mathrm{E}(\mathrm{e}_{\mathrm{t}}) = 0$
2. The value of error term matrix at each “t” is at least zero or higher: $\mathrm{E}(\mathrm{e}_{\mathrm{t}}\ \mathrm{e}_{\mathrm{t}}') = \Omega$
3. The error term is not serially correlated: $\mathrm{E}(\mathrm{e}_{\mathrm{t}}\ \mathrm{e}_{\mathrm{t}-\mathrm{k}}') = 0$

(Kunst, 2011)

Therefore, the equation targeted to estimate in this study is represented below in the matrix form for VAR(1) is:

$$\begin{bmatrix} y_{\ln Metrobus,t} \\ y_{\ln Bus,t} \\ y_{\ln Rail,t} \end{bmatrix} = \begin{bmatrix} c_{\ln Metrobus} \\ c_{\ln Bus} \\ c_{\ln Rail} \end{bmatrix} + \begin{bmatrix} a^1_{\ln Metrobus,\ln Metrobus} & a^1_{\ln Metrobus,\ln Bus} & a^1_{\ln Metrobus,\ln Rail} \\ a^1_{\ln Bus,\ln Metrobus} & a^1_{\ln Bus,\ln Bus} & a^1_{\ln Bus,\ln Rail} \\ a^1_{\ln Rail,\ln Metrobus} & a^1_{\ln Rail,\ln Bus} & a^1_{\ln Rail,\ln Rail} \end{bmatrix} \begin{bmatrix} y_{\ln Metrobus,t-1} \\ y_{\ln Bus,t-1} \\ y_{\ln Rail,t-1} \end{bmatrix} + \begin{bmatrix} e_{\ln Metrobus,t} \\ e_{\ln Bus,t} \\ e_{\ln Rail,t} \end{bmatrix}$$

4. Results

Recalling from the previous sections, this thesis aims to confirm or falsify the below hypotheses by using the results obtained from the econometric analysis:

“Hypothesis 1: Metrobus system is a substitute to Bus transportation.”

“Hypothesis 2: Metrobus system is a complementary service to Rail.”

In this section, firstly the obtained results from the econometric model will be presented, followed by the interpretation of the results.

4.1 Results obtained from the model

The below table summarizes the results obtained from the VAR(1) model in which the coefficients that are labeled with a (*) are significant at 5% significance level.

Table 8

Dependent variable	Indep. var. / Constant	Coefficient	P>|z|
lnMetrobus	lnMetrobus Lag 1	.9813802*	0.000
	lnBus Lag 1	1.035843	0.394
	lnRail Lag 1	-.8090108	0.506
	Constant	-4.318551	0.779
lnBus	lnMetrobus Lag 1	.0008533	0.824
	lnBus Lag 1	.7935343*	0.000
	lnRail Lag 1	.0422453	0.638
	Constant	2.962329*	0.009
lnRail	lnMetrobus Lag 1	.0096002*	0.004
	lnBus Lag 1	.030613	0.695
	lnRail Lag 1	.7827022*	0.000
	Constant	3.036859*	0.002

4.2 Interpretation of the model

The results obtained from the model shall be analyzed with a perspective gained from the cross correlation results. First of all, it is observed that every variable has a significant positive relationship with itself at lag 1 (significant at 1% significance level). These effects are:

1. On average, there is 98% Metrobus ridership increase at lag zero, when there is 1% Metrobus ridership increase at lag 1, ceteris paribus. This effect is significant at 1% significance level (p-value: 0,000).
2. On average, there is 79% Bus ridership increase at lag zero, when there is 1% Bus ridership increase at lag 1, ceteris paribus. This effect is significant at 1% significance level (p-value: 0,000).

3. On average, there is 78% Rail ridership increase at lag zero, when there is 1% Rail ridership increase at lag 1, ceteris paribus. This effect is significant at 1% significance level (p-value: 0,000).

Second of all, it is observed that Metrobus ridership has a positive significant impact on the Rail ridership. This effect is summarized as:

4. On average, there is 1% Rail ridership increase at lag zero, when there is 1% Metrobus ridership increase at lag 1, ceteris paribus. This effect is significant at 1% significance level (p-value: 0,004).

This finding proves that the Hypothesis 2 holds which means that Metrobus is a complimentary service to Rail since an increase in the ridership levels of Metrobus leads to an increase in the ridership levels of Rail in the next month.

