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# Monorail system feasibility study for developing countries: The case study of Eskişehir-Turkey

*Gelişmekte olan ülkeler için monoray sistemi fizibilite çalışması: Eskişehir-Türkiye vaka çalışması*

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# Monorail System Feasibility Study for Developing Countries: The Case Study of Eskişehir-Turkey

## Highlights

- ❖ Investigation of the structural, technological and environmental characteristics of the monorail
- ❖ Economic and financial evaluation in transportation projects
- ❖ Sensitivity analysis for the transportation projects
- ❖ Interpreting transportation projects according to the different discount rates

## Graphical Abstract

The monorail system was examined and compared with other public transportation systems. Economic and financial analyses were performed to investigate monorail applicability in developing countries.

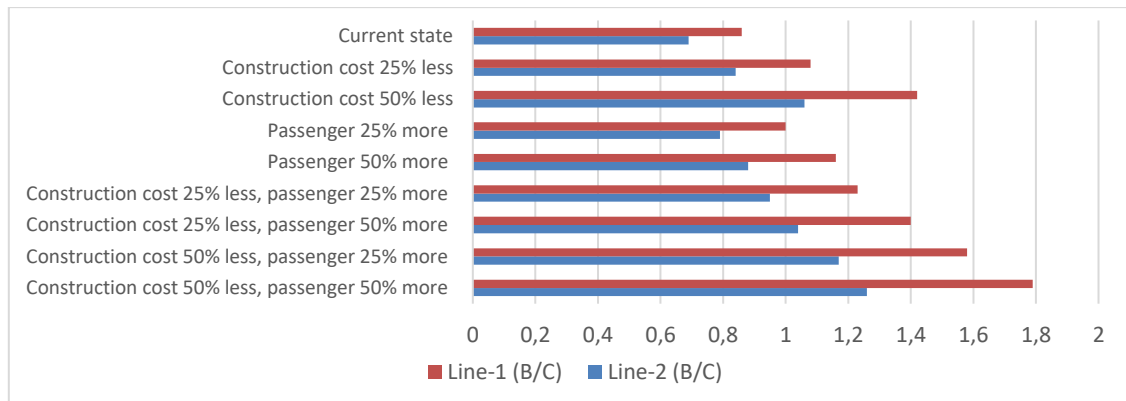


Figure. Benefit-cost ratios of sensitivity analysis for line-1 and line-2

## Aim

The aim is to examine the monorail system technically and investigate its applicability in developing countries.

## Design & Methodology

Evaluation criteria of transportation systems and economic-financial analysis methods of transportation projects were implemented.

## Originality

It is the first detailed study describing the evaluation criteria of public transportation systems and comparing the results obtained on two different routes in the economic-financial evaluation of public transportation projects. It is a guiding study for municipalities, decision-making institutions and other public transportation feasibility studies.

## Findings

The necessary conditions for the implementation of the monorail system and how the public transportation projects should be evaluated in terms of the national economy-operator institution were determined.

## Conclusion

In the economic analysis (from the national economy point), in order to obtain feasible results, it could be sufficient to increase the number of daily passengers to 55 thousand or decrease the construction costs to 15 million \$/km. For financial analysis (from investor point), the construction cost of 10 million \$/km or 67 thousand passengers per day could be sufficient to cover half of the cost.

## Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

# Gelişmekte Olan Ülkeler için Monoray Sistemi Fizibilite Çalışması: Eskişehir-Türkiye Vaka Çalışması

*Araştırma Makalesi / Research Article*

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## ÖZ

Monoray sistemi, 100 yılı aşkın süredir kullanılan çevre dostu, hızlı ve yüksek kapasiteli toplu taşıma sistemlerinden biridir. Monoray sistemi gelişmekte olan ülkelerde tramvay, hafif raylı sistem ve metroya göre daha az tercih edilmektedir. Bu çalışmada, monoray sisteminin geleneksel raylı sistemlere alternatif olma olasılığı teknik ve ekonomik açıdan incelenmiştir. Özelliklerinin 21. yüzyıl teknolojisi ve gereksinimlerine uygun olduğu tespit edilmiştir. Monoray'ın gelişmekte olan ülkelerde uygulanabilirliğinin ekonomik incelemesinde; Eskişehir, seyahat ve maliyet verileri kullanılarak iki ayrı hat üzerinde ekonomik ve finansal fizibilite çalışmaları yapılmıştır. Eskişehir sonuçlarına göre Türkiye dahil %10 güncelleştirme oranına sahip ülkeler için ekonomik analizde günlük yolcu sayısının 55 bine yükselmesi veya inşaat maliyetlerinin 15 milyon \$/km'ye düşmesi yeterli olabilir. Ayrıca güncel verilerle, uygulanabilir olması için yaklaşık %8'lik bir güncelleştirme oranı yeterli olabilir. Mali analiz sonuçlarına göre maliyetlerin çoğu %10'luk bir güncelleştirme oranı ile karşılanamamış ve mali durum desteği gerekebilir. Mali analiz için pozitif bir güncelleştirme oranı uygulanabilir olması için yeterli olmayabilir.

