Budapest University of Technology and Economics
Faculty of Transportation Engineering and Vehicle Engineering
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MASTER'S THESIS

Economic Feasibility of Monorails, Istanbul Havaray Case Study

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ABSTRACT

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As the demand for public transportation increases rapidly, the governments try to find more sustainable modes more than ever to supply this demand, so does Turkish government. The main aim of this thesis is to show the audience why can the underestimated monorail systems can be a good solution for the everlasting sustainable public transportation search.

Monorails exist for more than 150 years first has been installed in London wharf for cargo transportation then Ireland and Germany (Wuppertaler Schwebebahn, still operating since 1901) followed and until then in this 150-years interval, many monorail systems installed all around the world. After being beaten by the superior modes, people ceased to research and develop monorail systems until 1980's. After 1980's because of the new technologies allowed monorails to be cheap, safe, fast, modern, sustainable and large in capacity, they are getting popularity again all around the world with Asia being the flag carrier.

They are being less popular bring some disadvantages with them, most of the governments don't include them in their transportation master plans, some people don't believe their safety because they weren't tested and used enough. With the increasing popularity it is foreseeable that these problems will be solved soon.

Havaray has been introduced in Turkey in 2014, since then, the governments have gained lots of information about monorail systems in Turkey. The 14.5-km-long monorail system has brought so much excitement. Turkey is now ready to adjust its transportation master plan in Istanbul and planning to install it.

Economic feasibility analysis of Havaray has taken place in this thesis, by using the real data and estimations from municipalities' sources it has been calculated and surprisingly, Havaray is feasible according to calculations, even with the sensitivity analysis which has been calculated to spot how rigid is the project for the unexpected external impacts.

1. Introduction

The fact that rail transportation systems are highly expensive systems and most of the time they are the precursor infrastructures for further projects, any wrong investment decision can give birth to unreversible economic and urban development consequences. That's why, when investing on rail road networks, other alternative transportation modes has to be thought and analysed and investment should be done to the best alternative among the others. The best alternative should be the optimum solution for demand of transportation, urban planning, design, economic feasibility, maintenance and implementation (time and inconvenience). A good decision is crucial for inhabitants who are the stakeholders for those projects.

Every now and then, people suffered because of poor decisions that costed the taxpayers money and peace all around the world. Knowing that transportation systems have one of the bigger pieces from GDP worldwide, the good decisions can significantly change the world and ease of life while bad ones can make the opposite. As a transportation engineer, I can say, every detail should be thought before implementing a system and should be optimized through the demands of society. My thesis is mainly about this decision and how it is being done with a case study of feasibility analysis in Istanbul, Turkey for Havaray monorail system.

In 2014 studies begun country-wide to understand and implement this system as it thought to be a solution for the traffic of Istanbul, one of the most crowded cities in the world. The Havaray is thought to take place between Kucukcekmece and Basaksehir which are the two of the fastest populated regions of the city within the past years. If this project will be implemented and operated successfully, without doubt, it will be a precursor in the Europe.

The aim of this thesis is to give the audience an explanation about why Turkish government wants to implement a monorail system in Istanbul and its economic feasibility analysis based on factual data and having the audience get insight about this underrated mode of transportation. To realize the aim of this thesis, an economic feasibility analysis and a sensitivity analysis, will take place.

A quantitative research has taken place in the aim of implementing an economic feasibility analysis to the project of Havaray Istanbul. The necessary data has been collected from the authorities, Turkish governmental sources, Istanbul Metropolitan Municipality, earlier researches on Havaray, articles and interpolation of the past data of other public transportation modes when necessary since Havaray will be the first monorail system in Istanbul when it will be built. Analysis of the data has been done in consideration with current situation on public transportation, economics, inflation, government and sociological factors. To implement the economic feasibility analysis, after all the factors have been spotted and corrected, an intensive Cost Benefit Analysis has been done and the results from several Cost Benefit Analyses with different scenarios has also been done in order to make the Sensitivity Analysis. The reason this method of Economic Feasibility Analysis has been chosen is because this is the most common usage of Feasibility Analyses in the world.

2. Monorail

2.1 *History of Monorails*

The monorail patent can be traced back to UK patent No. 461 by Henry Palmer in 1821, who shaped his invention into form at London Wharf in 1824 for freight transport. Throughout the time the rails were made of wood instead of iron and the track was straddled by horse-drawn cars.

In 1888, a straddle-type monorail driven by a steam locomotive was built over a line approximately 15 km long in Ireland and was used for 36 years until 1924 to transport goods. A suspended-type monorail with iron wheels was designed in 1901 over a length of 13.3 km in Wuppertal, Germany, and still serves as the oldest monorail in use as a major transport network.

After World War II, research and development of the restored monorail was vigorously pursued, and in 1957 an experimental straddle-type (ALWEG type) monorail was installed in a suburb of Cologne, Germany. Instead, in 1960, a suspended-type experimental monorail (SAFEGE type) was constructed in a suburb of Orleans, France. Such two systems marked the start of Modern Monorail development.

In 1959, Disneyland in Los Angeles brought the world's first ALWEG-type monorail into practical service, followed by Turin (1961), Seattle (1962), and Disneyworld in Florida 1971).

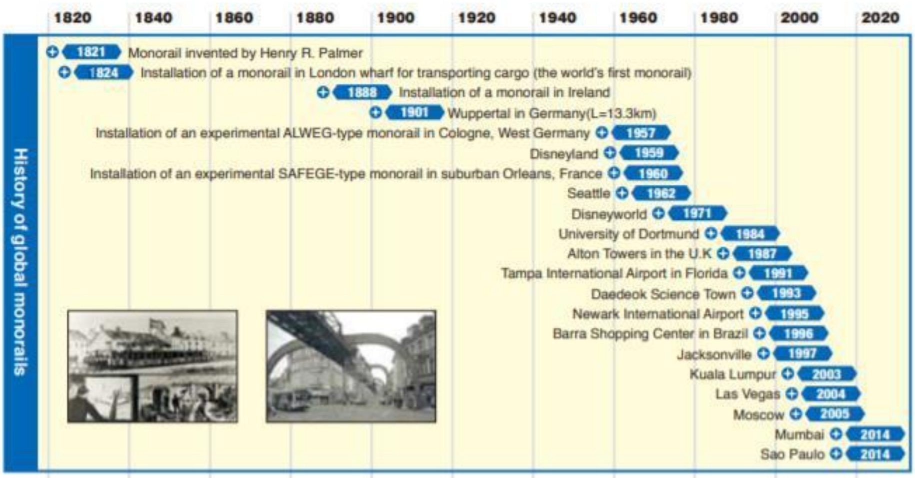


Figure 1: History of Monorails
(Source: http://www.nihon-monorail.or.jp/assets/pdf/2016ENGLISH.pdf)

2.2 *Monorail Applications around World*

2.2.1 Choqging Monorail

Chongqing Metro or Chongqing Rail Transit is a rapid transit network of 75 km that serves the Chongqing city in China. The subway started service in 2005 and serves nearly 32 million people in need.

The project is part of the initiative of the Chinese government to improve the country's western regions. It is one of the three rapid transit systems currently operating in the region, with Chengdu Metro and Xi'an Metro as the other two. Average subway ridership is around 400,000 passengers.

In addition to being one of China's biggest cities, Chongqing is also one of the fastest-growing areas. With the majority of the population relying on transportation buses, the Chongqing provides a reliable, cheap means of transportation that matches the city's growth.

The project, which was sponsored by the Bank of Japan for International Cooperation, is unique to China as much of the construction work was constructed over hills and rivers. The three lines of the metro are using heavy monorail technology as a way to operate on this.

Line 1 is a 16.4 km strong railroad subway from Chaotianmen to Shapingba. This contains 14 stations and holds about 36,000 passengers an hour. About half of the line is elevated, with the remainder underground.

In 1992 a construction contract for the line was awarded to a Hong Kong based company on a build, operate and move basis. Following several years of construction being put on hold, work resumed in June 2007, with phase one of the line being placed into service in July 2011. The speed of service on this line is about 100kmph.

The line's Phase II extension is 20.2 km from Shapingba to University Town and is scheduled to be finished by 2013. The line will stretch to 37 km after completion of the second phase and will include 23 stations. Phase III was also suggested and is currently under preparation.

Line 2 is a monorail line with a length of 19.15 km which opened in 2005. It is the first line to be opened in the network and stretches to Xinshancun from Jiaochangkou in the central District. The line is largely elevated and contains 18 stations. It utilizes Hitachi straddle monorail technology. In 2006 the line's Phase II extension extended it from Dongwuyuan to Xinshancun.

A 6.2km-long phase III extension of line 2 is under construction. The extension will stretch the line into Chongqing's Banan district. An extension of phase IV is also expected.

Line 3 extends across China's Yangtze and Jialing rivers 39.1 km from north to south. This includes 29 stations and stretches from Ertang to Jiangbei Airport. The line is of monorail straddle-beam form.

Line 3 construction began in April 2007, with trial operations in June 2011. Initially the Lianglukou to Yuanyang segment was opened in September 2011, with full stretch open in December 2011. The overall construction cost of the line is projected at around $2.1billion.

Figure 2: Choqging Monorail

(Source: https://www.procaffenation.com/chinese-monorail/)

2.2.2 Mumbai Monorail

Mumbai Monorail, India's first monorail project, was designed for Mumbai City, known as India's commercial capital. It is the second-longest monorail in the world following Osaka Monorail Main Line, Japan.

In January 2010, a 108 m Monorail test run was successfully performed. In February 2012 the technical test over a length of 2.2 km was successfully completed. In February 2014, the first section of line 1 opened to the public. Line operations were halted in November 2017 after a coach caught fire.

The Project is owned by the Metropolitan Area Development Authority of Mumbai (MMRDA). In November 2008, the MMRDA selected a consortium comprising Larsen & Toubro and Scomi Engineering (LTSE) to execute the project. The LTSE group, led by Larsen & Toubro (L&T), will continue to implement the Build-operate-Transfer (BOT) project until 2029. The project's total investment is Rs24.6billion ($501.9 m).

The Mumbai Monorail will have the capacity to carry up to 200,000 passengers a day in early 2019 when it is fully operational. [12]

The monorail project has been viewed as a better solution in areas where roads can not be widened due to sideline structures. It eliminates property losses for residents, as well as reducing the government's cost of purchasing properties.

The monorail is easily accessible and eco-friendly and causes less noise pollution compared to the metro rail systems. This also eliminates traffic congestion, which provides travelers with high reliability which maneuverability.

Figure 3: Mumbai Monorail

(Source https://www.zeebiz.com/india/)

2.2.3 Chiba Monorail

In 1977, Chiba City decided to introduce this suspended monorail as a response to the worsening traffic and noise pollution due to the rapid increase of the population in 1960's. No accident has been recorded since service began in 1988. The 15.2 km business span is the longest in the suspended monorail category worldwide. Passenger numbers reached more than 400 million. Chiba Urban Monorail plays an important role in maintaining reliability and safety for everyone in the city as a key transportation system. The new train, Urban Flyer, received a good design award in 2012. Viewed as an upside-down train, this suspended monorail attracts people from all around the world.

Figure 4: Chiba Monorail

(Source https://hu.wikipedia.org/wiki/Chiba_Monorail)

2.2.4 Osaka Monorail

Metropolitan Osaka is Japan's second largest city and is considered the economic and cultural center. Train lines are paramount from the city center to nearby areas. The Osaka monorail is being designed to connect these outer communities with a half-circle network that will eventually encircle the city with more than 50 km of track. The first segment of 6.6 km opened in north Osaka in 1990. The line now begins at the domestic airport in Osaka, heads east along a highway, then turns south with the highway and crosses a spectacular arched bridge constructed for the monorail only. With the monorail corridor in mind, a spur line has been added that links the network to a university and to a new city being built from scratch. The Hitachi four-car trains draw direct current of 1500 volts from the bus bars running along the side of the guideways. The devastating nearby Kobe earthquake in 1995 proved to be a test for the Osaka Monorail. It defied the violent earthquake and proved to be a vitally important transportation link in the area as traffic on the parallel freeway was completely jammed with evacuees.

Its daily ridership is more than 100.000 people.[11]

Figure 5: Osaka Monorail

(Source https://www.japanvisitor.com/japan-transport/osaka-monorail)

2.2.5 Tokyo Monorail

The Tokyo Monorail represents the best in the manufacture and engineering of mono rail vehicles, including implementing the technologies required for higher quality passenger capacity and operation, as well as reducing maintenance costs and energy consumption. The lead trailers, which contain the sixcar train's driving cab, lack a traction motor to reduce the train's total weight. The carbody is made from Friction Stir Welded aluminum alloy plates, w hich together with a lightweight design give exceptional strength.

SYSTEM OUTLINE

TRACK	Double Track (including an underground section and station beneath the airport runway to avoid aircraft operation disruption)
LINE LENGTH	17.8km
NO. OF STATION	11
NO. OF FLEET	21 trains (126 cars)
TRAIN FORMATION	6 - car per train
LINE VOLTAGE	DC750V
MAX SERVICE SPEED	80km/h
SERVICE DAYS PER YEAR	365 days
PUNCTUALITY	Averages a below 10 second delay in scheduled diagram
ANNUAL PASSENGERS	45,388,710 passengers (2014)
AVERAGE DAILY NUMBER	124,353 passengers (2014)
TOTAL NUMBER SINCE 1964	1,876,931,204 passengers (2014)
VEHICLE RUNNING PERFORMANCE	
AVERAGE DAILY DISTANCE (WEEKDAY)	56,029.8 car • km
AVERAGE DAILY DISTANCE (WEEKEND)	53,312.4 car • km

Figure 6 : Properties of Tokyo Monorail

(Source https://www.hitachi-rail.com/pdf/tokyo_monorail.pdf)

Figure 7: Tokyo Monorail

(Source https://pigment.tokyo/article/detail?id=34)

2.2.6 Tama Toshi Monorail

The network currently has one 16 km long double track section. The line features 19 stations. Trains of the Hitachi Type 1000 run on the track. 120,000 people use this monorail system every day.

Figure 8: Tama Toshi Monorail

(Source https://www.japanvisitor.com/japan-transport/tama-monorail)

2.2.7 Sao Paolo Monorail

The São Paulo Monorail system is a 24-kilometer-long rail line between Vila Prudente and Cidade Tiradentes.

The new line, also known as Expresso Tiradentes, will act as an extension of the Companhia do Metropolitano de São Paulo (CMSP / São Paulo Metro) metro line 2. The project would cost $1.6billion. It opened in the year 2014.

The monorail network would minimize travel time from two hours to 50 minutes between the two destinations benefiting 500,000 passengers a day.

The project was awarded to Bombardier-led The Express Monotrilho Leste Consortium (Eastern Express Monorail Consortium). The gross contract value is $1.44bn, of which a share of Bombardier is $1.4bn. [10]

The other group leaders are the Brazilian civil-building firms Queiroz Galvão and Construtora.

Figure 9: Sao Paolo Monorail

(Source https://www.railwaygazette.com/projects-and-planning/sao-paulo-line-15-extended)

2.3 *Monorail Types*

2.3.1 Suspension Monorail

Suspension Monorails are the types of Monorails which are hanged to the rail track which is over the vehicle. The first modern Suspension Monorail Schwebebahn started to operate in 1901 at Wuppertal/ Germany. Schwebebahn moves with its double flanged steel wheels hanged under the steel guidance rail. Because of its appearance, suspension monorails often remind people cable cars but in contrast to cable cars, suspension monorails have very rigid guidance tracks.

Years after Schwebebahn, new generation suspension monorails have been designed. Those new generation suspension monorail vehicles which has a system with rubber wheeled bogies are hanged under box sectioned concrete beam tracks. The vehicles are hanged with a pendulum type air suspension which provides balance and comfort even with high velocities.