Other findings from the model results are:

5. Metrobus ridership increase at lag 1 leads to an increase in Bus ridership in the upcoming month, ceteris paribus.
6. Bus ridership increase at lag 1 leads to an increase in Metrobus ridership in the upcoming month, ceteris paribus.
7. Rail ridership increase at lag 1 leads to a decrease in Metrobus ridership in the upcoming month, ceteris paribus.

None of the above listed findings are significant at 5% significance level. This implies that there is no proven positive or negative relationship between the ridership levels of Metrobus and Bus. Hence, Hypothesis 1; that is qualitatively discussed and visualized with Graph 5 does not hold.

5. Conclusion and Discussion

This thesis began with the purpose of answering the research question *"What is the effect of introducing the BRT system in Istanbul on the ridership of other main public transport modes?".* In order to reach this goal, firstly a literature review is conducted, then a quantitative analysis on the problem is made.

Firstly, the definition of a BRT system is made by comparing the existing literature. It is concluded that a BRT system is a PT mode which aims to increase ridership by offering frequent bus services with exclusive rights of way on segregated running ways and stations with amenities. This analysis on the existing literature showed that BRT systems have many common aspects with LRT systems. For this reason a qualitative analysis on the comparison of the two systems is conducted. The comparison between BRT and LRT pointed out that both systems have the same goal of increasing ridership and there are indeed similarities between the two such as having exclusive right of way on segregated running ways and stations with same level of amenities. Also, the main differences are pointed out such as LRT systems are more permanent, environmentally friendly and perceived to offer higher service quality. These superiorities of LRT over BRT are overcome by the BRT systems by having incremental implementation process, higher flexibility and cost efficiency. Hence, it is concluded that there is not enough signs to perceive one system is superior to the other, therefore depending on the characteristics of the transport market; either BRT or LRT systems can be implemented to increase the PT ridership levels.

After outlining the BRT system as a concept, the congestion problem in Istanbul and the measures that address this problem is elaborated. It is represented that a BRT system was selected as one of the solutions that address congestion in Istanbul due to various reasons; especially the inability to construct an LRT system over the two Bosphorus bridges. In the case of Istanbul, various articles and reports have claimed that the Istanbul BRT system, Metrobus, achieved the goal of increasing PT ridership by offering a service that is substitute to private and public road transport options and it has become a complimentary service to railway systems with “good” integration. These hypotheses regarding solemnly the public transportation are tested by using a VAR model under Multivariate Time Series Analysis. The quantitative analysis showed that Metrobus system indeed has become a complimentary service to the rail system. This effect is on average 1% increase in the ridership levels of the Metrobus system leads to 1% ridership increase on the rail system in the month following, ceteris paribus. Contradicting with the hypothesis that Metrobus is expected to take over the public road transport ridership, the quantitative analysis showed that there are signs that indicate Metrobus system could also be a complimentary service to Bus services, yet there is no any significant evidence to confirm or deny these signs.

Reviewing the existing literature showed that there is limited research on the BRT systems in terms ridership and mainly the available studies focus on the ridership attracting features of the BRT systems. Different from the existing literature, this thesis studied the impact of a BRT service as a whole system on the other available PT modes in the transport market of Istanbul. This research can also be repeated for other transport markets that have recently implemented a ridership deriving PT system. Moreover, the findings give insight on the effects of such PT systems, in this case a BRT system, to the reader.

One of the limitations in this thesis is the unavailability of the existing studies that have approached to the BRT ridership subject from an overall transport market perspective. Moreover, it is qualitatively discussed that the private transport services have a high share in Istanbul transport market and hence they are important factors to analyze. But the monthly ridership levels of the private transport services for the same period of time is not available. Hence, this has limited the study to only focus on the public transportation even though the private transportation is an important element. Therefore, the impact of Metrobus system on the ridership levels of private transport services can be an interesting research topic for further studies. Lastly, the available data used in this study is limited. The variables used are the main categories of the different PT services. More detailed observations on the ridership levels of each service as well as controlling for various factors such as; the number of transits, distance travelled by the users etc. could allow to analyze the impacts of Metrobus system on other transport modes more efficiently.