**Anahtar Kelimeler:** Toplu taşıma sistemleri, monoray, ekonomik ve finansal fizibilite, duyarlılık analizi.

## Monorail System Feasibility Study for Developing Countries: The Case Study of Eskişehir-Turkey

### ABSTRACT

The monorail system is one of the environmentally friendly, high-speed and high-capacity public transportation systems that have been used for more than 100 years. The Monorail system is less preferred than the tram, light rail transit and metro in developing countries. In this study, the possibility of the monorail system to be implemented an alternative to the traditional rail systems was examined in technical and economic terms. It has been determined that its features are in accordance with 21st-century technology and requirements. In the economic examination of the applicability of monorail in developing countries; by using the travel and cost data of Eskişehir-Turkey, economic and financial feasibility studies on two separate lines were made. According to the results of Eskişehir, for the countries which have 10% discount rate including Turkey, an increase in the number of daily passengers to 55 thousand or a decrease in construction costs to 15 million \$/km could be sufficient in the economic analysis. Also, with current data, a discount rate of about 8% could be sufficient to be feasible. For financial analysis, the majority of costs could not be covered at a 10% discount rate and financial state support could be required. For financial analysis, a positive discount rate could not be sufficient to be feasible.

**Keywords:** Public transportation systems, monorail, economic and financial feasibility, sensitivity analysis.

### 1. INTRODUCTION

Since the industrial revolution, the rate of urbanization has been increasing every year. While the proportion of people living in the urban areas was 46.69% in 2000, it increased to 55.71% in 2019 [1]. Moreover, the rapid increase in the total population has increased the urban population much faster. With the increasing urban population, the demand for travel has increased, cities have grown in area and mobility by using vehicles has become mandatory for people. The bicycle, which is one of the personal vehicles, does not have its own lane in many countries, affected by long-distance and terrain-weather conditions. The motorcycle is not safe and has a

high mortality rate. These reasons have obligated people to use public transportation or automobile [2].

The lack of proper planning of the public transport systems/network causes people to use automobiles. The increase in the number of automobiles causes traffic congestion and consequently this seriously damages the health of people and the national economy [3]. In the USA, federal and local governments spent \$209 billion in 2007, \$218 billion in 2008 and \$160 billion in 2009 to mitigate the effects of increased traffic congestion [4]. In addition, the increased time spent in traffic and the number of automobiles causes environmental pollution. [5]. Despite efforts to reduce the use of fossil fuels today, it is important to reduce automobile use simply because transportation modes are still dependent on fossil fuels. For example, 28% of the total greenhouse gas emissions

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in the USA originate from transportation [4]. Briefly, the insufficiency of the public transportation systems/network in any region is one of the important factors affecting the quality of life.

Public transportation systems are divided into three categories: rubber-wheel, rail and special system [2]. Rubber-wheeled public transportation systems are the minibus, the bus used in almost all cities and the bus rapid transit system that has increased its popularity in recent years. Rail public transportation systems are tram, light rail transit (LRT) and metro system, which have been used in many cities for many years [2,6]. As a special system, monorail, which is generally speaking, less preferred than other systems, is supposed to take a higher position among other systems as investigated and explained in this research.

The monorail is a public transportation system that generally moves above the ground and uses a single rail where the line is usually made of reinforced concrete. It is a special system that is different from the rubber-wheel and rail systems. It proceeds by wrapping line which has 0.70-0.85 m wide on with rubber-wheels [7]. Since it mostly moves on 9-12 m high columns, it gives passengers the opportunity to watch from different angles [8]. In addition to the public transportation use of the monorail system; it is used in many places such as tourism, amusement park and zoo because of the advantages of visual angle. Monorail moves in two different ways: In straddle type monorail, the vehicles are overlapped on a single line; in the suspended type monorail system, the vehicles move under the line in the manner suspended [9]. The monorail has qualified characteristics for the 21st century because of operating driverless, high capacity, environmental and fast.

