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Economic Analysis of High-Speed Railways: A Holistic Methodological Approach

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Abstract:- The most controversial issue regarding a high-speed railway investment is the huge capital cost, and the main question is whether its benefits will be worth the huge investment costs. High-speed railways have long planning processes and face great risks. Therefore, a holistic approach has been required under conditions of uncertainty. The purpose of this paper is to unify the methods for determining the huge rail investment costs. This paper investigated the economic analysis of high-speed railways as a part of a new silk iron road corridor, in terms of both passenger and freight railway transport between Europe and Asia. In this context, a benefit-cost evaluation of the Ankara-Sivas high-speed railway as a part of the backbone railway line of Turkey's Edirne-Kars high-speed railway corridor has been carried out. A holistic methodological method is presented for evaluating the benefit-cost analysis of both high-speed and freight railways. The economic analysis results show that in cross-continental countries, network effects must be taken into consideration when evaluating the high-speed railway's benefit-cost analysis.

Keywords:- *High-Speed Railway; Benefit-Cost Analysis; Rail Freight; Railway Economics.*

I. INTRODUCTION

Railway networks are the arteries of countries, as with other modes of transportation. Besides being critical infrastructure for cities and countries, they have vital importance for regional economic and social development. Although rail systems are considered to be 30 years in project evaluations, they can continue to be the critical infrastructure of countries for a century [1]. HSR lines maintain improved accessibility between the core cities of countries and offer a more secure, comfortable, faster, intelligent, and environmentally friendly transport mode for people's mobility [2]. HSR can be used concurrently for freight transport between countries and continents [3].

HSR lines are high-tech transport modes that require specialized infrastructure and special trains with installed sub-systems like train control systems, traction power distribution systems, and communication[4].

New lines are intended to operate at speeds of at least 250 km/h while existing conventional lines are considered high-speed railways if they exceed 200 km/h. HSR has been developed for passengers, but some countries also use it for freight transport [5-6].

Although governments have a strong motivation to invest in HSR in terms of the potential positive impacts on society, high-speed rail investment is a crucial decision for governments because HSR investments present technical, financial, economic, and operational challenges, which require an extra large-scale investment budget [7-8]. The assessment of huge projects needs a comprehensive cost-benefit analysis. Quantifying the economic benefits of the projects is limited by the methods currently used [9]. Due to uncertainties, there is a risk that the planned benefits will not be realized in large-scale projects. Analytical methods like the benefit-cost ratio (BCR) provide an understanding of the social benefits and economic costs of investment with a life expectancy of 50 or 100 years [10]. These methods provide analytical tools for determining the intricate social, economic, and environmental criteria that influence and are influenced by railway investments. In addition, the modeling methods provide a way to incorporate analytical rigor and stakeholder input into the state's current transportation planning and rail planning processes.

Different researchers have carried out HSR economic analyses. Decision-making units have used variable evaluation methods, including the benefit-cost analysis (BCA) of HSR lines. The key challenges for HSR investment are cost-effectiveness and economic viability. The main challenges in railway investments are the incompatibility between the planned and realized costs of high-speed rail, as well as the estimated traffic volume and actual traffic volume during operation. A comprehensive assessment of investments in the Europa and Los Angeles-San Francisco high-speed rail lines was conducted [11]. The CBA technique was used for Spain's high-speed railway projects. For a social discount rate of 4%, the social profitability of the Madrid-Sevilla HSR was examined for a 6.5 million passenger volume [12].

General evaluations were made about the regional effects of HSR investments [13]. The CBA of existing or new lines was evaluated. Because infrastructure and operating costs are easily accessible data, evaluations are focused on them rather than on the benefits [14-15]. Another HSR line analysis was done for the Riyad-Hammam HSR corridor through a spreadsheet cost model, and the demand model was determined [16]. The conceptual design in terms of

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qualitative and quantitative aspects was realized by using the Value Engineering (VE) method for the Jakarta-Surabaya HSR project feasibility [17]. Most studies of HSR are focused on individual lines and one function, like passenger traffic. But this paper evaluates the HSR as a part of a network that is named the "new iron silk road" for both passenger and freight transport.

II. ANKARA-SIVAS HSR LINE IN THE CORRIDOR NEW IRON-SILK RAILWAY NETWORK

Turkey is a polycentric country that connects Asia and Europe via the Marmaray undersea railway tunnel and in the "middle corridor", between Beijing and London, called the "new Iron Silk Road," which is a crucial trade network. The 'Edirne-Istanbul-Ankara-Sivas-Kars Railway' linking Europe to China is a part of this corridor [18]. In this context, the Ankara-Sivas (Ank-Siv) HSR line improves both regional accessibility and the trade volume network in the middle corridor [19]. The volume of trade via railway between China and Turkey, including transit cargo, is estimated at 50 million tons of cargo annually by 2025 [20].

Network effects are crucially important in the context of the integration of countries and continents. The location has a crucial role in the transportation of transcontinental routes, such as the 11,483-kilometer new silk iron road between China and Europe [21]. To appraise the investment project, it is required to research the network effects. An estimation of the network effects of the railway project should be presented. Railway freight transport has several main benefits like safety, cost-effectiveness, and speed. Rail freight transport is comparatively faster than shipping, taking between 15 and 18 days, and more cost-effective than air freight. The major challenge is the difficulty of converting them into monetary items with some qualitative effects. The usage of the high-speed network for mixed freight traffic accelerates the development of a high-speed freight network, whereby network effects like future interoperability conditions should be taken into consideration. The main challenge of HSR is economic rather than technological due to the huge infrastructure costs. The cost per passenger is high in corridors with low traffic flow, which makes it financially unfeasible [22]. The justification for investment in HSR depends on the rail network, existing and estimated future traffic demand.