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7. Appendix

1. Correlogram lnMetrobus

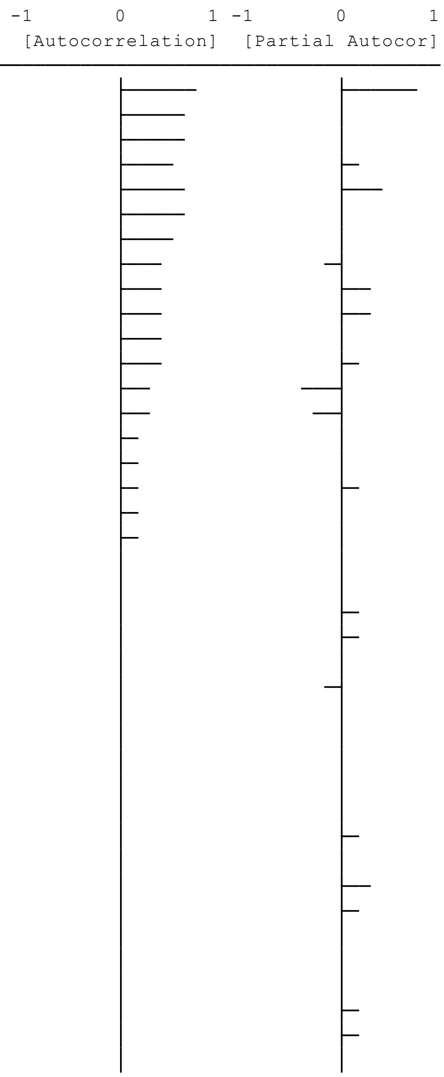
```
. corrgram lnMetrobus
```

LAG	AC	PAC	Q	Prob>Q	-1 0 1 [Autocorrelation]	-1 0 1 [Partial Autocor]
1	0.9588	0.9630	91.047	0.0000		
2	0.9148	-0.0567	174.81	0.0000		
3	0.8702	-0.0028	251.42	0.0000		
4	0.8242	-0.0245	320.89	0.0000		
5	0.7781	0.0030	383.48	0.0000		
6	0.7310	-0.0123	439.34	0.0000		
7	0.6837	0.0082	488.75	0.0000		
8	0.6362	0.0026	532.03	0.0000		
9	0.5888	0.0104	569.51	0.0000		
10	0.5415	0.0114	601.59	0.0000		
11	0.4944	0.0104	628.64	0.0000		
12	0.4460	-0.0238	650.92	0.0000		
13	0.3963	-0.0172	668.72	0.0000		
14	0.3467	0.0074	682.51	0.0000		
15	0.2972	0.0110	692.77	0.0000		
16	0.2478	0.0066	699.99	0.0000		
17	0.1987	0.0160	704.69	0.0000		
18	0.1485	-0.0176	707.35	0.0000		
19	0.0977	-0.0018	708.52	0.0000		
20	0.0469	0.0055	708.79	0.0000		
21	-0.0039	0.0118	708.79	0.0000		
22	-0.0156	0.0089	708.82	0.0000		
23	-0.0243	0.0132	708.9	0.0000		
24	-0.0328	-0.0003	709.04	0.0000		
25	-0.0405	-0.0069	709.25	0.0000		
26	-0.0476	0.0097	709.56	0.0000		
27	-0.0542	0.0006	709.96	0.0000		
28	-0.0604	0.0013	710.46	0.0000		
29	-0.0663	-0.0029	711.08	0.0000		
30	-0.0730	-0.0066	711.84	0.0000		
31	-0.0799	0.0050	712.77	0.0000		
32	-0.0872	0.0042	713.88	0.0000		
33	-0.0930	0.0007	715.17	0.0000		
34	-0.0976	-0.0030	716.62	0.0000		
35	-0.1019	-0.0019	718.22	0.0000		
36	-0.1068	-0.0011	720.01	0.0000		
37	-0.1122	-0.0056	722.02	0.0000		
38	-0.1174	0.0044	724.25	0.0000		
39	-0.1220	-0.0005	726.71	0.0000		
40	-0.1258	-0.0033	729.37	0.0000		