The monorail system was invented in 1821 and has examples in many parts of the world [10]. There are ten monorail lines with a total length of approximately 112 km in Japan and an average of 636,816 passengers per day used these lines in 2017 [11]. The longest monorail line which is about 75 km opened in Chongqing-China in 2005 and was used by 751,000 daily passengers in 2015 [12]. The monorail system is proven to be a successful system as the operating period of the Wuppertal Monorail in Germany is more than 100 years [13]. There are also some monorail systems under construction [14]. Examples of the monorail system are mainly found in developed countries such as Japan, China, the USA and Germany [10]; while in developing countries, implementation of the monorail is observed to be rare. For example, there are few monorail lines in Malaysia, India, United Arab Emirates and Brazil [8]. However, there are many examples of the tram, light rail transit and metro in developing countries. Considering the public transportation system in Turkey from developing countries: There are trams in eight cities, LRT in four cities, metro in four cities and all these serve many lines. In addition, there are many lines of tram, LRT and metro currently under construction [15]. Although construction of monorail system was considered in İstanbul, Ankara,

İzmir and Kocaeli cities, it could not go further than the project phase [16].

In this study, the monorail system, which is not preferred in developing countries, was examined and compared with the tram, LRT and metro according to the evaluation criteria. The economic and financial analyses were made according to two lines and different conditions in order to examine the applicability in developing countries. The Passengers and line data, which were taken from the transportation master plan of Eskisehir-Turkey, were used. Benefit-costs and revenue-expenses were calculated for two lines in detail. The necessary conditions for the implementation of the monorail system in developing countries were examined and presented.

## 2. MONORAIL SYSTEM

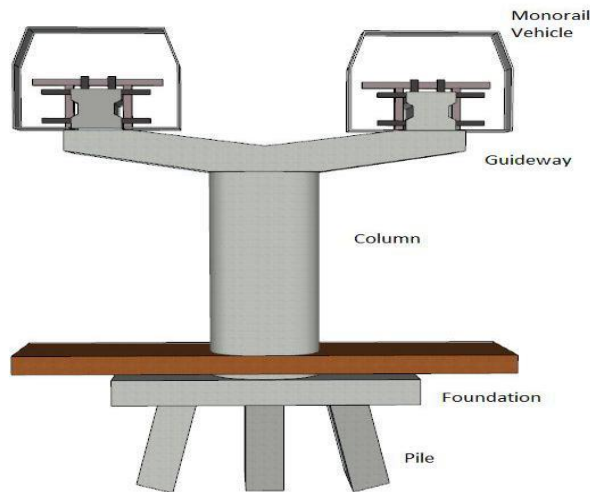
The monorail is defined as "passenger or freight transport vehicles using a single rail". The monorail can be used above ground, level or underground. However, it is mostly used above the ground [17]. Level crossing monorails can not move in mixed traffic due to their line (guideway) and vehicle characteristics [18]. Vehicles move on a line made of reinforced concrete or steel. The line and signaling systems used by the monorail only belong to itself, it does not intersect with other vehicles and pedestrians. Passenger capacities and service levels of monorail systems are as successful as rail systems [19]. Monorail vehicles have rubber-wheels and wrap the line. Having rubber-wheels increases friction. In this way, higher slopes can be climbed compared to rail systems. In addition, high friction provides an advantage in the horizontal curve design of the monorail system. The monorail horizontal curve design is given in Figure 1. While the minimum curve radius in LRT and metro is 250-300 meters, it is 40-60 meters in monorail systems [7,16]. Therefore, the monorail system is easier to design and this reduces the cost. However, high friction increases energy consumption.



Figure 1. Horizontal curve design of monorail [13]

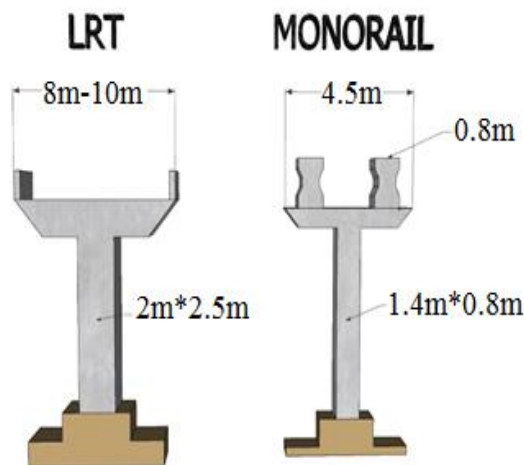
The monorail system consists of structural elements, electronic elements and other elements. Structural elements are shown in Figure 2: It consists of a

foundation, column, guideway and stations. Electronic elements are monorail vehicles, signaling systems and electrical power systems. Other elements are vehicle maintenance and repair facilities, vehicle parking lots, control centers, management and business buildings [2].