One important parameter is the rubber wheels. Rubber wheels provide more traction force than the steel ones while they reduce noise and vibration. Because of these rubber wheels are embedded inside the concrete beam, they provide safety even with extreme hot or cold weather conditions. The electric is given to the bogies by the conductive rail inside the box beam.[3]

In case of explosion of the rubber wheels or air pressure loss, steel emergency wheels are activated which allows extra safety to the vehicle.

Vehicles move via electric engines which located on the top of vehicles, the energy feed is coming from the sides of the closed line beam.

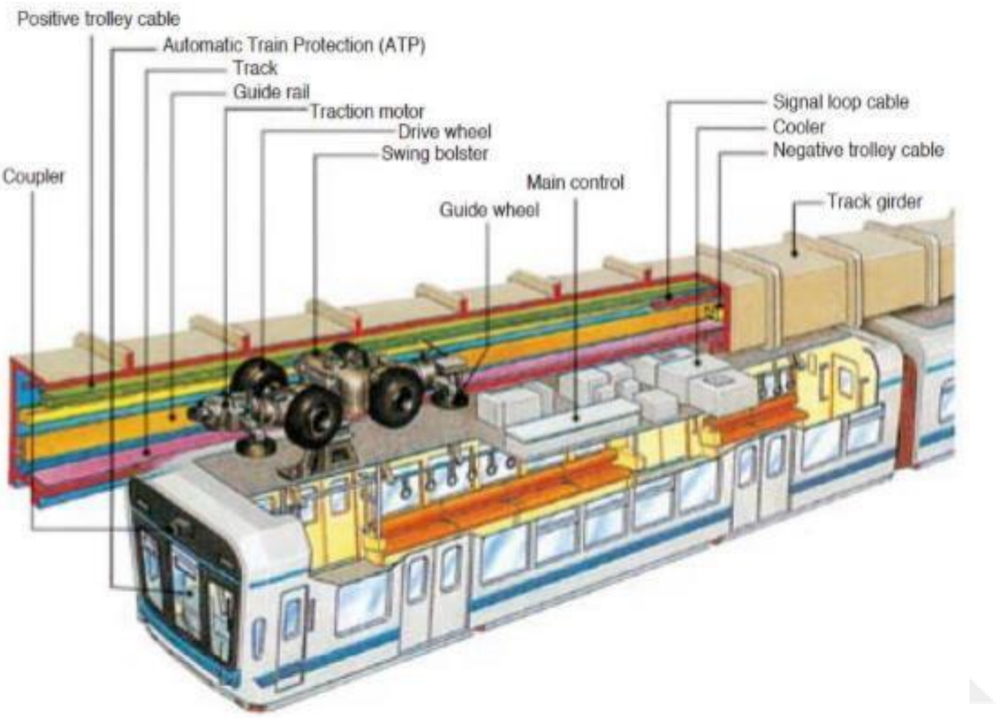


Figure 10: Suspension Monorail Elements[3]

2.3.2 Straddled Monorail

Straddle Monorails can be defined as the monorails which surround the beam track under them, they are the most common used monorail types in the world. Those beam tracks can be made of reinforced concrete or steel. The vehicle surrounds a narrow beam track which placed higher than the other traffic modes level in order not to have a conflict with them. As the figure shows a straddle monorail has 2 series of stabilizing wheels on each side which makes straddle monorails to overturn almost impossible in any extreme condition. The guidance beam usually less than half of the width of the vehicle, for safety reasons, monorail vehicle designed steer horizontally no more than it is required. However, there are exceptions, most straddle monorail applications have rubber wheels and reinforced concrete guidance beams.

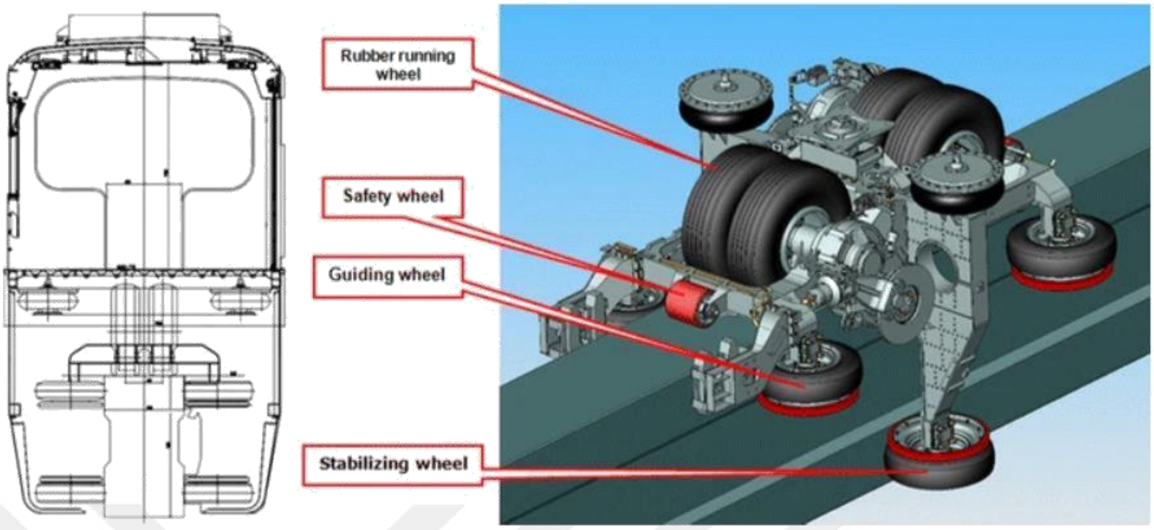


Figure 10: Bogie of a Rubber Wheeled Straddle Monorail[3]

Columns are highened along the road which allows monorails to have a separate autonomous traffic. Monorail stations are generally built as viaducts and higher than the ground level.

Until 2010's, there were a lot of studies that suggest that monorail technologies consume more energy than railroad technologies but, the new generation monorail technologies from Japan have changed this situation, as monorails became more and more common, new advancements led monorails to consume less energy than most railroad technologies.

For steel tracked and wheeled systems, incline is a serious problem but not for rubber wheeled monorails. A rubber wheeled monorail system can climb more than %15 incline grade without safety concerns while generally railroad systems designed for maximum %3.

Even with the rubber wheels, straddle monorails have switch systems just like railway systems. The switches which located in the entrance of stations thanks to those switches, two-way traffic can be handled from one line. Those rubber wheels have a long lifespan and the maintenance requirement and costs of the monorail lines are low. In urban public transportation. Straddle monorails receive the necessary electricity from the electric lines which are locate in the sides of beam track.

2.4 *Costs and Benefits of Monorail*

In this section I will give general information about the kinds of costs and benefits of Monorail systems, which will be researched comprehensively while I will analyse the economic feasibility.

2.4.1 Costs of Construction

Construction costs for monorail consists of pillars, viaducts, platforms, control and maintenance center, storage and works for electromechanics. In monorails, the occupation of lands is lower than other modes of transportation due to their elevation from the ground, therefore, the cost of used lands is less. Since guidance beams can be manufactured outside the building and installed readily, the indirect costs can be minimised.

Generally, there are many variables which influence the price of building a monorail system (and most forms of rail transit). Included factors [9] are as follows:

• Total device length: In many cases, the longer a device is, the lower the costs.

• Topography: Are there many roads or rivers to cross the landscape flat or hilly?

• Location: What access do building equipment have? Will there be heavy traffic or other constructional impediments?

• Utilities: relocation of water, power lines, telephone lines, etc. may have a huge effect on changes in costs.

• Land: What amount of land or easements must be purchased?

• Passenger requirements: How large and how many vehicles are needed? How long will they wait in stations?

• Speed: What are device speed requirements? Are there long enough interstation distances to expect a higher speed?

• Number of stations: Cost is applied to each additional station.

• Special Structures: Cost factor can be tunnels, bridges, overpass reconstruction or urban structures?

• Geotechnical conditions: What are the conditions on the subsurface? They can have a significant impact on the cost of foundations.

• Environmental mitigation: Will it require restoration, protection of wildlife or sound walls?

2.4.2 Costs of Vehicles

Although costs of vehicles vary, general knowledge is that monorail vehicles cost no more than light rail vehicles, the cost per vehicle for Havaray Istanbul is stated as 1.200.000 Euros per vehicle by the Istanbul Metropolitan Municipality.

2.4.3 Costs of Operation

Supporters of railway technologies assert that operating cost savings are a major advantage and a major reason why this mode is such an attractive choice compared to various bus service alternatives. For moderate traffic as well as heavier passenger volumes it's believed that rail technologies tend to be much cheaper to operate than comparable bus service. The major reasons why rail-based technologies are cheaper to other modes are including (LR Progress, 2001): Train vehicles generally provide more passenger space, and in special cases the trains' length could be increased easily by adding more cars. The largest recurring cost in any enterprise are the salaries and benefits of the employees and the significant cost advantage for driverless APM(Automated People Mover)'s is that they do not need operator/driver and less other kind of employees, which wages make up about 70%- 80% of ongoing operating costs. Especially in rush hour (or other peak periods, like special events) they can handle heavy passenger loads and accommodate and move much more rapidly and efficiently. (even when the trains operate on public arterials, there's significantly less conflict with other traffic than there would be if expensive fleets of buses were used instead) Elevated APM's never mix with traffic, which makes them safer and more reliable. This also means the system can be automated, which will allow it to operate with little or no ongoing subsidy

For APMs cases applying driverless systems along with the most advanced engineering technologies, recurrent costs are much lower to LRT technologies. Comparing other modes of transportation, three major advantage factors which decrease energy demand for monorails and APMs are: Aerodynamic Drag Mechanical Fiction, Acceleration and Deceleration

In general, automated rail technologies including APMs and driverless monorails are superior in cost efficiency to other choices. Where bus systems are need relatively lower capital investment, they are so costly to operate especially in periods of longer than 10 years. Though for LRT technologies, driver operating cost is lower than bus, still the automated driving problem seems unsolved. So, among the current urban transportation technologies APMs are the best choice in heavy and moderate passenger load cases.[3]

2.5 *Alternative Features of Monorails*

Safe and Comfortable Ridership

Since monorails travel along an exclusive elevated track, it ensures comfortable, safe and punctual operation without any traffic jam concerns. In addition, because they ride along a thin single track or on a box-type track, they are immune to extreme natural conditions such as strong winds, rainstorms and snowfall.

Flexible Route Alignment and Train Configuration

Owing to the ability to work across sharp curves and wide longitudinal gradients, versatile route settings (such as double, single, and loop tracks) can be implemented depending on the physical conditions of the urban region. Furthermore, different systems can be configured to suit the demand for ridership, with the variation in car size available from compact to large, and the number of cars comprising a train from two cars to six or more. [13]

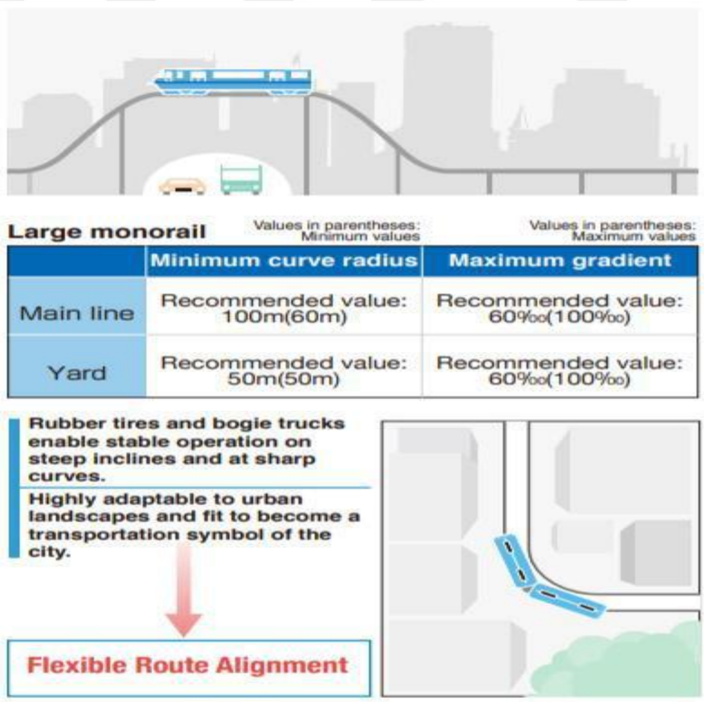


Figure 11: Flexible route alignment [13]

(Source http://www.nihon-monorail.or.jp)

Quiet, Clean, and Minimum Sunlight Obstruction (low pollution and environmental impact)

Rubber tires and air springs reduce noise and vibration and eliminate exhaust gas problems. The single-track system also provides ample exposure to sunlight right directly under the tracks, reducing its environmental effects and ensuring adaptation to urban settings.

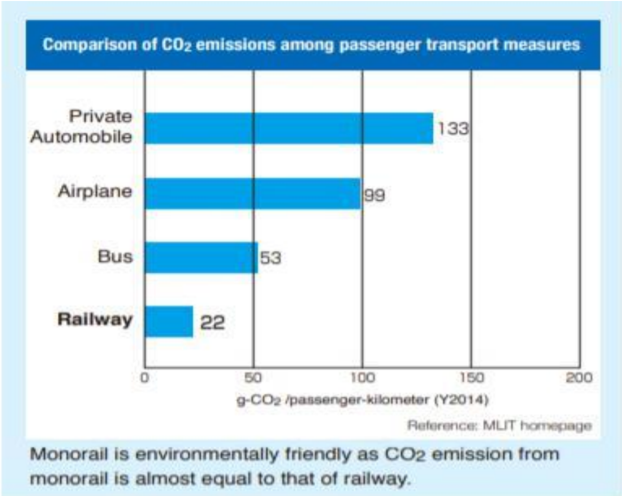


Figure 12: CO_2 emissions among passenger transport modes

(Source http://www.nihon-monorail.or.jp)

Contribution to Community Renovation

The introduction of a monorail network in company with the construction of urban facilities such as shopping centres, schools, cultural buildings and general playgrounds will serve as an integral part of urban development / renewal initiatives to help solve various urban problems such as reactivation of downtown areas and urban enlivenment, thus efficiently reorganizing urban traffic networks. By planting trees and embracing innovative architecture, new attractive urban spaces can be implemented alongside its smart structure and minimal obstruction of overhead space with low effect on the surrounding environment and scenery. Urban monorails are a new form of transportation that enables people to rediscover the beauty of urban environments.

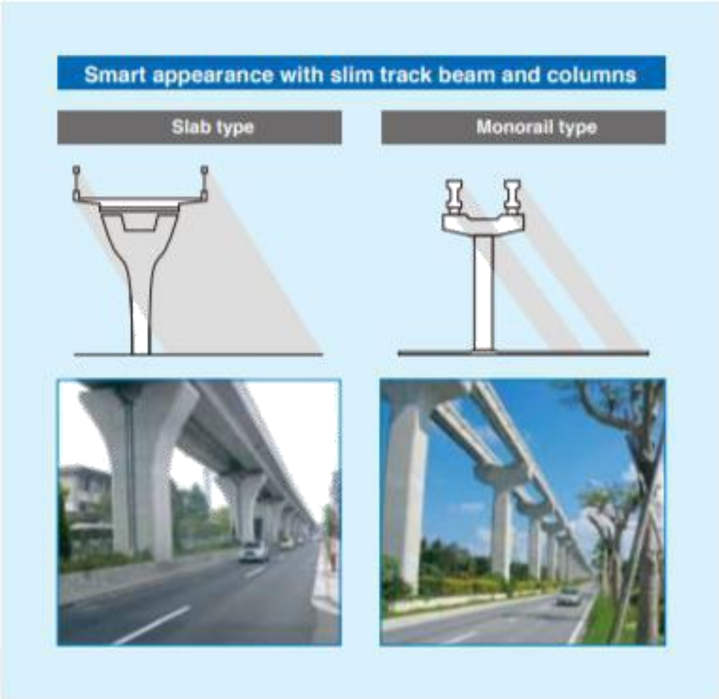


Figure 14: Smart appearance of Monorails

(Source http://www.nihon-monorail.or.jp)

Roles of Urban Monorails

The urban monorail is an ideal means of transportation, adaptable to intermediate distances and able to meet reasonable demands in transportation. The urban monorail's carrying capacity varies according to size and period of service. Its single way carrying capacity varies from about 2,000 to 33,000 passengers an hour. If a compact monorail system consisting of four cars is run at intervals of 10 minutes, the one-way carrying capacity per hour will be 2,000 passengers, and if run at intervals of 2,5 minutes the capacity will increase to 7,000 passengers. This carrying capacity is about half that of a wide monorail system, 1.6 times LRT and nearly four times that of buses. In terms of project costs, monorails are also superior, with construction being only one third of what is needed for the subway.[13]

Effective Utilization of Urban Space

Monorails can be constructed over existing roads, parks, squares, rivers, railroad tracks, etc., exploiting the potential for flexible alignment. Less requirement of acquiring new land plays a significant role in efficient installation of monorails.