2. Correlogram lnBus

```
. corrgram lnBus
```

LAG	AC	PAC	Q	Prob>Q
1	0.8428	0.8730	70.335	0.0000
2	0.7312	0.0619	123.84	0.0000
3	0.6336	0.0202	164.45	0.0000
4	0.6026	0.2329	201.59	0.0000
5	0.6575	0.4562	246.28	0.0000
6	0.6530	0.0038	290.85	0.0000
7	0.5945	-0.0849	328.21	0.0000
8	0.4796	-0.1308	352.8	0.0000
9	0.4185	0.2893	371.74	0.0000
10	0.4165	0.2572	390.72	0.0000
11	0.4325	0.0213	411.42	0.0000
12	0.4668	0.1518	435.83	0.0000
13	0.3697	-0.3908	451.32	0.0000
14	0.2514	-0.3664	458.57	0.0000
15	0.1854	-0.0174	462.56	0.0000
16	0.1414	-0.0177	464.92	0.0000
17	0.1949	0.1613	469.44	0.0000
18	0.1863	-0.0272	473.62	0.0000
19	0.1301	-0.0693	475.69	0.0000
20	0.0417	0.0942	475.91	0.0000
21	-0.0030	0.1210	475.91	0.0000
22	0.0267	0.1875	476	0.0000
23	0.0751	0.2069	476.72	0.0000
24	0.0929	-0.0649	477.85	0.0000
25	0.0225	-0.1976	477.92	0.0000
26	-0.0457	0.0923	478.2	0.0000
27	-0.0909	-0.0234	479.33	0.0000
28	-0.0890	0.0575	480.42	0.0000
29	-0.0210	0.0187	480.49	0.0000
30	-0.0001	-0.0490	480.49	0.0000
31	-0.0141	0.1372	480.51	0.0000
32	-0.0626	-0.0792	481.09	0.0000
33	-0.0664	0.3407	481.75	0.0000
34	-0.0282	0.2058	481.87	0.0000
35	0.0355	0.1098	482.07	0.0000
36	0.0531	0.0495	482.51	0.0000
37	0.0027	-0.0936	482.51	0.0000
38	-0.0408	0.1906	482.78	0.0000
39	-0.0629	0.1400	483.43	0.0000
40	-0.0366	0.0481	483.66	0.0000



3. Correlogram lnRail

```
. corrgram lnRail
```

LAG	AC	PAC	Q	Prob>Q	-1 0 1 [Autocorrelation]	-1 0 1 [Partial Autocor]
1	0.9255	0.9486	84.819	0.0000		
2	0.8654	0.0882	159.78	0.0000		
3	0.8137	0.0444	226.76	0.0000		
4	0.7712	0.1105	287.58	0.0000		
5	0.7528	0.3296	346.17	0.0000		
6	0.7193	0.0080	400.25	0.0000		
7	0.6747	-0.0732	448.37	0.0000		
8	0.6153	-0.0862	488.85	0.0000		
9	0.5727	0.3024	524.31	0.0000		
10	0.5438	0.1731	556.67	0.0000		
11	0.5288	0.1099	587.62	0.0000		
12	0.5182	0.1802	617.7	0.0000		
13	0.4759	-0.2171	643.37	0.0000		
14	0.4338	0.0652	664.96	0.0000		
15	0.3971	-0.0829	683.28	0.0000		
16	0.3623	-0.0004	698.72	0.0000		
17	0.3463	0.1585	713	0.0000		
18	0.3175	0.0629	725.16	0.0000		
19	0.2734	-0.0724	734.3	0.0000		
20	0.2233	0.1141	740.47	0.0000		
21	0.1798	0.1891	744.53	0.0000		
22	0.1487	0.0609	747.34	0.0000		
23	0.1288	0.2974	749.48	0.0000		
24	0.0944	-0.0837	750.64	0.0000		
25	0.0721	-0.1559	751.33	0.0000		
26	0.0552	-0.0106	751.74	0.0000		
27	0.0392	-0.1055	751.95	0.0000		
28	0.0368	0.1338	752.14	0.0000		
29	0.0477	0.0943	752.46	0.0000		
30	0.0443	-0.0311	752.74	0.0000		
31	0.0291	-0.0750	752.86	0.0000		
32	0.0079	0.0177	752.87	0.0000		
33	-0.0071	0.0218	752.88	0.0000		
34	-0.0123	-0.0502	752.9	0.0000		
35	-0.0022	-0.0178	752.9	0.0000		
36	-0.0073	-0.0533	752.91	0.0000		
37	-0.0282	-0.0867	753.03	0.0000		
38	-0.0480	0.0384	753.41	0.0000		
39	-0.0665	0.0460	754.14	0.0000		
40	-0.0680	0.0710	754.91	0.0000		