**Figure 2.** Structural elements of monorail system

Rail systems can be built on raised structures like monorails. However, a large column area is required for an elevated tram, LRT and metro. Also, a lot of infrastructure changes have to be made for rail systems viaducts to be built. Figure 3 shows examples of LRT and monorail columns. The column area required for monorails is smaller and does not cause infrastructure changes as much as rail systems [13].



**Figure 3.** Light rail system and monorail column examples [20]

Many criteria must be considered in determining the public transportation systems to be used in the city. The priority of these criteria varies according to the technological and financial power of the country [21]. Within the scope of this study, the monorail system was evaluated according to the criteria for determining public transportation systems and compared with other systems.

**2.1. Evaluation in Terms of Safety**

Monorail systems have a 100% protected guideway. Therefore, the risk of collision with other vehicles and pedestrians is eliminated. The number of accidents in the monorail system is quite low. In April 1999, the monorail vehicle derailed due to the material forgotten on the rail of the Wuppertal Monorail and 5 people died [10]. The other accident occurred at Disneyworld in 2009. One person died as a result of a collision with monorail vehicles due to a systematic error at the time Disneyworld was closed [22]. Although fatal accidents in trams are not too many, there are too many accidents because they pass through level crossings. The number of accidents resulting in injury and death in the metro system is quite high compared to the monorail system. Some of the accidents that occurred in recent years are as follows: 9 dead 75 injured in the 2009 Washington accident [23], and 25 dead 135 injured in the 2008 Chatsworth accident, Los Angeles [24].

**2.2. Evaluation in Terms of Economy**

Building monorail systems above the ground are cheaper than tunnel and cut-and-cover systems, and more expensive than level systems. Although the cost of rail systems varies according to the location of the route, the average kilometer costs are given in Table 1.

**Table 1.** Average costs of rail systems per km [25]

Type	Cost /km (\$)
Level Systems	15-30 million
Viaducts Systems	30-75 million
Cut-and-Cover Systems	60-100 million
Tunnel Systems	150-180 million

The investment cost of the monorail is expensive compared to a tram, on a par with LRT and is approximately 30% cheaper per km than a metro system. Table 2 shows the investment costs for metro, LRT and monorail.

**Table 2.** Investment costs of metro, light rail transit and monorail [8,25]

Line	Type	Cost /km (\$)
Caracas, Venezuela	Metro	90 million
Skytrain, Bangkok	Metro	74 million
İzmir	LRT	64 million
Line 3, Manilla	LRT	50 million
Las Vegas	Monorail	61 million
Kuala Lumpur	Monorail	37 million
Mumbai	Monorail	27 million

In terms of operating costs, the wheels of the monorail system are rubbers and the line is reinforced concrete, so energy costs are higher than the rail system. However, its ability to operate without a driver reduces personnel costs. In addition, since the monorail guideway is reinforced concrete, periodic maintenance such as

grinding or lubrication is not performed like steel rails. The rubber-wheels of the monorail vehicle last around 160,000 km [8].

**2.3. Evaluation in Terms of Energy Consumption**

Monorail systems use electrical energy. Therefore, it can be preferred in terms of energy consumption. However, the energy consumption of the monorail system is approximately 25% higher than the rail systems [16].

**2.4. Evaluation in Terms of Capacity**

Capacities vary according to the number of wagons in the set, wagon size and minimum headway. In cities where the demand is high, the monorail can reach a high enough capacity to meet the travel demand even at peak hours. The capacities of public transportation systems are given in Table 3. In hourly passenger capacity per direction, minimum headway is taken as 3 minutes for a bus and 5 minutes for a tram.

**Table 3.** Capacities of public transportation systems [2,6,26]

Type	System	Passenger Capacity (passenger/hour/direction)
Bus	Rubber-wheels	80 – 3000
Tram	Rail	600 – 6000
LRT	Rail	10,000 – 20,000
Metro	Rail	Min 20,000
Monoray	Specialized	Max 45,000

**2.5. Evaluation in Terms of Reliability**

Monorail systems are successful in terms of regularity since they have their own way, allow to increase the trips during peak hours, and also have a passenger information system. Since it usually moves on raised structures, there are no problems such as delay and trip cancellation [27].