Figure 13: CO_2 emissions among passenger transport modes

(Source https://www.forbes.com/sites/geoffreymorrison/2016/07/30/the-hanging-monorail-of-chiba-japan/)

3. Technology of Monorail Systems

3.1 Properties of Monorail System Elements

Track

The most important element of a monorail system is the track. Tracks of monorails are rarely steel but mostly made of reinforced concrete beams. The vehicle and the beam should be perfectly balanced with each other, sides of the beam and guiding wheels should fit well. Wider beams allow wider vehicles to be used but they are not preferred because of the urban aesthetics. For the reasons of gravity center and comfort, it is enough to have a vehicle to beam width ratio of 4 however, beam width and length is flexible as long as the structural integrity is protected.

Tracks are designed within three dimensions. At curves, the beam is not only bending horizontally but vertically also. The magnitude of bending is relative to the curve radius. Because of the various conditions, the concrete beams should be frameworked and manufactured regarding to different lengths and curves. Even though the minimum curve radius of monorail systems are 40 meters, because of riding comfort, these curves are not preferred.

In order to increase the visual aesthetics and distances between two footings, arch type beams are used.

Column Structure

Columns are one of the basic elements of monorail systems. Column size and track length are in reciprocal proportion however, distances between footings and column size is direct proportional. For Seattle monorail project, approximately 90 cm diameter 9m long columns and distances between footings have been calculated as 36.5 meters. Figure below shows the corresponding design.

In case of traffic underneath monorail track, it is suggested that footings should be at least 5 meters high however, in recent projects for landscape purposes, the implementors tend to make column height at least 10 meters. The difference in elements according to the manufacturers are show in the figure.

Rubber wheeled traction motor and guidance

Apart from tracks, the main difference between traditional railways and monorails are the rubber wheeled traction motors. The load bearing rubber wheels of the vehicle is moving towards the concrete track on the other hand, the guidance wheels are pressing onto sides of track beam.

In a monorail traction motor, 2 axles, 4 load bearing, 4 guidance and 4 balancing wheels exist. The lifespans of those wheels are known as 160.000 km.

Switching system

In monorail systems, switching is very important. Because of the size of tracks, the switching time is too much. Traditional railways have a switching time of 0,6 seconds while monorail systems have 15 seconds of switching time. If the monorail system is planned to have continuously switching, the headways should be increased. A sample switch in monorail system is given in the figure.

Station properties

Monorail systems often have viaduct type stations but if there is need, underground and ground level stations are also made. Mostly in monorail systems, mid peroned or side peroned stations are used. Highrise stations are more expensive than the ground level stations however they provide visual aesthetics. In stations, announce, internal communication, passenger information, time data, emergency stop, fee collection and tourniquet systems are mostly available.

Other properties

Energy

In straddled monorails, vehicles are fed through the sides of tracks and collecting this energy with their energy collecting wedges. The energy is provided via transformer stations along the track. The DC (Direct Current) Energy produced in these stations are transmitted to sides of tracks and after to the vehicle, the vehicle transforms the DC into AC and feed the various voltage and various frequency (VVVF) traction motor. This type of motors are preferred because they need less volume on bogies and because of their new speed control systems. Only Bombardier M6 vehicle works with the AC coming directly from the transformers.

The electric engines mounted into vehicles are giving power to the monorails. Energy consumption in rubber wheeled versions are more. The reason behind that is the rubber wheels moving on tracks have larger rotating resistance and bigger circular inertia. In total monorail systems consume 25 percent more energy than other railway technologies.

Slopes

Theoretically, railway systems can't move safely more than %10 degree while, Rubber wheeled traction systems can safely move in more than %15 degree. In practice steeper slopes require stronger engines and not good for passenger comfort, because of these, Railways in practice designed for %3,5 – %4,5 degrees while rubber wheeled monorails are generally designed for %6 - %7 however there are monorail systems where they work in %10 degree.

Velocity – Capacity

Monorail systems are defined as fast modes of public transportation because of they have their own tracks. The average operating speed of monorails are comparable with metro systems, both systems are moving in their separate tracks. Monorail systems have maximum velocity of 80 km/hour which is the same with metro systems. However, their operating speeds are 30-35 km/hour in average.

Monorail systems can operate in higher capacities. They can supply the demand up to 40000 passengers per hour

Acceleration – Deceleration

Rubber wheeled vehicles have better acceleration and deceleration capabilities. But because of monorails have their own tracks, they don't need to have ultimate deceleration or acceleration systems because of that, this good acceleration and deceleration capability is not so important for monorails.

Weather conditions

For straddle monorails, the rubber wheeled vehicles are more sensitive to snow and icing than the other steel wheeled railway vehicles. Because of that, in some cases, the tracks would need heating therefore their energy costs can be higher. Suspension monorails on the other hand, because of their tracks are closed and protected, they don't get affected from bad weather conditions.

Noise

Rubber wheeled systems are more silent than even the best railway technology in case of narrow curves. Besides, monorail vehicles are designed as their sides cover the wheels that provides a better sound insulation.

Maintenance

Concrete monorail tracks require less maintenance than other railway systems. Wheels have the endurance up to 160.000 km. Monorail vehicles have good life span like railway systems (30+ years)

Safety

Because of monorail vehicles surround the track, they are immune to overturning and derailing. Because of they have their own lane, it is also impossible for them to collide with other vehicles or pedestrians. In that point of view, monorails are considered as one of the safest modes of transportation. Because of their good safety records, the cost of accident and deaths are low.

Monorail systems are operating above the ground level, which leads to discussions about evacuation in case of emergency. In suspension monorails, emergency evacuations can be done via emergency exit located under the vehicle while in straddle monorails evacuation can be done from horizontal emergency exits.

Comfort

Suspension monorail vehicles can wobble while taking over a curve which will lead to a decrease in lateral forces. In straddled monorail systems on the other hand, the suspension is provided via bellows. Lateral forces are decreased by superelevations on curve locations.

Either straddle and suspension monorail systems make passengers watch the city from above and enjoy their ride without any noises and it is known that monorail systems are chosen by passengers because of their comfort and entertainment.

Environmental Factors

Monorail systems use electric energy, which is the cleanest energy available. They are also one of the most noise reduced transportation modes. They are high in capacity, safe and secure, fast and comfortable, low energy and maintenance cost, reliability and punctuality. It is also known that monorail systems make public transportation enjoyable whereas encouraging people to choose public transportation over private. Also, they are giving a modern look to the city, increasing the landscape, adding value to the cities in other words.

Monorails are not interfering with the current traffic therefore they don't affect the traffic or pedestrian circulation. Because of their quick implementation times and doesn't interfere with the current infrastructure, they are giving the residents minimum inconvenience while implementing. As seen in the figure, they provide a modern landscape into the cities and increasing their prestige.

At the same time, they don't cover so much space in nature prior areas and gives possibility to wild animals pass underneath and it is possible to hide their columns with various plants. In consideration of these, they are more nature friendly than other transportation modes.

Monorails cover smaller spaces in city surfaces. In dense city centers, the columns are planned to be locate in refuges. This way, they don't occupy any space where actively used. At the same time, they are reducing the visual pollution to minimum.

3.2 Technology of Monorail Vehicles

Monorail vehicles are manufactured by Hitachi, Bombardier, Urbanaut, Futrex Systems and OTG High Road companies. Hitachi and Bombardier are the biggest manufacturers and market leaders among all. These two companies manufactured large amount of monorail systems in the world and have invested large amount of money into the development of straddled monorail systems.

3.2.1 Hitachi

Hitachi bought out Alweg's copyrights in order to develop straddled monorail systems. Hitachi made some changes in the vehicles and created new bogies that make long vehicles better steer in narrow curve radiuses and make the number of wheels in a bogie from 2 to 4 and make the lengths of cars from 10 meters to 14 meters which significantly increased vehicle capacity.

Hitachi began using the Osaka Project Series 1000 monorail vehicle which began service in 1980. For the Series 1000 model, by doing so, the vehicle has elevated 1.1 meters from the floor, they have improved vehicle comfort.

Monorail networks are beginning to compete with metro systems with their new models due to their high capacities. On the other hand, Hitach also built a small-monorail design to compete with Bombardier's M-6 model which is cheaper.

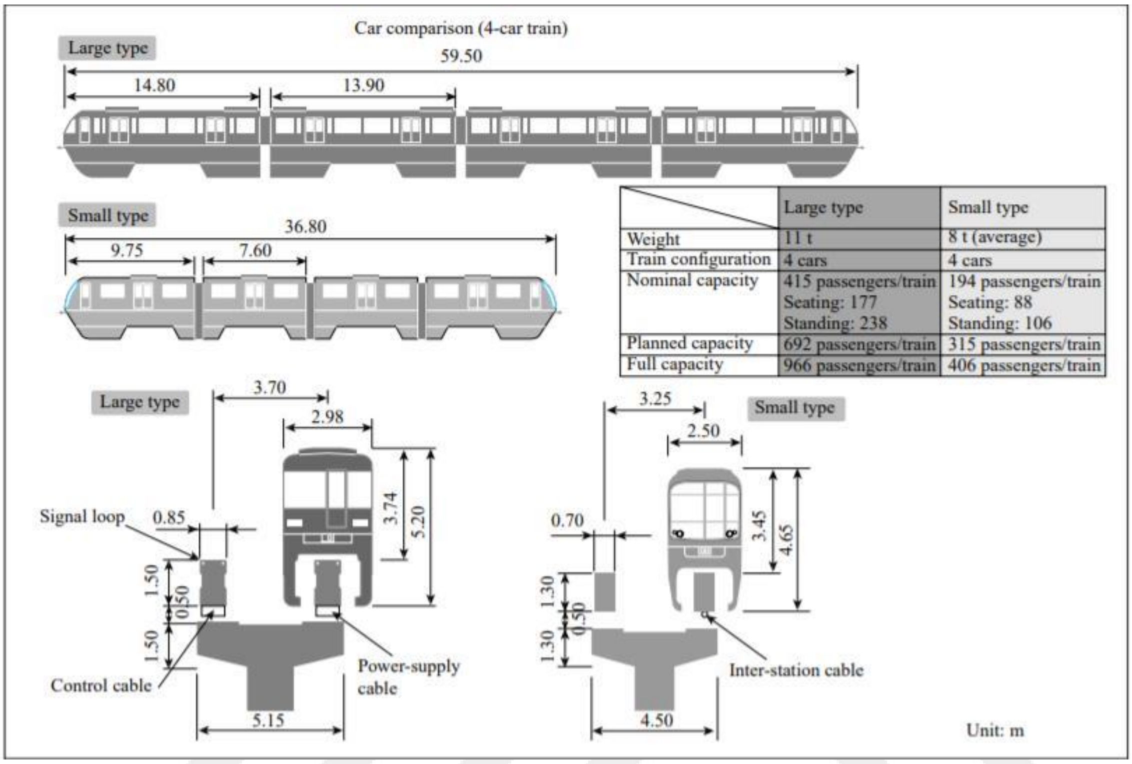


Figure 15: Hitachi Large and Small type monorail dimensions

(Source http://www.hitachi.com)[5]

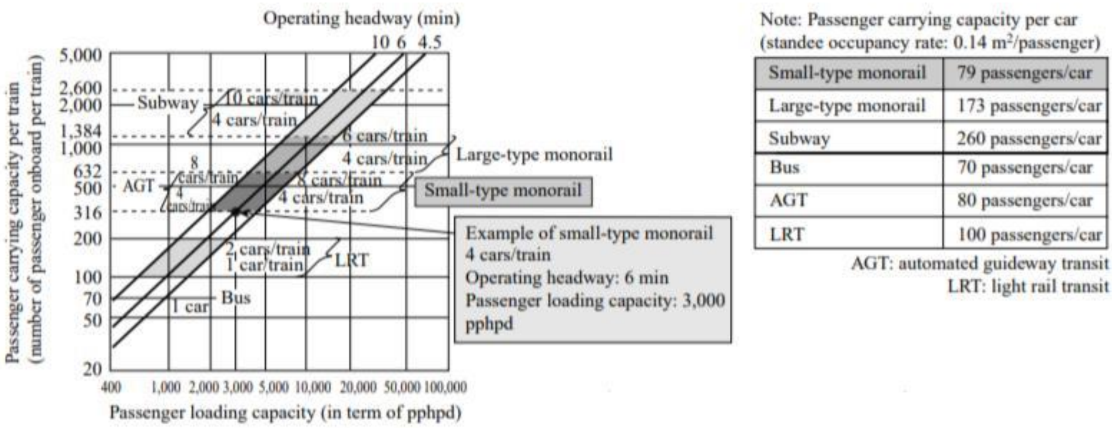


Figure 16: Hitachi Monorail in comparison with other public transportation modes

(Source http://www.hitachi.com) [5]

3.2.2 Bombardier

The general knowledge in the sector about the Bombardier monorail vehicles is that they manufacture costly and aesthetic vehicles. This is because they place the load bearing wheels at the end of the cars, which contributes to more traction and lighter vehicles lining the track. The height and capacities of the vehicles are smaller than those of Hitachi.

The newest manufactured "Innovia Monorail 300" version is longer, taller and wider than the previous version of the "Bombardier M-6" model and the capacity is increased by more than 50 percent (from 224 to 356) because of the dimensional differences. This innovation gives the company a competitive position in the sector.

INNOVIA Monorail 300 offers sleek aesthetics, spacious interiors and passenger-friendly travel experience. The inter-car walk allows for free movement of passengers and enhances protection for travellers. Flexible seating arrangements allow system optimisation to meet customer-specific requirements.

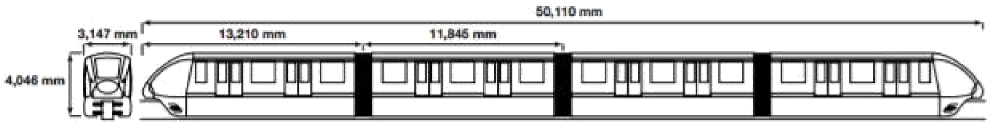
Fully automated driverless operation makes regular, safe and efficient service possible, attracting more customers and producing more revenue. Along with the INNOVIA Monorail 300 system, BOMBARDIER * CITYFLO * 650 Automatic Train Control (ATC) system, achieves shorter headways and excellent operating efficiency.

The design of the INNOVIA Monorail 300 integrates a high degree of reliability and durability of the equipment that enables the system to work safely without the need for on-board attendants thus enabling flexibility in staff utilization for the operator.

Slender guide beams are used in this urban transit system, which both guide the vehicle and provide its structural support. The trains INNOVIA Monorail 300 allow smaller trains.

The INNOVIA Monorail 300 technology incorporates the design and operational features required for rigorous urban line-haul service, including full automation, emergency evacuation walkways, high-speed guideway switching, bi-directional service and public transportation safety requirements enforcement.