4. Dickey-Fuller test for lnMetrobus

```
. dfuller lnMetrobus, lag(1)

Augmented Dickey-Fuller test for unit root         Number of obs   =        94
```

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-1.855	-3.518	-2.895	-2.582

MacKinnon approximate p-value for Z(t) = 0.3534

5. Dickey-Fuller test for lnBus

```
. dfuller lnBus, lag(1)

Augmented Dickey-Fuller test for unit root         Number of obs   =        94

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -2.168            -3.518            -2.895            -2.582
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.2181
```

6. Dickey-Fuller test for lnRail

```
. dfuller lnRail, lag(1)

Augmented Dickey-Fuller test for unit root         Number of obs   =        94

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -1.876            -3.518            -2.895            -2.582
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.3434
```

7. Dickey-Fuller test for dlnmetrobus

```
. dfuller dlnmetrobus, lag(0)

Dickey-Fuller test for unit root                   Number of obs   =        94

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -9.096            -3.518            -2.895            -2.582
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0000
```

8. Dickey-Fuller test for dlnbus

```
. dfuller dlnbus, lag(0)

Dickey-Fuller test for unit root                   Number of obs   =        94

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)            -10.855            -3.518            -2.895            -2.582
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0000
```

9. Dickey-Fuller test for dlnrail

```
. dfuller dlnrail, lag(0)

Dickey-Fuller test for unit root                   Number of obs   =        94

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)            -10.575            -3.518            -2.895            -2.582
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0000
```

10. Johansen Cointegration test

```
. vecrank lnMetrobus lnBus lnRail, lags (12) max
```

Johansen tests for cointegration

Trend: constant — Number of obs = 84

Sample: January 2007 - December 2013 — Lags = 12

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	102	211.17504	.	25.9443*	29.68
1	107	219.97501	0.18903	8.3443	15.41
2	110	223.23403	0.07466	1.8263	3.76
3	111	224.14717	0.02151		

maximum rank	parms	LL	eigenvalue	max statistic	5% critical value
0	102	211.17504	.	17.5999	20.97
1	107	219.97501	0.18903	6.5180	14.07
2	110	223.23403	0.07466	1.8263	3.76
3	111	224.14717	0.02151		

11. Vector Autoregression model

```
. var lnMetrobus lnBus lnRail, lags(1)

Vector autoregression

Sample:  February 2006 - December 2013            No. of obs      =        95
Log likelihood =  76.33267                        AIC             = -1.354372
FPE            =  .0000518                        HQIC            = -1.224019
Det(Sigma_ml)  =  .0000402                        SBIC            = -1.031777
```

Equation	Parms	RMSE	R-sq	chi2	P>chi2
lnMetrobus	4	1.36439	0.9596	2254.113	0.0000
lnBus	4	.100684	0.8019	384.4947	0.0000
lnRail	4	.08759	0.9495	1786.121	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnMetrobus						
lnMetrobus L1.	.9813802	.0519576	18.89	0.000	.8795451	1.083215
lnBus L1.	1.035843	1.21512	0.85	0.394	-1.345749	3.417434
lnRail L1.	-.8090108	1.217262	-0.66	0.506	-3.1948	1.576779
_cons	-4.318551	15.415	-0.28	0.779	-34.5314	25.89429
lnBus						
lnMetrobus L1.	.0008533	.0038342	0.22	0.824	-.0066615	.0083681
lnBus L1.	.7935343	.0896687	8.85	0.000	.617787	.9692817
lnRail L1.	.0422453	.0898267	0.47	0.638	-.1338118	.2183023
_cons	2.962329	1.137536	2.60	0.009	.7328004	5.191858
lnRail						
lnMetrobus L1.	.0096002	.0033355	2.88	0.004	.0030627	.0161378
lnBus L1.	.030613	.0780077	0.39	0.695	-.1222792	.1835052
lnRail L1.	.7827022	.0781452	10.02	0.000	.6295405	.9358639
_cons	3.036859	.9896044	3.07	0.002	1.09727	4.976448