**2.6. Evaluation in Terms of Environmental Effects**

Monorail systems are environmentally friendly as they run on electricity. The CO<sub>2</sub> emission values of the vehicles are shown in Table 4. The low number of passengers increases the emission value per passenger.

**Table 4.** CO<sub>2</sub> emission values [11,28]

Type	CO <sub>2</sub> emission (g/passenger-km)
Bus	53
Rail systems	22
Monorail	23.6

Monorail systems are more successful than rail systems in terms of noise pollution because they move at height, the line is reinforced concrete and the vehicle wheels are rubber. While friction of steel rails and steel wheels in rail systems causes noise pollution, the monorail can serve silently even in horizontal curves. While the metro noise level is ~ 90 dBA, the noise level of the Monorail is 75 dBA [15,29].

**2.7. Evaluation in Terms of Operating Speed**

Monorail systems are fast systems due to the fact that they do not stop outside the station, move on a 100% protected guideway. Having high acceleration thanks to the rubber-wheel and can easily reach speeds between 60-90 km/h. Operating speeds of public transportation systems are given in Table 5.

**Table 5.** Operating speeds of metro, monorail, LRT [30]

Type	Operating Speed (km/h)
Metro	25-60
Monorail	25-40
LRT	18-40

**2.8. Evaluation in Terms of Flexibility**

Since monorail systems are mostly used above the ground, the structural elements are built specifically for the line that the monorail can use. LRT, monorail and metro systems are not flexible. Systems that do not have their own way are flexible systems [31].

**2.9. Evaluation in Terms of Comfort**

Rubber-wheeled vehicles generate less vibration than steel-wheels ones [17], so monorail is a comfortable public transportation system. In addition, the monorail systems are high above the ground, giving the passengers the opportunity to view the city from above and provide visually good service to the passengers. The monorail is also used for this purpose in many places.

**3. FEASIBILITY STUDY of MONORAIL in ESKİŞEHİR**

Two different routes were determined for the monorail line planned for Eskişehir. The first of these routes is the SSK-Otogar line which is operated by street trams. This line is called line-1. There are many problems arising from the street tram system on the line. Constructing the monorail system on this line can solve these problems. Gaffar Okkan and Eskişehir Technical University (ESTÜ) İki Eylül campus, which is operated by buses and is in high passenger demand, were determined as the second route. This line is called line-2. Details of the lines are given in Table 6. The monorail was calculated for two different lines, data on the line was taken from the 2035 transport master plan. When evaluating transportation projects, the economic and financial analysis must be calculated.

**Table 6.** Information on routes planned for Eskişehir

	Line-1	Line-2
Line Length (km)	10.5	4
Number of daily passengers in 2021	45,471	24,560
Number of daily passengers in 2045	54,609	60,575

### 3.1. Economic Feasibility Study

The aim of the economic feasibility study is to evaluate the project in terms of the national economy [32]. In the economic feasibility study, the economic benefits and costs of the monorail project were determined. The shadow price coefficient is used to convert financial investment and operating costs into economic costs [2]. The shadow price was accepted as 0.70 [16]. The economic net present value (NPV), benefit/cost ratio (B/C) and internal rate of return (IRR) of the project were calculated by using the costs and benefits in case of implementation and non-implementation of the project within the evaluation period. Benefits and costs were calculated with fixed prices for 2020. It was assumed that at the end of their economic life, bus, tram, and monorail vehicles will have a permanent value of 10% of the purchase price. The evaluation period considered for line-1 and line-2 is 26 years, 1 year for the construction, and 25 years for the operation. The discount rate is 10% [16].

Economic costs of the project: Construction costs, investment costs of monorail vehicles, operating and maintenance costs (O&M). Economic benefits of the project: Reduction in tram/bus investment costs, reduction in tram/bus operating costs, reduction in environmental impact costs, reduction in accident costs, the economic value of travel time gains.

#### 3.1.1. Costs

The costs of the monorail system were calculated using the costs of the monorail projects and the cost percentage distribution. The costs of the monorail line are given in Table 7.

**Table 7.** Costs of monorail planned for Eskişehir [10,16,17,33]

Items of work	Cost
<b>Construction (million \$/km)</b>	20.16
<b>Medium-vehicle (million \$)</b>	1.25
<b>Small-vehicle (million \$)</b>	0.75
<b>O&amp;M (\$/km)</b>	5.7

In the monorail project planned for Eskişehir, it was planned to use a four-vehicle medium monorail set for line-1. The set cost is \$ 5 million and the set capacity is 580 passengers. The vehicle occupancy rate was taken as 73%, which is the average occupancy rate of the tram in Eskişehir [34]. The number of trips and the number of sets to be purchased was calculated according to years.