Automated Monorail System **INNOVIA Monorail 300 Technology**



Vehicle Data

Type of vehicle	*INNOVIA* Monorail 300
Maximum train consist	2- to 8-car trains

Dimensions and Weight

Length (end car overall)	13,210 mm
Length (end car over coupler)	13,032 mm
Length (mid car)	11,845 mm
Width (overall)	3,147 mm
Rooftop to top of running surface	3,019 mm
Floor to top of running surface	450 mm
Doorway width (clear opening)	1,600 mm
Doorway height (at threshold)	1,930 mm
Wheelbase (centreline to centreline)	9,200 mm
Vehicle weight empty (average)	14,000 kg

Technical Characteristics

Power distribution	750 Vdc
Propulsion system	permanent magnet bogie mounted
Vehicle guidance	straddle beam monorail
Vehicle operation	bi-directional
Braking	regenerative/friction
Suspension	pneumatic spring
Bogies	2 single axle dual tire per car
Carbody	aluminum carbody, steel underframe, composite end cap
Windows	tinted, single glazed
Doors	2 bi-parting doors per side per car
Air-conditioning	roof-mounted module containing twin HVAC units
Fire safety design	floor rating meets ASTM E-119, NFPA 130 compliant

Performance and Capacity

Maximum design speed	80 km/h
Acceleration rate (service)	1.0 m/s²
Brake rate	1.0 m/s²
Minimum horizontal curve radius	46 m
Maximum sustained gradient	10%
Recommended maximum gradient	6% (based on ride quality)
Wheelchair locations	1 per car (flexible)
Passenger seats per car	16 (flexible)
Design capacity**	
• 2-car trains at 75 sec headways	11,300 pphpd
• 4-car trains at 75 sec headways	24,100 pphpd
• 8-car trains at 75 sec headways	49,600 pphpd
Vehicle capacity (standees + seated) per 4-car train (flexible)	
@ 4 pass./m²	292 + 64 = 356
@ 6 pass./m²	438 + 64 = 502

Figure 17: Bombardier INNOVIA 300 Fact Sheet

(Source http://www.monorails.org/pdfs/INNOVIA%20300.pdf)

3.2.3 Urbanaut

The modern, innovative, much more flexible, and less expensive Urbanaut is seen as the future of monorail transport. The Urbanaut design, engineering, and construction are unique features derived from a long research, development, model testing, and functional implementation of the Urbanaut technology.

The inventor, Einar Svensson, a world monorail authority, was a pioneer and engineer with the Alweg Monorail Company, 20 of which were built worldwide.

Basic Technology of the Urbanaut

Urbanaut is a smaller, faster, and less costly modern superior monorail, where the guide way is around half the vehicle width. The technology does not rely on a type of massive beams. The vehicle runs on top of the runway and is driven and stabilized by a special finely shaped center rail that locks the vehicle to the guideway which can be a 1.1 m long slab at the surface and sub-surface.

The vehicles are driven electrically using a confined small rubber-tired wheel bogie with a powerful electromagnetic motor in the wheel or a linear induction (MLIM) device with no touch. The attractive aerodynamic vehicles are non-polluting and use rubber tires without noise. The device uses the latest technologies in the fields of automated operation, monitoring, communication, supervision and maintenance and the latest principles for energy saving.

Flexibility in Planning More Efficient Passenger Service – Simple Switching of Guide ways

Unlike other monorails that straddle and surround a large beam-way the Urbanaut has 4 different types of simple, lightweight small switches, depending on the application:

1. Flexible rail guide with middle

2. Swivel style -Two direct ways to move at the same point

3. Passive or active low-speed onboard switching for off-line stations and maintenance facilities

4.Shuttle switch for stations with "pinched end"

Choice of switching allows more freedom to plan guide way layouts incorporating greater and more efficient passenger service.

Special Portable Elevated Prefabricated Structures

Special attractive, unique off-street Urbanaut structures and stations made of portable concrete or steel components were developed and applied. You will find slender supports along the parking lane, or on the sidewalk. Special elevated structural design allows for spans of up to 150 '(45 m) between foundations to bridge large streets and intersections, thereby eliminating interaction with surface traffic and underground services. The assembly technique makes current installations easy to add or remove.

Capacity and Speed

Urbanaut has the potential capacities to compete with existing light rail and other types of monorails. By utilizing the 2 basic vehicle components (an end and a middle car) in single, dual, or multiple combinations, a train of vehicles can be designed for the appropriate capacity, varying from 2,000 to 40,000 passengers per hour.

Special small single and PRT vehicles utilize smaller guideway loops that provide direct service to the community and can also operate on the same guideway as full size vehicles. The speed and capability of vehicles, up to 140 mph (225 km/hr) depends on spacing between station stops, which controls practical and economic feasibility of a potential installation.

Cost

Urbanaut is not like other monorails based on a large beam way so it has great versatility. Use a 1.1-meter-long concrete slab, the guide way can be installed at the surface or in a tunnel, with minimal environmental effects.

The height of the vehicle is 30 percent lower than a straddle monorail model, and thus much lighter, allowing for a slender support system and less power to run and maintain.

Extensive independent monorail and light rail alternatives studies suggest that Urbanaut technology is far superior, much simpler, and can cost 30-40% less than other monorail types and 1/3 less than light rail. This means more flexibility in the preparation and choices for building forms

Special unique structural concepts, the ability to climb 12 percent grades, two optional propulsion systems, switching capacity, vehicle design, size and weight, maintenance and operation, reusable energy devices, high application flexibility and overall simplicity are key factors that account for the significantly lower cost and efficiency of the Urbanaut.

Urbanaut Preliminary Feasibility Studies

Under a Preliminary Feasibility Agreement, Urbanaut will discuss options and provide proprietary and other useful documents, illustrations, videos, cost guidelines and advice to minimize unforeseen issues, and provide guidance to help advance a project for further study. It is in the interest of the Urbanaut that a project be cost-effective and profitable for the many contractors, consultants and agencies involved.

"Total Projected O&M Cost for a Specific Project"

Operating Cost Elements	HOV/Bus Alternative	At-Grade LRT Alternative	Urbanaut® Monorail Alternative
Cost per Revenue Vehicle Km/Mile	\$2.85/\$4.60 (Dsl) \$2.70/\$4.35 (CNG)	\$6.95/\$11.17	\$1.55/\$2.50
Cost per Revenue Vehicle Hour	\$56.00 (Diesel) \$55.30 (CNG)	\$150.00	\$38.00
Cost per Place Km/Mile	\$.04/\$.06 (Diesel/CNG)	\$.07/\$.12	\$.08/\$.13
Total Average Annual Cost	\$8,830,000* (Diesel) \$8,350,000* (CNG)	\$12,621,150.*	\$4,000,000.*

Figure 18: Urbanaut Operation and Maintenance Costs[7]

(Source http://www.urbanaut.com)

Figure 19: Urbanaut Monorail in Las Vegas,Nevada

(Source https://www.prnewswire.com/)

4. Pre-investment Procedure For Havaray

The investments and costs for railway systems are high therefore, it has to be deeply considered before initiating a project. In case of wrong implementation and planning, backing out from these projects are also highly costly. For that reason, it is obligatory for the authorities to plan the feasibility of those projects before implementation. All the cases where it is not predicted, can increase the costs of the projects also the implementation time which leads to make projects highly ineffective.

The same procedures apply for planning in monorail applications, they have to achieve the optimum benefit/cost ratio. The priority areas when finding this best benefit/cost ratio are, it should be responsive to the demand, cost of implementation and cost to environment. The governing policy should be described with a strategic perspective. If that has been provided, funding the project would be easier.

4.1 Plans and Regulations of Turkish Government

Governmental decisions, legislations and feasibility analyses are the three decisive factors in means of railway network investments.

The Turkish 10th Development plan which consists of 2014-2020 years, is about providing integration and cost optimization within the urban transportation types and emphasizing the importance of sustainable urban transportation infrastructure and respectively, the planning in urban landscape is getting improved to reach this goal.

To maintain this goal, the 10th Development plan is suggesting that problematic cities which has more than 100.000 inhabitants, have to plan their sustainable masterplan in urban transportation in every five years.

Especially for urban railroad systems, in the Turkish 10th development plan, the transportation demand has to reach at least in peak hours for one way travel; for tram lines 7000 passengers/hour, for light rail systems 10000 passengers/ hour, for metro systems 15000 passengers/hour to initiate the projects on railway transportation.

The prior policy is to make higher life standarts and providing the sustainable development which can be abbreviated as KENTGES in Turkish however in this plan there is no mention about the monorail systems directly. Public transportation topics are included in the 5th goal of KENTGES.

The strategies below are mentioned in the masterplan in transportation subjects of KENTGES.

- The legislation to provide integration between urban landscape planning and urban transportation will be made.
- The urban transportation plans will be applied in consideration with environmental, technical, economic and sociologic matters.
- There will be maintenances made to improve accessibility of public transportation services.
- The service quality and technology of public transportation systems will be increased.

As a result, beginning from the development plan, in all of the higher scaled strategy documents it became an obligation for cities to make their main transportation plans and the main responsibilities (landscape and transportation) inside the city borders has been given to the municipalities.

As we check the main strategies on national scale, the construction of transportation main networks has been attested in the Law of Municipalities in the number of 5216 and its 7th point, which is about the responsibilities of municipalities, mentioned as it is the responsibility of municipalities to determine the main plan of the transportation networks of the cities, all the services which has and will be operated at land, sea, water and rail and every type of public transportation which includes taxies their price tariffs, time scales and itineraries are the main responsibilities of the municipalities.

Scope of KENTGES in 10th Development Programme

In Turkey, the need for improving quality of spatial life in urban settlements, strengthening economic and social structure, and restructuring the spatial planning system has been gradually increasing.

Considering this fact, it is envisaged to prepare an “Urban Development Strategy and Action Plan” in the “Medium Term Programme”. In the Ninth Development Plan 2010 Programme, “Improving Urban Life Standards and Ensuring Sustainable Development” was identified as a primary policy. Moreover, a “Sustainable Urban Development and Action Plan” was foreseen to be prepared under the responsibility of Republic of Turkey Ministry of Environment and Urbanisation by the end of June 2010. Also, it was also provided that the policies and activities intended for solution in relation to legal, technical and administrative problems in the establishment of healthy, balanced and safe cities were to be identified in the Strategy and Action Plan.

Furthermore, the matter of “Taking decision of High Planning Council in relation to approval of the Integrated Urban Development Strategy and Action Plan for Sustainable Urban Development” is envisaged with the reference number 22.1013.2.02 in the section “IV-Secondary legislation foreseen to be ratified in years 2010-2013” under the title of “22-Regional Policy and Coordination of Structural Instruments” within the framework of regulations to be done which were disclosed in April 2007 in the context of Turkey’s Programme for Alignment with the EU Acquis (2007-2013).

“Integrated Urban Development Strategy and Action Plan”, the short name of which is the Urban Development Strategy (KENTGES), includes areas, themes and dimensions of settlements and urbanization as well as settlements and spatial planning. It associates the space-related sectors with an integrated approach and provides harmonization with the fundamental national policies within the framework of sustainability principles. With an understanding which adopts the system of values and principles on urbanization, settlements and spatial planning, KENTGES is considered a strategy document, having the nature of a reference framework document at the national level.

Considering not only the dominant role of the cities in socio-economic development but also their functions assumed in the spatial organization and the relations between the settlements, the concept of urban development emerges as a fundamental element in the context of regional development.

In preparation of KENTGES;

- Commission Reports and Final Declarations of the Urbanization Council,
- Findings and assessments in relation to the issue of urbanization in Turkey, taking place in
- the Project of Integration of Sustainable Development to Sectoral Policies which is carried out by SPO, sustainability framework, approaches and models in the urbanization area,
- The Ninth Development Plan, Medium Term Programme, Annual Plans, Private Specialization Commission Reports, National Strategy Documents,
- UN-Habitat, Spatial Planning Guide, Agenda-21 and the relevant strategy and action plans,
- European Urban Act, Guidelines for Spatial Development of the Europe, European Spatial
- Development Perspective, and similar Documents

were taken into consideration.

The main purpose of KENTGES is to improve the livability level as well as the quality of spatial and life in settlements and to establish a road map for strengthening of economic, social and cultural structures of settlements.

The current status of urbanization, settlements and spatial planning system in Turkey as follows;

Main themes and subtitles in relation to the work areas of the commissions established during the Urbanization Council process involve all areas relating to urbanization, settlements and spatial planning in Turkey. In the Commission work, the current status of these areas has been analyzed; problems, potentials and opportunities have been introduced together with institutional structuring and its legal dimensions. Moreover, the council proposals, strategy and action options have been formed by considering these analyses.

As a result of the council reports prepared in relation to urbanization, settlements and spatial planning as well as the preparatory meetings held during the KENTGES process, the current status has been analysed, and problems and solutions have been introduced.

Basic problem areas, findings and assessments in relation to urbanization In the Ninth Development Plan, “Settlements and Urbanization, Private Specialization Commission Report”, the main problems and the sub-problem areas relating to these in relation to urbanization, settlements and spatial planning have been identified. These are;

- Under the title of Regional Disparities; regional disparities and local development problems,
- Under the title of Settlements and Urbanization; problems for quality of life, settlements and urban areas vulnerable to natural disasters, protection of natural and cultural properties, illegal housing, restoration and transformation, lack of technical and social infrastructure [1]

4.2 Process of Investments

In this section, it will be mentioned about the investment process of monorails as urban railway transportation systems and the work must be done in every step of investment

It is very important to make transportation master plans before the rail system investments are made. It is necessary to determine the basic principles, policies, strategies and basic practices to be followed in the transportation master plans to be prepared for urban transportation problems and transportation related issues.

The transportation master plan should also consider the developments in transportation in parallel with the development of the city and should be based on the land development plan, population and employment decisions proposed.

For municipalities to make high-cost monorail investment decisions, it is important to establish the Transportation Master Plan, which determines the short, medium and long-term planning decisions, and includes monorail investment in the plan. In such a case, a comprehensive study should be conducted that follows a methodological process and aims to set up mathematical methods and demand forecasting models in order to carry out the investment process effectively and obtain the expected benefit at optimum cost.

In the light of these, the investment process of monorails can be managed in four parts which are;

1.Collection and Evaluation of Required Information

- Demographic, socio-economic and placement data of the area which is impacted by the monorail
- Planned and continuing projects and investments of the city
- Existing traffic and transportation infrastructure

2.Estimation of Passenger Demand

3.Preparation of Pre and Definitive Projects

4.Preparation of Feasibility Analysis

4.3 Itinerary of Havaray

In this section, it is examined the Havaray Istanbul's itinerary which is planned to be implemented between Küçükçekmece and Başakşehir districts of Istanbul Province.

The monorail line of the project is 14,650 km long and it consists of 17 stations, Distances between the stations are given in the chart next page. And the map below shows the connection of the planned monorail line with connection to the other lines.