It is planned to use small monorail vehicles for line-2. The sets consist of 4 wagons, with a total cost of 3 million dollars and capacity is 280 passengers. The O&M cost per km of this monorail system was taken as \$ 5.3. The vehicle occupancy rate was again taken as 73% and calculations were made accordingly. The operating speed of monorail vehicles was taken as 25 km per hour for two lines. Because the city is small and the stations are close to each other, the minimum value of the monorail operating speed was chosen. The speed of the tram is 17 km/h and the bus is 15 km/h.

#### 3.1.2. Benefits

- Reduction in tram/bus vehicle costs: It refers to the decrease in vehicle purchases in the tram or bus in the case of constructing the monorail. The tram set is \$ 2,850,000, the bus is \$ 165,000. The tram capacity is 240 passengers and the bus capacity is 70 passengers. The vehicles to be bought by years were calculated [2].
- Reduction in tram/bus O&M: It refers to the decrease in operating and maintenance costs in the tram or bus in the case of constructing the monorail. Maintenance and operating costs are \$ 4.81/vehicle-km for the tram, \$ 1.68/vehicle-km for the bus [2].
- Reduction in environmental impact costs: In the case of constructing monorail, environmental impacts mean an economic assessment of impacts such as emissions and noise. Environmental impact costs per urban km are calculated as \$ 0.013 for cars and \$ 0.051 for buses [2,32].
- Reduction in accident costs: In the case of monorail construction, it means lower accident costs. \$ 35,020 was taken per million vehicles-km [2,32].
- Economic value of travel time gains: The time difference provided by a monorail system compared to a tram or bus is calculated over the years. As the time value, 3.03 \$/hour/passenger was used [2].

### 3.2. Financial Feasibility Study

The purpose of the financial feasibility study is to evaluate the revenues and expenses of the project in terms of the investor/operating organization [32]. In the financial feasibility study of the monorail line planned to be constructed in Eskişehir, a 26-year evaluation period for two lines was taken as a basis like economic feasibility. Costs considered in the financial evaluation are as follows: Construction costs, investment costs of monorail vehicles, operating and maintenance costs. Project revenues are as follows: Ticket and advertising revenues. Expenses were taken as in the economic feasibility study. Ticket revenue is \$ 0.37/passenger, advertising revenue is \$ 1000 per month [2].

## 4. RESULTS and DISCUSSION

Economic and financial analysis results were calculated according to the above information. In order to evaluate its applicability, sensitivity analyses were calculated by decreasing construction costs and increasing the number of passengers at certain rates.

### 4.1. Economic Feasibility Results

In the case of constructing a monorail instead of the street tram in line-1 and constructing a monorail instead of the bus in line-2 for the current Eskişehir data, the costs are given in Table 8. The costs were converted into net present values for 2020. The length of the line-1 increased the construction costs, vehicle cost and operating costs.

**Table 8.** Costs for economic assessment

Items of work	Line-1 cost (NPV)	Line-2 cost (NPV)
<b>Construction</b>	\$146,222,278	\$55,703,725
<b>Vehicle</b>	\$23,557,081	\$14,134,249
<b>O &amp; M</b>	\$16,343,801	\$9,963,442
<b>Total</b>	\$186,123,160	\$79,801,416

According to economic feasibility results, the profits are given in Table 9 for 2020 NPV. Operating the Line-1 by tram increased the gain in vehicle reduction, and the time gain increased as the line was long. It is seen that the length of the line in the projects to be made, the slowness of the old system and the fastness of the new system are important in terms of time gains. Likewise, it is the parameter that affects the results mostly in other studies [16] and has a share of 73.2% [32]. Operating Line-2 by bus increased the gain in environmental costs. Making electrical systems instead of petroleum-based systems is important for environmental gains.

**Table 9.** Profits for economic assessment

Items of work	Line-1 profit (NPV)	Line-2 profit (NPV)
<b>Reduction in tram/bus vehicle costs</b>	\$47,233,726	\$4,465,688
<b>Reduction in tram/bus operating costs</b>	\$47,632,898	\$18,092,115
<b>Reduction in environmental impact</b>	\$336,395	\$528,991
<b>Reduction in accident costs</b>	\$516,699	\$363,241
<b>Economic value of travel time gains</b>	\$65,120,827	\$31,866,134
<b>Total</b>	\$160,840,545	\$55,316,169

The final results of the two lines were calculated as NPV, B/C and IRR and are given in Table 10. Although Line-1 gives better results, after 26 years of evaluation, it appears to have a negative impact on the country's economy. Especially the loss of \$ 25 million in Line-1 shows how big the losses are of making another system instead of the rail system investments. It is seen that the monorail project is not feasible for these two lines with these costs, benefits and discount rate. According to the IRR results, it can be seen that it can be feasible if the maximum discount rate for line-1 is 7.68% and for line-2 is 5.93%. In the study conducted for Istanbul Monorail, the IRR was calculated as 17.7%, because the number of passengers was approximately 320 thousand and the operating speed was 33.1 km/h [16]. İstanbul and Eskişehir results show how important the number of passengers and travel time gain is for applicability of public transportation projects.