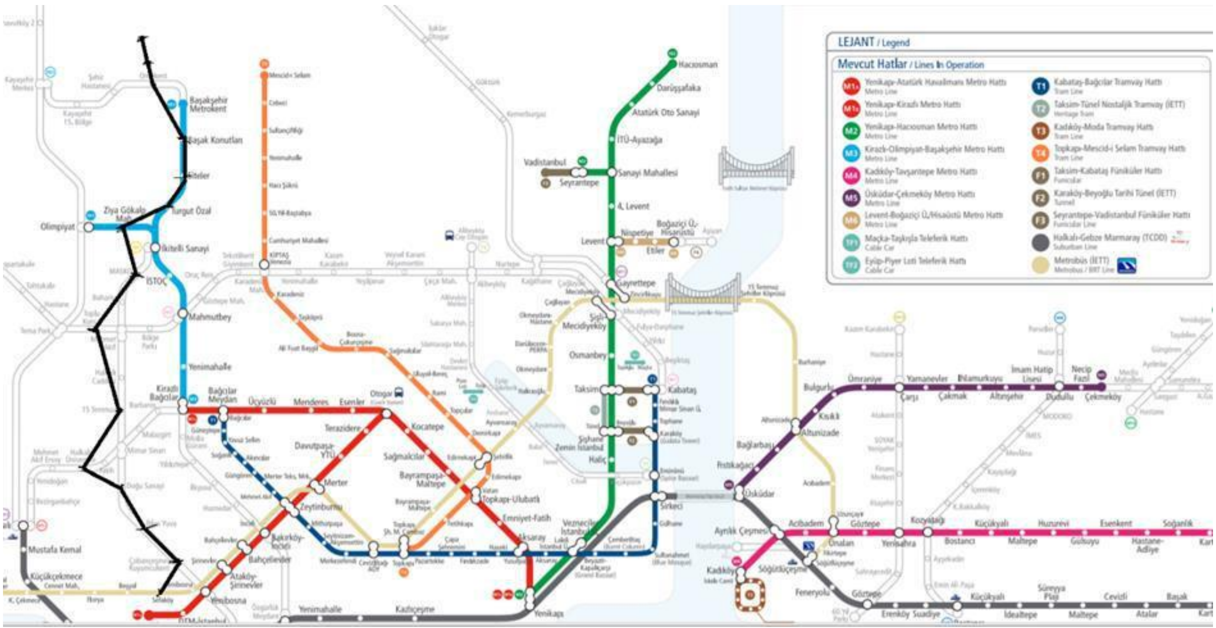


Figure 20: Itinerary of HAVARAY mounted on Istanbul Public Transportation Map (Black Line)

(Source https://www.ibb.istanbul/)

Table 1:Distances between the stations [8]

NR	STATION	DISTANCE BETWEEN PREVIOUS STATION(m)	STARTING POINT (km)
1	Sefaköy	0,00	0,00
2	Armani Park	900,00	0+900,00
3	Borusan	750,00	1+650,00
4	Sanayi	650,00	2+300,00
5	Gümrük Yolu	900,00	3+200,00
6	Halkalı Merkez	900,00	4+100,00
7	TOKİ - 1	1.100,00	5+200,00
8	TOKİ - 2	500,00	5+700,00
9	Arena Park	900,00	6+600,00
10	Masko	1.400,00	8+000,00
11	Ziya Gökalp	800,00	8+800,00
12	Atatürk Oto Sanayi - 1	1.000,00	9+800,00
13	Atatürk Oto Sanayi - 2	1.000,00	10+800,00
14	Başak Konutları	600,00	11+400,00
15	Onurkent	1.100,00	12+500,00
16	Oyakkent	1.000,00	13+500,00
17	Fatih Terim Stadyumu	1.150,00	14+650,00
	TOTAL	14.650,00	

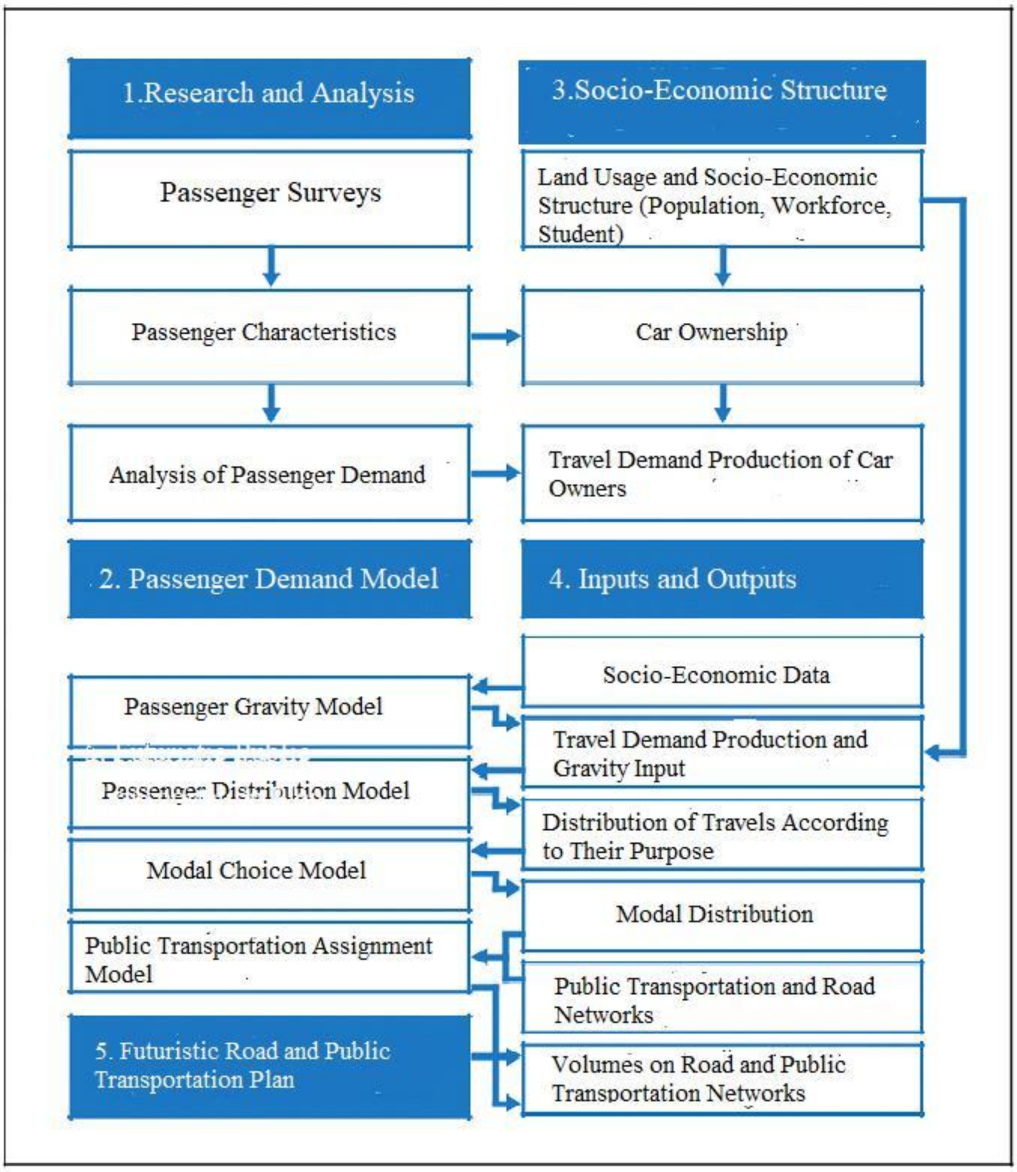
4.4 Forecasting Passenger Demand

It is known that the share of road transportation is very high in the distribution of urban trips in Istanbul. As a result of feeding the new and high capacity rail system lines with less capacity road public transportation systems, it is predicted that the capacity utilization rate for each line will increase and thus the efficiency of the public transportation system will increase. On the one hand, urban accessibility will increase and on the other hand, a more livable urban environment will be created.

In case of the construction of the projected line, taking into consideration the consequences of the considerable increase in the travel demands between the regions where the projected monorail line is located and the city center, integration will be provided with other rail system lines that are in service in these regions, which are under construction and planned. A very important alternative will be created for private and public transport journeys.

Sefaköy - Halkalı - Başakşehir Monorail Line, consistent with the general goal of reducing the motor vehicle traffic, improving the public transportation infrastructure and directing the transportation demand from private vehicles to public transportation vehicles, as stated in the Istanbul Transportation Master Plan, is more livable both in the region and in the city. Travel demand calculation process of Istanbul Metropolitan Municipality is shown in the table below.[2]

Table 2: Istanbul Metropolitan Municipality Demand Calculation Process [2]



The travel demands expected to emerge in the future on the monorail line have been estimated by the Transportation Planning Directorate using the model created and calibrated within the scope of the Istanbul Transportation Master Plan Study. These estimates were made for the number of passengers getting on/off the stations for 2024 and 2040 and provide data for determining the operating characteristics of the planned rail system (frequency, vehicle capacity, number of vehicles to be purchased, etc.). The forecasted demand can be seen in the graph next page.

Table 3 : Peak hour traffic forecast on Havaray (2024-2040 pphpd)[4]

	Sefaköy -İkitelli Direction						İkitelli -Sefaköy Direction					
	2024			2040			2024			2040		
Station	Board	Land	Inside	Board	Land	Inside	Board	Land	Inside	Board	Land	Inside
Sefaköy	4.636	0	0	7.557	0	0	0	8.409	8409	0	13.707	13.707
Armani Park	1.680	52	4.636	2.738	85	7.557	658	2.924	10.675	1.073	4.766	17.400
Borusan	1.536	272	6.264	2.504	443	10.210	2.111	1.170	9.734	3.441	1.907	15.866
Sanayi	2.826	1.866	7.528	4.606	3.042	12.271	5.308	1.330	5.756	8.652	2.168	9.382
Gümrük Yolu	916	283	8.488	1493	461	13.835	686	398	5.468	1118	649	8.913
Halkalı Merkez	297	1.647	9.121	484	2.685	14.867	946	404	4.926	1542	659	8.029
TOKİ -1	1.002	818	7.771	1.633	1333	12.667	952	441	4.415	1.552	719	7.196
TOKİ -2	1.089	198	7.955	1.775	323	12.967	164	25	4.276	267	41	6.970
Arena Park	1.925	3.876	8.846	3.138	6.318	14.419	2.993	898	2.181	4.879	1.464	3.555
Masko	244	1.157	6.895	398	1.886	11.239	711	188	1.658	1159	306	2.703
Ziya Gökalp	207	792	5.982	337	1291	9.751	282	247	1.623	460	403	2.645
Atatürk Oto Sanayi -1	94	2.079	5.397	153	3.389	8.797	558	114	1.179	910	186	1.922
Atatürk Oto Sanayi -2	75	386	3.412	122	629	5.562	108	18	1.089	176	29	1.775
Basak Konutları	255	703	3.101	416	1146	5.055	164	86	1.011	267	140	1.648
Onurkent	14	2.550	2.653	23	4.157	4.324	888	75	198	1447	122	323
Oyakkent	2	41	117	3	67	191	126	78	150	205	127	245
Fath Terim Stadyumu	0	78	78	0	127	127	150	0	0	245	0	0

4.5 Management Plan and Inventory Analysis

In this section, according to the estimated travel demands for the evaluation period between 2024 and 2048, the number of operation plans and vehicles required to carry the traffic expected in the future on the project subject monorail line are examined. (All calculations are made in 2014 by the Istanbul Metropolitan Municipality)

Considering the distribution of the journeys during the day, the other rail system lines operating in Istanbul will be operated for 18 hours a day, similar to the current operating hours. It is predicted that 50% of the total journeys in monorail line will be at peak hours (07: 00-09: 00; 17: 00-20: 00) and 40.5% of them will be during off-peak hours (06: 00-07: 00; 09: 00-17: 00) and 9.5% of them will be held at late hours (20: 00-24: 00).

The properties related to the operation of the Monorail Line are given in the chart. As can be seen from the chart, the average commercial speed was calculated as 35 km/h and a 1.5-minute turning time was taken into account at the terminal stations.

Table 4: Operation Properties of Havaray[8]

Properties	Havaray
Line Length (Km)	14,948
Average Speed (Km/h)	35,0
Waiting time at end(mins)	1,5
Total Lap Time (mins)	54,3
Operating Speed (Km/h)	33,1
Station Count	17

In the Sefaköy - Halkalı - Başakşehir Monorail Line, it is decided to operate large types of traincars in series of three traincars, and the passenger capacity of the motor traincars to be located at the ends is 140 passengers, consist of 29 seated and 111 standing (6 people / m2) passengers and the capacity of non-motored traincars which will be located in the middle of the train was considered to be 159 passengers, consist of 33 sitting and 126 standing (6 people /m2).Thus, the capacity of a 3-car series is calculated as 439 passengers. The average occupancy rate was accepted as 1.00 at peak hours.

Throughout the evaluation period, the maximum traffic for the peak hours, off-peak hours and night hours, the required sequence intervals that can meet the maximum travel demands, and the daily tour and the number of required series / vehicles for the period between 2024-2048 are shown in the chart. The number of vehicles was calculated by considering the reserve rate of 8,6% to meet the travel demands foreseen for the future.[4]

Thus, 75 traincars (69 operative, 6 spare) will be needed in 2024. Due to the frequency of trips that will change depending on the increase in traffic, it is estimated that 18 additional traincars will be needed in 2026 and 30 additional vehicles in 2032 and the purchases of these vehicles will take place in 2026 and 2032 and until the end of evaluation period in 2048, it is estimated that in total of 123 traincars will be needed. In order to minimize the environmental and visual pollution of the planned project, the vehicles that do not have a catenary system and take the energy supply from the tracks are focused on. [4]

Table 5: Max Traffic (pphpd), Headway and Vehicle Count (2024-2048)(İbb, 2014).

Passengers/ Hour				Min Required Headway (Minute)			Planned Min Headway (Minute)				
Year	**Peak**	**Off Peak**	**Late**	**Peak**	**Off Peak**	**Late**	**Peak**	**Off Peak**	**Late**	**Daily Tour Count**	**Train Count**
2024	9,570	4,307	2,393	2,8	6,1	11	2,5	6	11	232	23
2025	9,925	4,466	2,481	2,7	5,9	10,6	2,5	5,5	10	242	23
2026	10,293	4,632	2,573	2,6	5,7	10,2	2,5	5,5	10	242	29
2027	10,675	4,804	2,669	2,5	5,5	9,9	2	5	9,5	283	29
2028	11,071	4,982	2,768	2,4	5,3	9,5	2	5	9,5	283	29
2029	11,467	5,160	2,867	2,3	5,1	9,2	2	5	9	285	29
2030	11,863	5,338	2,966	2,2	4,9	8,9	2	4,5	8,5	298	29
2031	12,259	5,517	3,065	2,1	4,8	8,6	2	4,5	8,5	298	29
2032	12,655	5,695	3,164	2,1	4,6	8,3	2	4,5	8	300	39
2033	13,051	5,873	3,263	2	4,5	8,1	2	4	8	315	39
2034	13,447	6,051	3,362	2	4,4	7,8	1,5	4	7,5	367	39
2035	13,843	6,229	3,461	1,9	4,2	7,6	1,5	4	7,5	367	39
2036	14,239	6,408	3,560	1,8	4,1	7,4	1,5	4	7	369	39
2037	14,635	6,586	3,659	1,8	4	7,2	1,5	3,5	7	389	39
2038	15,031	6,764	3,758	1,8	3,9	7	1,5	3,5	7	389	39
2039	15,427	6,942	3,857	1,7	3,8	6,8	1,5	3,5	6,5	391	39
2040	15,823	7,120	3,956	1,7	3,7	6,7	1,5	3,5	6,5	391	39
2041	16,219	7,299	4,055	1,6	3,6	6,5	1,5	3,5	6	394	39
2042	16,615	7,477	4,154	1,6	3,5	6,3	1,5	3,5	6	394	39
2043	17,011	7,655	4,253	1,5	3,4	6,2	1,5	3	6	420	39
2044	17,400	7,830	4,350	1,5	3,4	6,1	1,5	3	6	420	39
2045	17,798	8,009	4,450	1,5	3,3	5,9	1,5	3	5,5	424	39
2046	18,205	8,192	4,551	1,4	3,2	5,8	1,5	3	5,5	424	39
2047	18,621	8,379	4,655	1,4	3,1	5,7	1,5	3	5,5	424	39
2048	19,309	8,689	4,827	1,4	3,1	5,6	1,5	3	5,5	424	39

4.6 *Surveys*

In Turkey, monorail systems have started to be known more by many governors and to be included in the investment agenda of local governments. Monorail systems; has become an investment option in addition to urban rail systems such as metro, light metro, light rail and tram. There are projects that have reached the tender stage of feasibility, project and implementation works.

In order to determine and analyze the preference of the monorail system Turkish local administrators; A survey-based research study was carried out to obtain the opinions and evaluations of the heads of departments responsible for transportation in Metropolitan Municipalities and Provincial Municipalities(cities that have a population below 750.000). The authorities of 17 municipalities, 5 of which were provincial municipalities and 12 metropolitan municipalities, were interviewed in this study. However, authorities wanted their identity to be unanounced therefore their identity are announced as x1, x2... This survey study has been carried by Emre Memis (Istanbul Technical University) at December 2016.