**Table 10.** Final results of two lines for economic feasibility

	Line-1	Line-2
<b>NPV</b>	\$-25,282,615	\$-24,485,247
<b>B/C</b>	0.86	0.69
<b>IRR</b>	7.68%	5.93%

**4.2. Financial Feasibility Results**

In the case of constructing a monorail instead of line-1 street tram and constructing a monorail instead of line-2 bus for the current Eskişehir data, the expenses are given in Table 11. The expenses were converted into net present values for 2020. Since the costs are multiplied by the shadow price in the economic evaluation, the values are higher here, but the distribution and rates of expenses are the same.

**Table 11.** Expenses for financial assessment

Items of work	Line-1 expenses (NPV)	Line-2 expenses (NPV)
<b>Construction</b>	\$209,726,278	\$79,895,725
<b>Vehicle</b>	\$33,830,972	\$20,298,583
<b>O &amp; M</b>	\$23,348,287	\$14,233,489
<b>Total</b>	\$266,905,537	\$114,427,798

According to financial feasibility results, the revenues are given in Table 12 for NPV 2020. Line-1 ticket revenues are higher due to the high number of passengers in the first years. Although the number of passengers for the second line increased significantly towards the last years, the revenue for 2020 NPV is low due to the discount rate is 10%.

**Table 12.** Revenues for financial assessment

Items of work	Line-1 revenues (NPV)	Line-2 revenues (NPV)
<b>Ticket</b>	\$51,920,508	\$42,983,130
<b>Advertisement</b>	\$108,924	\$108,924
<b>Total</b>	\$52,029,433	\$43,092,055

The final results of the two lines were calculated as NPV, B/C and IRR and are given in Table 13. The results are quite bad compared to the economic evaluation. With current data, the monorail system gives better results for line-2, but the loss of \$71 million indicates that this is also not feasible. According to the IRR results, in order to be applicable for financial evaluation, the maximum discount rate for Line-1 has to be -5.24% and -0.33% for line-2. These values show that monorail projects must financially be supported by taking into account the national economy gains in economic evaluation.