The survey consisted of 12 questions which were;

1. If they know about the Monorail system
2. If they have experienced the Monorail systems in any foreign country
3. Knowledge about Monorails
    - Capacity
    - Speed
    - Cost
    - Manufacturers
    - Comparison with Alternatives
    - Advantages and Disadvantages
4. If they think about implementing a monorail system within their region
5. If they are aware of news about the monorail studies in Turkey
6. If they want or don’t want to implement a monorail system in their region
7. The comparison of monorail with other systems, their mode of choice and the reason

8. In case of implementation of monorail systems what are the procedures to be followed by the municipalities and their difficulties.
9. Financing techniques in case of monorail investments
10. Opinion about the thoughts of inhabitants of the region
11. Their additional thoughts about the monorail systems.
12. What are the other alternative public transportation systems your municipality is having an interest at the moment

Evaluation of the survey results

In this section, the responses of the Metropolitan Municipalities and other Provincial Municipal authorities were evaluated as holistic; As a result of the interviews conducted within the scope of the research, the responses of the municipal authorities were examined and interpreted in detail and in a holistic manner in each topic.

Regarding the question of "whether they heard monorail systems or not";

3 out of 17 municipality officials replied that they have never heard of the monorail.

Regarding the question of "whether or not he/she used monorail in any country";

Some municipality officials stated that they experienced the monorail systems in Germany, Japan and England.

Regarding the question of "Information about monorail";

Cost, capacity and advantages of monorails were the most known topics. It is seen that the least known subject was monorail manufacturer firms.

The officials who think/want to implement a monorail system in their cities stated that monorail system is;

- Offering alternative solutions to traffic and transportation problems.
- Providing fast and comfortable service in high technology in public transportation.
- Providing a low passenger capacity solution for regions that do not require high capacity systems in terms of passenger potential,
- Protecting city and sea integrity in coastal cities,

• The monorail is suitable for the geographical features of the city, street and boulevard structure and rough terrain conditions,

• Providing the opportunity to go over the streams, rivers and canals passing through or around the city,

• Expropriation and construction costs are appropriate,

• Access to fairs, university areas and tourism regions and easier to provide integration with other urban rail systems,

• It is a sustainable transportation mode and reduces dependence on petrol,

• Provides autonomy in travel,

The officials who don't think/want to implement a monorail system in their cities stated the reasons they don't think about implementing monorail systems are;

- Narrowness of the current roads and the infrastructure of their city is not avaliable
- Insufficient population/ travel demand
- High costs for small size cities
- There aren't any other public transportation mode to integrate available.
- Not appropriate because of the scattered population of city
- Can spoil the historical texture of the city

Regarding the question of wheter they are following the news about monorail studies in Turkey;

4 Metropolitan Municipality officials stated that they follow the works and developments related to the monorail in Ankara, Kocaeli, Mersin, Izmir, Istanbul on the web pages of the Municipalities and the Ministry of Transport, Maritime Affairs and Communication, as well as media.

Regarding the question about the comparison of monorail systems with other modes;

Some municipal officials responded that the effects of different public transport systems should be examined in multiple dimensions and that different urban rail systems should not be viewed as alternatives but as complementary.

Regarding the question of procedures and processes that local governments should follow in monorail investments;

The municipal officials gave partial responses to the procedures and processes related to monorail investment. Opinions on the procedures and processes regarding the monorail investments obtained as a result of combining the answers given to the question are as follows.

- To Realize these kind of projects, it is needed to ensure the participation of all decision-makers in the city and to receive university support.
- Starting the rail system investment processes after the transportation master plan studies for determining passenger demand-capacity and carrying out transportation studies
- The approval of the General Directorate of Infrastructure Investments of the Ministry of Transport, Maritime Affairs and Communications will be required for the feasibility studies of the institutions / organizations that will provide loans regarding monorail costs, but this process is difficult and long.
- At least 36 months are required for the Transportation Master Plan, General Directorate of Infrastructure Investments and bidding process.
- At least 3-5 years needed for feasibility and preliminary projects.
- At least 6 months are required for the Environmental Impact Analysis process.
- At least 24 months for the construction and delivery process

Regarding the question of financing alternatives related to monorail investments; The participants answered that the following financing methods can be used for these investments. Equity , domestic and international loans , build-operate-transfer model, EU funds, loans and foreign incentives ,İLBANK credit Funds provided by Ministry of Transport, Maritime Affairs and Communications.

Regarding the question of city inhabitants;

When the answers given to this question are examined, it is concluded that the city residents are the users of the rail system in general, and the fast, safe, comfortable, environmental and new generation monorail systems that do not require much intervention to the infrastructure will attract a great deal of attention by the city residents.

Additional thoughts on monorail applications;

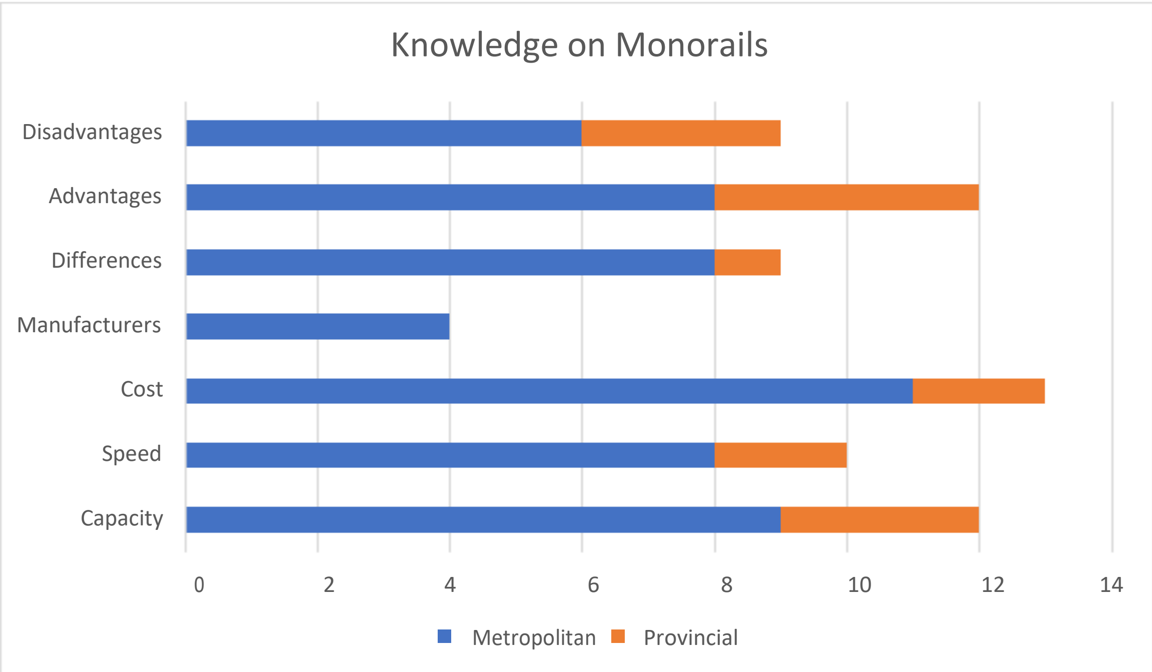
The remarkable answers are; monorail negatively affects the city silhuette, it is a system that has not yet been implemented in Turkey, its advantages-disadvantages should be described very well, the cost-benefit analysis for monorail should be compared with other systems, it should be a preferable system in Turkey in the years to come. is that it is more convenient to use the monorail system instead of removing the existing metrobus lines.

Regarding the question of new transportation systems of interest other than subways, trams and monorails;

When the answers given were analyzed as a whole, it was seen that 4 cablecars and 2 funicular responses were given due to the rough and high slope land structure, on the other hand 2 metrobus, 1 mini metro, 1 railbus, 1 electric bus, 1 tram answers has been given for normal terrain land structure.

The chart below is to show the knowledge levels of Turkish municipality officials about the properties of monorail systems. The total number of participants were 17.

Chart 1 :Knowledge of Turkish municipality officials about monorail systems(December '16)



The table below is to summarize the Turkish municipality officers' perspective on railway public transportation modes and their superior and inferior properties.

Table 6: According to Municipality Officers, Superior and Inferior properties of Railway PT Modes

	Superiority	Inferiority
MONORAIL	- They are applicable in dense city centers - They are applicable in steep surfaces - Modern look - Low investment costs - Low expropriation costs - They are fast - Can be used also in the regions where travel demands are lower - Easier access to the stations - Don't need to apply wide curves	- They are not suitable for the historical landscape in the old towns - May be unefficient in flat surfaced cities - Lack of knowledge and technical services - Difficult and expensive to supply spare parts
METRO	- High Capacity - Fast	- Very Expensive - Time of construction is long - Hard to apply to the places where the ground water level is high
LRT	- Don't need to apply wide curves - Can be a good solution in low travel demand areas	- More expensive than monorails
TRAM	- Operational and Maintenance costs are low - Easy access to the stations	- Low autonomy, interfering with the road traffic

5. Feasibility Analysis on Havaray

A feasibility study is an analysis that takes all of a project's relevant factors into account—including economic, technical, legal, and scheduling considerations—to determine the probability of completing the project successfully. Project managers use feasibility studies to determine the pros and cons of undertaking a project before they invest a lot of time and money into it.

A feasibility study is simply an assessment of the practicality of a proposed plan or project. As the name implies, these studies ask: Is this project feasible? Do we have the people, tools, technology, and resources necessary for this project to succeed? Will the project get us the return on investment (ROI) that we need and expect?

The goals of feasibility studies are as follows:

- To understand thoroughly all aspects of a project, concept, or plan
- To become aware of any potential problems that could occur while implementing the project
- To determine if, after considering all significant factors, the project is viable—that is, worth undertaking

As feasibility studies are important in any kind of industry, they are highly important for public transportation as well, an investment cannot be sustainable if it is not feasible, or simply it has less benefits than its costs. And Havaray is not an exception to that. Therefore, this part of my report is about questioning the feasibility of the planned Havaray project. To maintain an intensive feasibility study, first we need to spot the components of it, which are not limited to costs, benefits, sensitivity analysis, different investment scenarios, discount rates, liquidation costs, debt to capital ratio.

5.1 Costs

In an economic feasibility analysis, the estimations and acceptations for the following costs which will apply to this project are explained in the below parts.

These costs can be classified as

- Investment Costs (Construction and Traincars)
- Repair, Maintenance and Operation costs

5.1.1 Investment Costs

Investment Costs are the costs that the investors will spend before operating the Havaray, which are;

Construction Costs

Previously, Istanbul Metropolitan Municipality expected that the construction of Monorail line will be held in 3 years and it will be constructed between the years 2021 and 2023.

Cost of Stations

Electromechanical Works

Warehousing and Unexpected Costs

Monorail Traincars

The cost estimation for monorail traincars are done by Istanbul Metropolitan Municipality by comparing the market and analyzing an optimal cost of 1.200.000 Euro per traincar, however there hasn't been any brand information shared with public and all of these traincars will be bought in 2023, 75 vehicles will be bought and that will make the total of 90.000.000 Euro.18 traincars will be bought at 2026 and 30 will be at 2032.

Table 7: Investment Cost Matrix

Years	Construction Costs	Stations	Electromechanic Works	Warehousing	Traincars	Total
2021	36.622.600	3.570.000	7.900.000	2.520.000	0	50.612.600
2022	52.318.000	24.990.000	47.400.000	3.780.000	0	128.488.000
2023	15.695.400	42.840.000	102.700.000	6.300.000	90.000.000	257.535.400
Total	104.636.000	71.400.000	158.000.000	12.600.000	90.000.000	436.636.000

The total investment cost for the line excluding the monorail cars are estimated as 346.636.360 Euro and it is equal to approximately 23 Million Euro/km which can be seen as a fair cost in comparison with other projects. [4]

5.1.2 Maintenance and Management Costs

In Turkey, there is no monorail line that has been completed and is being operated yet, since the operating costs of these systems are similar to metro operating costs, in order to calculate the operating and maintenance costs of the Sefaköy - Halkalı - Başakşehir Monorail Line, the unit values observed in the metro lines currently operating in Istanbul were.used. Depending on the number of stations planned to be operated and the number of stations planned to be determined during the operation of the Sefaköy - Halkalı - Başakşehir Monorail Line, for every 3-vehicle series of vehicles there will be 4 workers, for every station there will be 4 security officers and 3 cleaning personnel is estimated to work and for the whole project it is estimated that 10 managers will work. For management employees, the estimated salaries are 1500 Euro/month and for other workers the salaries are 1250 Euro/ month.

The personnel will start to work after the construction. And the designated lifespan of operation is 25 years from 2024 to 2048.

There are 25 series of vehicles and 17 stations which is an equivalent of 219 workers and there will be 10 managers which will sum up to 3.465.000 Euros annually. The vehicle count will increase at years 2026 by 18 and by 2032 by 30 which will also increase the personnel number.

Cost of energy is estimated around 4.000.000 Euro annually the increase in the vehicle count will also affect this number in the next years. This number is calculated by comparing similar (Light Rail Transport) systems in Istanbul. [6]

The cost of maintenance in the track, stations and vehicles are estimated as 400.000 Euros per year (at 2024) since monorail systems are cheaper forms of public transportation comparing to others.[6]

Table 8: Total costs through the years

Years	Cost of Investments	Maintenance Co	Energy Cost	Employee Cos	Total Costs	PV of Costs
2021	-50612000				-50612000	-50612000
2022	-128488000				-128488000	-123546154
2023	-257535400				-257535400	-238105954
2024		-400000	-4000000	-3465000	-7865000	-6991956.36
2025		-420000	-4000000	-3465000	-7885000	-6740131.05
2026	-21600000	-449400	-4960000	-3465000	-30474400	-25047735.4
2027		-471870	-4960000	-3825000	-9256870	-7315838.82
2028		-495464	-4960000	-3825000	-9280463.5	-7052389.53
2029		-520237	-4960000	-3825000	-9305236.68	-6799245.29
2030		-546249	-4960000	-3825000	-9331248.51	-6556011.43
2031		-573561	-4960000	-3825000	-9358560.93	-6322308.44
2032	-36000000	-625181	-6560000	-3825000	-47010181.4	-30536917.4
2033		-656440	-6560000	-4425000	-11641440.5	-7271209.38
2034		-689263	-6560000	-4425000	-11674262.5	-7011259.54
2035		-723726	-6560000	-4425000	-11708725.6	-6761497.31
2036		-759912	-6560000	-4425000	-11744911.9	-6521532.68
2037		-797908	-6560000	-4425000	-11782907.5	-6290990.66
2038		-837803	-6560000	-4425000	-11822802.9	-6069510.7
2039		-879693	-6560000	-4425000	-11864693	-5856746.13
2040		-923678	-6560000	-4425000	-11908677.7	-5652363.65
2041		-969862	-6560000	-4425000	-11954861.6	-5456042.77
2042		-1018355	-6560000	-4425000	-12003354.7	-5267475.36
2043		-1069272	-6560000	-4425000	-12054272.4	-5086365.17
2044		-1122736	-6560000	-4425000	-12107736	-4912427.33
2045		-1178873	-6560000	-4425000	-12163872.8	-4745387.99
2046		-1237816	-6560000	-4425000	-12222816.4	-4584983.82
2047		-1299707	-6560000	-4425000	-12284707.3	-4430961.64
2048		-1364693	-6560000	-4425000	-12349692.6	-4283078.04
					ΣPV of Costs	-605828474

5.2 Revenues

In the feasibility study of Sefaköy - Halkalı - Başaksehir Monorail Line, "Business (Ticket) Revenues", "Rental Revenues" and "Advertisement Revenues" have been taken into account. This section includes the acceptance of the items in question and the estimated operating income during the evaluation period.