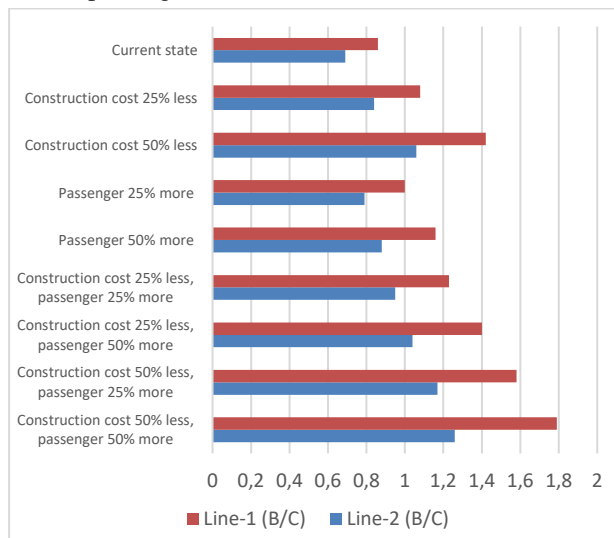


**Table 13.** Final results of two lines for financial feasibility

	Line-1	Line-2
NPV	\$-214,876,105	\$-71,335,743
B/C	0.20	0.38
IRR	-5.24%	-0.33%

**4.3. Sensitivity Analysis**

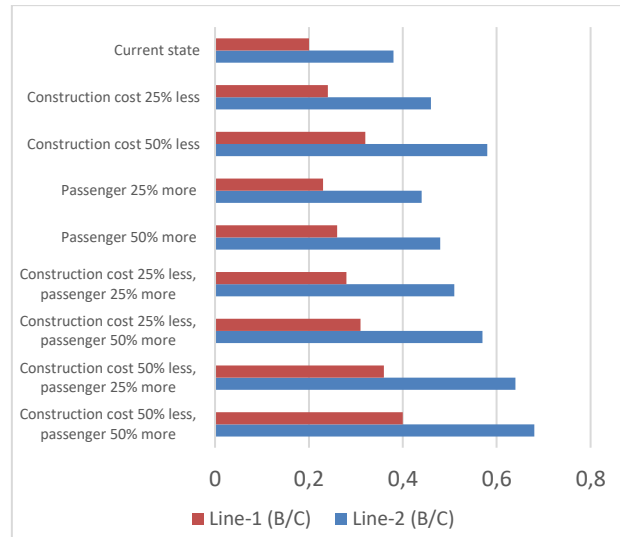
Construction costs constituted the majority of the costs. For the sensitivity analyses, this value was reduced by 25% and 50%. Although it is unlikely that construction costs could decrease by 50%, it may be in regions with low labor costs or infrastructure costs. In addition, this value took into account in order to determine at which km cost can be feasible results. The number of passengers was increased by 25% and 50% as the revenues are almost entirely obtained from the ticket revenues and the benefits depend on the number of passengers. These increases are possible due to the constantly increasing population of Eskişehir and the increase in the number of students at universities along the route. Sensitivity analyses were made for economic and financial evaluations. The results were evaluated according to the benefit-cost ratio. According to the economic sensitivity analysis results in Figure 4, for a discount rate 10% or less, even a 25% reduction in construction costs or a 25% increase in the number of passengers could be feasible for line-1 and could cover the vast majority of costs for line-2. It is seen that the transportation system, which has more advanced technology than the current transportation system, can provide significant benefits to the country's economy if it is made with certain costs or certain passengers.



**Figure 4.** Results of economic sensitivity analysis

According to the financial sensitivity analysis results in Figure 5, 40% of the expenses for line-1 and 68% for line-2 could be covered in case the construction costs are

50% less and the number of passengers is 50% higher. However, the affordability of all costs could not be found within the sensitivity analysis limits. It was not calculated 75% for construction cost because it is almost impossible this reduction. Feasible results could be obtained if construction costs are 50% less and the number of passengers increases by 100% for a discount rate 10% or less.



**Figure 5.** Results of financial sensitivity analysis

**5. CONCLUSION**

In this study, the characteristics of the monorail system were examined in detail and the possibility to be an alternative to traditional rail systems in developing countries was analyzed. As in every public transport system, the monorail system has advantages and disadvantages. Its ability to climb high slopes, easy horizontal curve design, relatively short construction period and allow traffic flow during construction are the advantages of the monorail system. The increase in energy consumption due to high friction and the inability to move in mixed traffic are its disadvantages.

The monorail system was examined economically and financially according to Eskişehir data in developing countries. Calculations were made considering 1 year of construction and 25 years of operation. It was found that the cost of construction for costs and the value of travel time gains for benefits are the most significant parameters to should be considered for public transportation projects, especially for a system having high construction cost.

According to the results of economic analysis, the B/C ratio for line-1 and line-2 was calculated as 0.86 and 0.69, respectively. For Eskişehir, which discount rate is 10%, if one-kilometer construction cost decreases to 15 million dollars or the number of daily passengers increases to 55 thousand, the project could be feasible in accordance with the economic analysis. The fact that the discount rate is around 8% could give feasible results within the existing data. If the discount rate could be 10% or higher,

the costs should be lower or the number of passengers should be higher for economic analysis.

According to the results of the financial analysis, the B/C ratio for line-1 and line-2 was calculated as 0.20 and 0.38, respectively. If the construction kilometer per km cost is 10 million dollars or the daily number of passengers is 67 thousand, the ticket and advertising revenues could cover more than half of the costs. For Eskişehir, because the average ticket price is \$0.37 and the discount rate is 10%, indicating the need for municipal support in this project. In case ticket prices are higher than \$0.37 and the discount rate is lower than 10%, the vast majority of costs could be affordable without any support. Certain government support would be required if the ticket price is less than \$ 0.37 or the discount rate is higher than 10%.

In future studies, the station-operating speed relationship could be investigated in more detail and optimum B/C results could be studied. The results of LRT and monorail systems on the raised structure can be studied for the same route.

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#### DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

#### AUTHORS' CONTRIBUTIONS

**Fatih YILDIZHAN:** Made the calculations, analyzed the results and wrote the manuscript.

**Murat KARACASU:** Made the calculations and analyzed the results.

#### CONFLICT OF INTEREST

There is no conflict of interest in this study.

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