5.2.1 Pricing and Ticket Revenues

The average ticket price of 4.25 TL (0.55€/journey) is foreseen based on the distribution of the different ticket types used by passengers in 2019 and the average revenue generated per trip was taken as basis in the rail system lines operated by. At 2024, it is estimated that there will be 87670 passengers daily which adds up to 32 million passengers for that year, and the revenue from tickets for the year 2024 is estimated as 17.600.000 Euro. The increase in passenger count through years are estimated to increase 3.7 percent and accepted as increasing linearly.

5.2.2 Income from Rentals

In order to meet the daily needs of monorail passengers; ATMs, food and beverage units, journalists, etc. Although it is anticipated that there will be leasable areas for commercial use and sales of souvenirs, it is assumed that a rent of 30.000 TL/month(3950 Euro per month) will be earned from the stations, taking into account that the areas in question on these elevated platforms will not be as big and more as the metro stations. There will be 17 stations and the revenue from renting these stations are calculated as 805000 Euro/year.

5.2.3 Income from Advertisements

Advertising revenues Similar to the rental revenues, it is assumed that poster - advertisement units and boards will be created at the stations where the intensive passenger flow is expected to take place, and there will be an average of 70,000 TL / month (9500 Euro) advertising revenue for each station during the operation phase, and monorail vehicles are on the elevated line in the important corridors of the city moreover while monorail vehicles are operated on the elevated line in the important corridors of the city, it is assumed that, unlike rail systems that are operated underground, a significant amount of advertising can be received on the vehicles in the form of dressing and it is foreseen that there will be 90.000 TL

/ vehicle / month (11650 Euro) in the operating phase. Income from the advertisements in stations are 1.938.000 Euro and from the vehicles 10.485.000 Euro yearly. As the number of the vehicles increase, the advertisement prices will rise.

5.2.4 Benefits to Society

Building an alternative mode of transportation to a city, without any doubt, will reduce the usage of others. In our case the monorail line is estimated to reduce private car and bus usages drastically, and the following elements can be added as benefits of this project since we are calculating the economic feasibility.

The beneficial elements of this project and their contributions to society is calculated by Istanbul Metropolitan Municipality by 2014.

Road transportation Operation Costs

In the scenario situation without a project, monorail line passengers are expected to use private cars, IETT buses and minibuses to make the same trips. Road vehicle operating costs, which is one of the important inputs of economic evaluation; Operating expenses such as fuel, oil, spare parts, vehicle maintenance work, tires, depreciation and fixed expenses such as vehicle time cost and vehicle maintenance time cost. Since the time costs of the passengers in the vehicles are added to the economic feasibility schedules as a separate cost item, not considered within the vehicle operating costs. You can see them separately in the time travel costs section of this thesis.

The modal distribution of passengers in both scenarios (with and without monorails) is used to analyze this difference and therefore used to spot how beneficial monorail line will be.

Considering the increase in private car ownership rate, which has gained a lot of momentum especially in recent years, for cars, buses and minibuses in 2024, respectively. Specific distribution rates accepted as 5% for cars, 55% for buses and 40% for minibuses. It is foreseen that it will be 15% for cars, 75% for buses and 10% for minibuses in 2048, which is the end of the evaluation period. As a result, in case the monorail line of the project is not built (without a project), road vehicle operating costs are calculated for the passengers who are expected to use other vehicles.

Road transportation Maintenance Costs

Using the budget figures of the Istanbul Metropolitan Municipality, Road Maintenance and Repair Directorate and the vehicle-km values foreseen for Istanbul. The difference on road maintenance costs have been calculated for the scenarios where monorail will be built or not.

Travel time value

Passenger time value is one of the most important parameters in economic feasibility studies of transportation projects. Many transportation projects can be economically feasible only if the economic value of the travel time gains to be achieved in passenger and freight transport of the project occupies an important place among the benefits of the project.

The method described below has been used to calculate the passenger and load time values used in the economic feasibility study for the Sefaköy - Halkalı - Başakşehir Monorail line.

Turkey has a GDP of 2,150 trillion Euro, the share of Istanbul is estimated as 21,3% of this which equals to 458 billion Euros if it is shared with an average of 18 million inhabitants, the average yearly salaries are estimated as 21203 Euro/ annum and it is known that on average in Turkey a person works for 2128 hours per year. So, on average, a person in Istanbul makes 9,96 Euro/ hour.

Decrease in accident costs

It is estimated that in Istanbul, there are approximately 1000 car accidents happen daily these accidents can be in different scales but in general, every accident cost the state some money, and the more private cars are used the more accidents happen, opening alternative modes of public transportation always result in decrease in private car users therefore, they decrease the money spent on traffic accidents.

Decrease in Environmental Costs

Environmental impact costs per km are estimated as 0.00833 Euro for cars, 0.00878 Euro for minibuses and 0.01700 Euro for buses, considering the noise pollution caused by motor vehicles such as automobile minibuses and buses in urban transportation, CO_2 emissions and similar criteria.

Efficient Land Usage

It is known that monorail lines are beneficial when it comes to land usage, which is a good source of public profit when it is thought that this project will be implemented in a metropolitan city like Istanbul where the land prices are the most valuable in Turkey.

As these Social benefits for Havaray project are difficult to estimate one by one, estimation is done by in comparison with other similar modes of transportation. Which is estimated to cost roughly 8 million Euros annually for this scale of projects.

Table 9: Total revenues through years

Years		PV of Revenues	Total Revenue	Tickets	Rentals	Adv Sta	Adv Veh	Society
2021	0	0	0					
2022	1	0	0					
2023	2	0	0					
2024	3	34517951	38828000	17600000	805000	1938000	10485000	8000000
2025	4	33746986	39479200	18251200	805000	1938000	10485000	8000000
2026	5	33004067	40154494.4	18926494	805000	1938000	10485000	8000000
2027	6	34276869	43371174.69	19626775	805000	1938000	13001400	8000000
2028	7	33510373	44097365.36	20352965	805000	1938000	13001400	8000000
2029	8	32771766	44850425.07	21106025	805000	1938000	13001400	8000000
2030	9	32059980	45631348	21886948	805000	1938000	13001400	8000000
2031	10	31373987	46441165.08	22696765	805000	1938000	13001400	8000000
2032	11	30712801	47280945.39	23536545	805000	1938000	13001400	8000000
2033	12	32695031	52345797.57	24407398	805000	1938000	17195400	8000000
2034	13	31979892	53248871.28	25310471	805000	1938000	17195400	8000000
2035	14	31290695	54185358.71	26246959	805000	1938000	17195400	8000000
2036	15	30626444	55156496.19	27218096	805000	1938000	17195400	8000000
2037	16	29986187	56163565.74	28225166	805000	1938000	17195400	8000000
2038	17	29369004	57207896.88	29269497	805000	1938000	17195400	8000000
2039	18	28774012	58290868.26	30352468	805000	1938000	17195400	8000000
2040	19	28200362	59413909.59	31475510	805000	1938000	17195400	8000000
2041	20	27647238	60578503.44	32640103	805000	1938000	17195400	8000000
2042	21	27113855	61786187.27	33847787	805000	1938000	17195400	8000000
2043	22	26599458	63038555.4	35100155	805000	1938000	17195400	8000000
2044	23	26103321	64337261.15	36398861	805000	1938000	17195400	8000000
2045	24	25624746	65684019.01	37745619	805000	1938000	17195400	8000000
2046	25	25163063	67080606.91	39142207	805000	1938000	17195400	8000000
2047	26	24717625	68528868.57	40590469	805000	1938000	17195400	8000000
2048	27	39409015	113630715.9	42092316	805000	1938000	17195400	8000000
		761274728						

5.3 Components of Economic Feasibility Analysis

Cost Benefit Analysis is basically an analysis that shows the sum of benefits such as financial gain to be obtained against the costs of a project / product / service to be carried out by businesses. The technique is often used when trying to decide on an investment action. When calculating the activity of the investment, generally the intangible benefits as well as the opportunity cost are included in the calculations. Benefit cost analysis not only provides financial projection of a potential project, but also takes into account non-financial issues such as indirect benefit or cost, such as customer satisfaction and even employee motivation. For example, companies or financial analysts often include many factors, such as labor costs, social benefits, and other factors that may arise later, when creating potential benefits and costs. Benefit cost analysis is very similar to the net present value that is frequently used by investors. When conducting a cost-benefit analysis, it is necessary to evaluate the future total benefits and total costs of a project at its present value. Since cost-benefit analysis is usually done from a long-term perspective, when performing cost-benefit analysis, we take into account the **net present value** of the figures we analyze because the value of money often changes due to inflation and other factors. As its name implies, net present value is a method used to determine the benefits of investing. Calculates the future benefits or costs of the project in terms of its present value. If the net present value is positive, action or decision will usually be a good investment. On the other hand, if it is negative, the opposite is valid.

Steps for Cost Benefit Analysis

Step 1: Creating a Benefit and Cost List

The first thing to do when performing a cost benefit analysis is to create a comprehensive list of all costs and benefits associated with a potential investment decision.

We need to consider not only the obvious costs (such as the cost of installation for the new software or the purchase cost of the software), but also all of the options such as the intangible opportunity cost that we will incur when we select other software or the cost of hiring an employee instead of the software.

We should also consider all the possible benefits of the investment decision. For example, how much can this project contribute additionally to revenues? What other benefits can there be if investment is made? For example, will the new project create new business opportunities or improve existing jobs and improve efficiency? Therefore, we must make sure that you consider the obvious financial benefits as well as the intangible benefits.

Step 2: Valuing Costs and Benefits Monetary

Once you have created a comprehensive list of costs and benefits for the analysis, you can give monetary values to each cost or benefit.

Values for certain benefits or costs on the list are clear. For example, costs such as the purchase cost or installation cost of a project can be obtained from the offer. However, when determining monetary values, it is necessary to take into account the intangible direct or indirect costs or benefits. For example, installing a new infrastructure can create traffic service level down for a few months, so this downtime or reduced efficiency can result in money loss for the company or government.

When we determine the monetary values for each cost or benefit, we complete the parts required for the equation.

Step 3: Create and Solve the Equation

Take the sum of benefits (the sum of all monetary values allocated to the benefits of the project) and the sum of the costs (all the monetary values of the project costs) and apply them to the benefit / cost equation. Don't forget to calculate the Present Values of every item in the list, always keep in mind that the purchasing power of the same amount of money changes through the years, that is called inflation and it is an inevitable truth.

Net Present Value(NPV)

Net present value (NPV) is a method used to determine the current value of all future cash flows generated by a project, including the initial capital investment. It is widely used in capital budgeting to establish which projects are likely to turn the greatest profit.

Net present value, or NPV, is used to calculate today's value of a future stream of payments.

If the NPV of a project or investment is positive, it means that the discounted present value of all future cash flows related to that project or investment will be positive, and therefore attractive.

To calculate NPV you need to estimate future cash flows for each period and determine the correct discount rate.

The formula for NPV varies depending on the number and consistency of future cash flows. If there's one cash flow from a project that will be paid one year from now, the calculation for the net present value is as follows.

The formula for NPV

$$NPV = \text{Cash flow}/(1+i)^t - \text{initial investment}$$

Where:

i = Discount rate

t= Number of time periods

Internal Rate of Return(IRR)

The internal rate of return, another approach used in the evaluation of investment decisions, is the discount rate that equals the present value of the net cash inflows that a project will provide during its economic life to the total value of the cash outflows. In other words, the internal rate of return is the discount rate that equals the net present value of the project to zero.

An enterprise should invest in projects whose internal rate of return is higher than the weighted average cost of capital. If it is not possible to realize more than one project, internal project should choose the highest project with higher than average weighted capital cost. However, if the projects taken into consideration are not mutually exclusive projects, the business must make the projects that have higher internal efficiency ratios than the weighted average capital cost provided that the projects are ranked from the highest to the lowest according to the internal rate of return, and within the investment budget respectively.

5.4 Results of Economic Feasibility Analysis

As a result, in the economic feasibility study for the Monorail Line, the benefits and costs that would appear if the monorail line was constructed were evaluated together. Expected cost increases were calculated as a result of the project.

Sefaköy - Halkalı - Başakşehir Monorail Line has an Economic Net Present Value (ENPV) of 140.325.052 Euro for 4 percent discount rate, economic internal rate of return (EIRR) of the project is 6,42% and the benefit / cost ratio is calculated as 1,231.

Table 10: Cost Benefit Analysis without the liquidation

Years	Cost of Investments	Maintenance Co	Energy Cost	Employee Cos	Total Costs	Cash Flow	Present Value	Total Revenue	Tickets	Rentals	Adv Sta	Adv Veh	Society
2021	-50612000				-50612000	-50612000	-50612000	0					
2022	-128488000				-128488000	-128488000	-123546154	0					
2023	-257535400				-257535400	-257535400	-238105954	0					
2024		-400000	-4000000	-3465000	-7865000	30963000	27525994	38828000	17600000	805000	1938000	10485000	8000000
2025		-420000	-4000000	-3465000	-7885000	31594200	27006855	39479200	18251200	805000	1938000	10485000	8000000
2026	-21600000	-449400	-4960000	-3465000	-30474400	9680094.4	7956332	40154494.4	18926494	805000	1938000	10485000	8000000
2027		-471870	-4960000	-3825000	-9256870	34114304.7	26961031	43371174.69	19626775	805000	1938000	13001400	8000000
2028		-495464	-4960000	-3825000	-9280463.5	34816901.9	26457984	44097365.36	20352965	805000	1938000	13001400	8000000
2029		-520237	-4960000	-3825000	-9305236.68	35545188.4	25972521	44850425.07	21106025	805000	1938000	13001400	8000000
2030		-546249	-4960000	-3825000	-9331248.51	36300099.5	25503968	45631348	21886948	805000	1938000	13001400	8000000
2031		-573561	-4960000	-3825000	-9358560.93	37082604.1	25051679	46441165.08	22696765	805000	1938000	13001400	8000000
2032	-36000000	-625181	-6560000	-3825000	-47010181.4	270763.968	175883	47280945.39	23536545	805000	1938000	13001400	8000000
2033		-656440	-6560000	-4425000	-11641440.5	40704357.1	25423821	52345797.57	24407398	805000	1938000	17195400	8000000
2034		-689263	-6560000	-4425000	-11674262.5	41574608.8	24968633	53248871.28	25310471	805000	1938000	17195400	8000000
2035		-723726	-6560000	-4425000	-11708725.6	42476633.1	24529197	54185358.71	26246959	805000	1938000	17195400	8000000
2036		-759912	-6560000	-4425000	-11744911.9	43411584.3	24104912	55156496.19	27218096	805000	1938000	17195400	8000000
2037		-797908	-6560000	-4425000	-11782907.5	44380658.2	23695196	56163565.74	28225166	805000	1938000	17195400	8000000
2038		-837803	-6560000	-4425000	-11822802.9	45385094	23299493	57207896.88	29269497	805000	1938000	17195400	8000000
2039		-879693	-6560000	-4425000	-11864693	46426175.2	22917266	58290868.26	30352468	805000	1938000	17195400	8000000
2040		-923678	-6560000	-4425000	-11908677.7	47505231.9	22547998	59413909.59	31475510	805000	1938000	17195400	8000000
2041		-969862	-6560000	-4425000	-11954861.6	48623641.9	22191195	60578503.44	32640103	805000	1938000	17195400	8000000
2042		-1018355	-6560000	-4425000	-12003354.7	49782832.6	21846380	61786187.27	33847787	805000	1938000	17195400	8000000
2043		-1069272	-6560000	-4425000	-12054272.4	50984283	21513093	63038555.4	35100155	805000	1938000	17195400	8000000
2044		-1122736	-6560000	-4425000	-12107736	52229525.1	21190894	64337261.15	36398861	805000	1938000	17195400	8000000
2045		-1178873	-6560000	-4425000	-12163872.8	53520146.2	20879358	65684019.01	37745619	805000	1938000	17195400	8000000
2046		-1237816	-6560000	-4425000	-12222816.4	54857790.5	20578079	67080606.91	39142207	805000	1938000	17195400	8000000
2047		-1299707	-6560000	-4425000	-12284707.3	56244161.3	20286663	68528868.57	40590469	805000	1938000	17195400	8000000
2048		-1364693	-6560000	-4425000	-12349692.6	57681023.3	20004735	70030715.91	42092316	805000	1938000	17195400	8000000
						NPV=	140325052						
				IRR=	6.42%								

According to these results, Sefaköy - Halkalı - Başakşehir Monorail Line Project is a project whose economic benefits are considerably higher than its economic costs in case the projected travel values are realized. The economic internal rate of return (EIRR) of the project is higher than the discount rate, which is generally based on economic feasibility for such infrastructure projects.

In other words, during the evaluation period, Sefaköy - Halkalı - Başakşehir Monorail Line Project because of its economic benefits are calculated to be considerably larger than its costs, is considered as a feasible project with projected construction/operation costs and travel demands. And this result is even without the liquidation rate, normally the infrastructure projects have around 10 percent liquidation rate in the end of their service, this is the cost that they will sell this project at the end of 25 years of usage. If it will be added to the revenue in 2048 which will account for 49.340.000 Euro;

The NPV will be: 157.436.981 Euro

The EIRR will be: %6,62

The benefit/cost ratio will be: 1,259

Table 21: Cost benefit analysis with 10% liquidation rate

Years	Cost of Investments	Maintenance Co	Energy Cost	Employee Cos	Total Costs	Cash Flow	Present Value	Total Revenue	Tickets	Rentals	Adv Sta	Adv Veh	Society
2021	-50612000				-50612000	-50612000	-50612000	0					
2022	-128488000				-128488000	-128488000	-123546154	0					
2023	-257535400				-257535400	-257535400	-238105954	0					
2024		-400000	-4000000	-3465000	-7865000	30963000	27525994	38828000	17600000	805000	1938000	10485000	8000000
2025		-420000	-4000000	-3465000	-7885000	31594200	27006855	39479200	18251200	805000	1938000	10485000	8000000
2026	-21600000	-449400	-4960000	-3465000	-30474400	9680094.4	7956332	40154494.4	18926494	805000	1938000	10485000	8000000
2027		-471870	-4960000	-3825000	-9256870	34114304.7	26961031	43371174.69	19626775	805000	1938000	13001400	8000000
2028		-495464	-4960000	-3825000	-9280463.5	34816901.9	26457984	44097365.36	20352965	805000	1938000	13001400	8000000
2029		-520237	-4960000	-3825000	-9305236.68	35545188.4	25972521	44850425.07	21106025	805000	1938000	13001400	8000000
2030		-546249	-4960000	-3825000	-9331248.51	36300099.5	25503968	45631348	21886948	805000	1938000	13001400	8000000
2031		-573561	-4960000	-3825000	-9358560.93	37082604.1	25051679	46441165.08	22696765	805000	1938000	13001400	8000000
2032	-36000000	-625181	-6560000	-3825000	-47010181.4	270763.968	175883	47280945.39	23536545	805000	1938000	13001400	8000000
2033		-656440	-6560000	-4425000	-11641440.5	40704357.1	25423821	52345797.57	24407398	805000	1938000	17195400	8000000
2034		-689263	-6560000	-4425000	-11674262.5	41574608.8	24968633	53248871.28	25310471	805000	1938000	17195400	8000000
2035		-723726	-6560000	-4425000	-11708725.6	42476633.1	24529197	54185358.71	26246959	805000	1938000	17195400	8000000
2036		-759912	-6560000	-4425000	-11744911.9	43411584.3	24104912	55156496.19	27218096	805000	1938000	17195400	8000000
2037		-797908	-6560000	-4425000	-11782907.5	44380658.2	23695196	56163565.74	28225166	805000	1938000	17195400	8000000
2038		-837803	-6560000	-4425000	-11822802.9	45385094	23299493	57207896.88	29269497	805000	1938000	17195400	8000000
2039		-879693	-6560000	-4425000	-11864693	46426175.2	22917266	58290868.26	30352468	805000	1938000	17195400	8000000
2040		-923678	-6560000	-4425000	-11908677.7	47505231.9	22547998	59413909.59	31475510	805000	1938000	17195400	8000000
2041		-969862	-6560000	-4425000	-11954861.6	48623641.9	22191195	60578503.44	32640103	805000	1938000	17195400	8000000
2042		-1018355	-6560000	-4425000	-12003354.7	49782832.6	21846380	61786187.27	33847787	805000	1938000	17195400	8000000
2043		-1069272	-6560000	-4425000	-12054272.4	50984283	21513093	63038555.4	35100155	805000	1938000	17195400	8000000
2044		-1122736	-6560000	-4425000	-12107736	52229525.1	21190894	64337261.15	36398861	805000	1938000	17195400	8000000
2045		-1178873	-6560000	-4425000	-12163872.8	53520146.2	20879358	65684019.01	37745619	805000	1938000	17195400	8000000
2046		-1237816	-6560000	-4425000	-12222816.4	54857790.5	20578079	67080606.91	39142207	805000	1938000	17195400	8000000
2047		-1299707	-6560000	-4425000	-12284707.3	56244161.3	20286663	68528868.57	40590469	805000	1938000	17195400	8000000
2048		-1364693	-6560000	-4425000	-12349692.6	107021023	37116664	119370715.9	42092316	805000	1938000	17195400	8000000
						NPV=	157436981						
				IRR=	6.62%								

5.5 Sensitivity Analysis

In order to measure how a monorail project changes according to various factors (scenarios); "Sensitivity Analysis" should be made to reveal the factors that affect profitability by making changes in the basic indicators (passenger revenues, increase in construction costs, energy costs, advertisement revenues etc.) that form the basic assumptions of the project. Basically, this analysis will show how sensitive our project is to unforeseeable events.

In the sensitivity analysis conducted in order to determine how the economic and financial feasibility study results change in case some basic parameters of the Sefaköy - Halkalı - Başakşehir Monorail Line; project components were increased or decreased by 20%, negatively affecting feasibility results, and the economic internal efficiency rate and benefit / cost ratio of the project were calculated for each case.

Increase in Investment Costs by 20 percent

Let's assume the investment costs (excluding traincars) will increase 20 percent due to a construction accident or some other reason, in this case, the investment costs will be as below;

For 2021 – 60.734.400 Euro, for 2022 – 154.185.600 Euro, for 2023 – 309.042.480 Euro

In this case NPV will be 75.455.556 Euro after the operation and the IRR will be 5,11% and the benefit/cost ratio will be 1,109.

Decrease in advertisement revenues by 20 percent

In this case the NPV will be 60.388.033 Euro after the operation and the IRR will be 5,07% and the benefit cost ratio will be 1,099.

Decrease in Passenger count by 20 percent

In this case because of the fall in ticket revenues and social benefits, NPV will be 59.216.182 Euro after the operation and the IRR will be 5,03% and the benefit cost ratio will be 1,097.

Increase in the Energy Costs by 20 percent

In this case NPV will be 141.285.263 Euro after the operation and the IRR will be 6,36% and the benefit cost ratio will be 1,227.

Increase in the Labor Costs by 20 percent

In this case NPV will be 145.312.775 Euro after the operation and the IRR will be 6,42% and the benefit cost ratio will be 1,235.

As we can see, in any of these cases, the IRR fall down under the discount rate as this is the critical point that this investment begins to be unfeasible. So, we can tell that this project has passed the sensitivity analysis even under the highly unlikely circumstances. Below table consists the results of the sensitivity analysis.

Ultimate Scenario

In this scenario, the government wants to increase the service level of the monorail system and bring some design rules which are;

- Peak hour occupancy rate should be designed as max 0.8 (was 1.00)
- Standing people in vehicles should have a rate of 4 people/m2 (was 6 people/m2)

In this scenario, the capacity of the vehicles will change drastically and therefore, new vehicles should be bought therefore, the operational costs will also be affected. The new capacity of the motored cars will decrease from 140 to 103 and non-motored cars will decrease from 159 to 117 therefore, the capacity of a 3-car train series will decrease from 439 to 323. And with the peak hour occupancy rule the capacity is estimated to be 258 people. With this drastically drop in the capacity, new car count in the initiation of the monorail line will be 126 and in 2026 there will be 30 cars needed and for the year 2032 this number will be 51 more. The costs of energy and operation will also increase by 70 percent. Even under these conditions, the project would have an EIRR of 4,48% and an ENPV of 32.691.145 Euro in other words, it is feasible. The results of cost benefit analysis are shown in next page.

Table 12: Cost Benefit Analysis Results in the Ultimate Scenario

Years	Cost of Investments	Maintenance Co	Energy Cost	Employee Cos	Total Costs	Cash Flow	Present Value	Total Revenue	Tickets	Rentals	Adv Sta	Adv Veh	Society
2021	-50612000				-50612000	-50612000	-50612000	0					
2022	-128488000				-128488000	-128488000	-123546154	0					
2023	-318735400				-318735400	-318735400	-294688794	0					
2024		-680000	-6800000	-3465000	-10945000	27883000	24787885	38828000	17600000	805000	1938000	10485000	8000000
2025		-714000	-6800000	-3465000	-10979000	28500200	24362090	39479200	18251200	805000	1938000	10485000	8000000
2026	-36000000	-763980	-8430000	-3465000	-48658980	-8504485.6	-6990067	40154494.4	18926494	805000	1938000	10485000	8000000
2027		-802179	-8430000	-3825000	-13057179	30313995.7	23957591	43371174.69	19626775	805000	1938000	13001400	8000000
2028		-842288	-8430000	-3825000	-13097288	31000077.4	23557511	44097365.36	20352965	805000	1938000	13001400	8000000
2029		-884402	-8430000	-3825000	-13139402.3	31711022.7	23170934	44850425.07	21106025	805000	1938000	13001400	8000000
2030		-928622	-8430000	-3825000	-13183622.5	32447725.5	22797342	45631348	21886948	805000	1938000	13001400	8000000
2031		-975054	-8430000	-3825000	-13230053.6	33211111.5	22436237	46441165.08	22696765	805000	1938000	13001400	8000000
2032	-61200000	-1062808	-11000000	-3825000	-77087808	-29806863	-19361970	47280945.39	23536545	805000	1938000	13001400	8000000
2033		-1115949	-11000000	-4425000	-16540948.8	35804848.7	22363603	52345797.57	24407398	805000	1938000	17195400	8000000
2034		-1171746	-11000000	-4425000	-16596746.3	36652125	22012316	53248871.28	25310471	805000	1938000	17195400	8000000
2035		-1230334	-11000000	-4425000	-16655333.6	37530025.1	21672654	54185358.71	26246959	805000	1938000	17195400	8000000
2036		-1291850	-11000000	-4425000	-16716850.3	38439645.9	21344171	55156496.19	27218096	805000	1938000	17195400	8000000
2037		-1356443	-11000000	-4425000	-16781442.8	39382123	21026437	56163565.74	28225166	805000	1938000	17195400	8000000
2038		-1424265	-11000000	-4425000	-16849264.9	40358632	20719042	57207896.88	29269497	805000	1938000	17195400	8000000
2039		-1495478	-11000000	-4425000	-16920478.2	41370390.1	20421588	58290868.26	30352468	805000	1938000	17195400	8000000
2040		-1570252	-11000000	-4425000	-16995252.1	42418657.5	20133694	59413909.59	31475510	805000	1938000	17195400	8000000
2041		-1648765	-11000000	-4425000	-17073764.7	43504738.8	19854995	60578503.44	32640103	805000	1938000	17195400	8000000
2042		-1731203	-11000000	-4425000	-17156202.9	44629984.4	19585137	61786187.27	33847787	805000	1938000	17195400	8000000
2043		-1817763	-11000000	-4425000	-17242763.1	45795792.3	19323781	63038555.4	35100155	805000	1938000	17195400	8000000
2044		-1908651	-11000000	-4425000	-17333651.2	47003609.9	19070602	64337261.15	36398861	805000	1938000	17195400	8000000
2045		-2004084	-11000000	-4425000	-17429083.8	48254935.2	18825286	65684019.01	37745619	805000	1938000	17195400	8000000
2046		-2104288	-11000000	-4425000	-17529288	49551319	18587532	67080606.91	39142207	805000	1938000	17195400	8000000
2047		-2209502	-11000000	-4425000	-17634502.4	50894366.2	18357050	68528868.57	40590469	805000	1938000	17195400	8000000
2048		-2319977	-11000000	-4425000	-17744977.5	171625738	59522650	189370715.9	42092316	805000	1938000	17195400	8000000
						NPV=	32691145						
				IRR=	4.48%								

Table 13: Sensitivity Analysis in different scenarios

Scenario	NPV (2048)	EIRR	BCR
Increase in investment costs by %20	75.455.556 Euro	5.11%	1,109
Decrease in advertisements by %20	60.388.033 Euro	5.07%	1,099
Decrease in Passenger Count by %20	59.216.182 Euro	5,03%	1.097
Increase in Energy Costs by %20	141.285.263 Euro	6.36%	1,227
Increase in Labor Costs by %20	145.312.775 Euro	6,42%	1,235
Ultimate Scenario	32.691.145 Euro	4,48%	1,043
Normal Case	157.436.981 Euro	6.62%	1,259

As can be seen in the table, the project is proven to be profitable in the possible scenarios because in none of them, the IRR goes below 4% (discount rate) and therefore, NPV never became below zero.

6. Conclusions

While choosing the most suitable railway technology for a city, it is wise to consider the topographic structure, socio-economic structure, transportation master plan, current transportation information, travel demand of the citizens and the current transportation capacity of the region, it is known that every transportation mode has their strong property to the other that is why it is impossible to say that there is a superior railway technology as every of them has different uses. In my thesis, I have evaluated the monorail systems in general, and calculated the economic feasibility of Istanbul's Havaray project even though monorail projects are underrated and uncommon in Europe, Istanbul's approach may be a pre-cursor for railway public transportation in Europe. The results for the economic feasibility analysis on Havaray was successful even with the implemented sensitivity analysis.

As a conclusion, in the light of calculations, cumulations of the past knowledge and information taken from the municipality officials themselves we can write the pros and cons of monorail systems in comparison to other railway public transportation modes. The pros of monorail systems accordingly can be written as follows;

- Suitable for intermodality, linking with the already existing transportation infrastructure is easy
- Can be used in steep surfaces without disturbance
- Fast construction process (most of the system elements can be manufactured before construction and assemble in the project area)
- During the construction, low inconvenience to the environment and traffic
- Suitable for variable weather conditions
- Highly autonomous, doesn't disturb the traffic
- They are fast and reliable in punctuality
- Low expropriation costs
- They look modern and gives a good landscape to cities

The cons of monorail systems accordingly can be written as follows;

- More difficult to evacuate passengers in case of emergency in comparison with some modes
- Due to its unpopularity, less information and trust available.
- Switching process is more difficult in comparison with other railway technologies
- They need elevated stations
- Doesn’t look good in old cities

Combining these both aspects, economic feasibility and experiences of people in urban planning field, we could say that Istanbul is a perfect fit for this project due to reasons below.

- Istanbul has a very steep land structure (it is often referred as seven hills).
- Because of Istanbul is located in an earthquake zone, modern architecture is a must for the city, apart from historical peninsula, Istanbul has a very modern architecture which will look good when enhanced with a monorail system.
- Ground water level in Istanbul is very high and this situation makes metro constructions less efficient.
- Sefaköy (one end of the line) is linked with the D-400 motorway which is the motorway that surrounds Istanbul laterally and also a connection point with Metrobus line (Daily ridership 800.000). Basaksehir (the other end) is a newly created residential area and the population of Basaksehir is constantly growing (on average 7% yearly).
- The past public transportation projects in Turkey shows that Turkish people adores the “fancy” public transportation lines and they become quickly interested. A monorail system can make public to decide to less use private cars which would make a significant change in a congested city like Istanbul.
- The monorail system is responsive to sudden increase in travel demand, adding vehicles to the system wouldn’t cause large infrastructural problems.

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