Then a holistic approach has been required under conditions of uncertainty. It has developed a new methodology to calculate and quantify costs and benefits through the BCA model for passenger and freight transportation mixed-use. It applies to the case of the Ankara–Sivas HSR as a part of the silk road railway corridor in Turkey.

III. ECONOMIC ANALYSIS METHOD

Railway planning and construction is a crucial task that takes ten or more years for predictions. Despite the project life being assumed to be 30 years, railways will be used for a century. Accordingly, an evaluation of the railway investment requires a cost-benefit analysis [23].

- *The Components of the HSR Construction Cost can be Divided into the Following Groups:*

- Expropriated price
- Project and engineering cost
- Civil and Station building construction cost
- Train units cost
- Tracks and travers
- Signalization and software costs
- Railway power supply systems (traction substations and catenary systems)

- *The Estimated Cost of HSR(M_o) Construction at (t') the Time of Review is Expressed as in (1).*

$$M_0=\sum_{j=1}^{n} M_j \ldots(\text{USD}) \quad (1)$$

Where

(n) is the number of HSR cost construction components.

HSR review cost value at t' time increases due to both rises in escalation and exchange rate [24].

The relationship between t, t', and T is formulated as in (2). during T(year) of construction.

$$T = t - t' \quad (2)$$

The incurred expenditure M_1 for the first year is stated below in (3).

$$M_1=M_0\left[\alpha_{f_1}\left(1+esc_{f_1}\right)+\alpha_{d_1}\left(1+esc^{*}_{d1}\right)\right] \quad (3)$$

Where

$$\alpha_{f_1}=\frac{\text{the realized expenditure for the first year in Dollar}}{\text{the planned expenditure for the first year}} \quad (4)$$

In (4) and (5) f_1 denotes foreign credits, and d_1 denotes domestic credits respectively.

$$\alpha_{d1}=\frac{\text{the realized expenditure for the first year in TRL}}{\text{the planned expenditure for the first year}} \quad (5)$$

Where

esc_{f_1} is the escalation ratio for the first year in USD [25].

$esc_{d_1}*$ is the value of the escalation ratio for the first year which is converted from TRL to USD as in (6).

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$$esc_{d1}{}^{*}=\left(\frac{esc_{1,TRL}-\Delta P_1}{1+\Delta P_1}\right)\times 100 \quad (6)$$

$esc_{1,TRL}$ is the escalation ratio in TRL for the first year.

$$\Delta P_1=\frac{P_1}{P_0}-1=\frac{P_t}{P_{t-1}}-1 \quad (7)$$

Where

ΔP : change of the ratio in parity in (USD/TRL),

P_1 : the average parity (USD/TRL) for the first year,

P_0 : the average parity (USD/TRL) for the previous year.

Similarly, the expenditure incurred in the second year is expressed as in (8).

$$M_2=M_0\left[\alpha_{f_2}\left(1-esc_{f_1}\right)\left(1+esc_{f_2}\right)+\alpha_{d_2}\left(1+esc_{d1}\right)\right] \quad (8)$$

The total construction cost at the time of the inauguration year (t) of HSR is given in (9).

$$M_{total}=\sum_{t=1}^{T} M_t \quad (9)$$

- *Time Value of Money*

The equity capital, foreign USD credits, and domestic TRL credits can be used together for the construction of HSR. The time value of money (i) to be used in economic analysis in Dollars (USD) is stated as in (10).

$$i=f(w_0,w_1,w_2,i_{USD},i_{TRL},k_{TRL},n_{USD},n_{TRL},tr) \quad (10)$$

Where

(n_{USD}) is loan maturity of USD credit,

(n_{TRL}) is loan maturity of TRL credit,

(tr) is the tax rate.

The minimum acceptable rate of return (MARR) in dollars or WACC (weighted average cost of capital) can be formulated as in (11).

$$i=\frac{w_0\times k^{*}_{TRL}+\left(w_1\times i_{USD}+w_2\times i^{*}_{TRL}\right)(1-tr)}{w_1+w_2+w_3} \quad (11)$$

Where;

$$w_0=\frac{\text{the equity capital amount used for construction of HSR}}{\text{the total investment amount of HSR}} \quad (12)$$

$$w_1=\frac{\text{the USD credit amount used for construction of HSR}}{\text{the total investment amount of HSR}} \quad (13))$$

$$w_2=\frac{\text{TRL credit amount used for construction of HSR}}{\text{The total investment amount of HSR}} \quad (14)$$

Where

k^{*}_{TRL} is the value of the rate of return on equity in TRL converted into USD

i^{*}_{TRL} is the converted value of loan interest rate in TRL to USD.

i_{USD} is loan interest rate in USD.

i_{USD} = SFOR + risk Premium.

SFOR is Secured Financing Overnight Rate (formerly LİBOR, London Interbank Offered Rate)

$$k^{*}_{TRL}=\left(\frac{k_{TRL}-\Delta P}{1+\Delta P}\right)\times 100 \quad (15)$$

$$i^{*}_{TRL}=\left(\frac{i_{TRL}-\Delta P}{1+\Delta P}\right)\times 100 \quad (16)$$

The addition of w_0, w_1, w_2 is always equal to 1.

$$w_0+w_1+w_2=1.00 \quad (17)$$

- *Benefit and Cost Analysis (BCA)*

BCA is a microeconomic approach. It is based on project design criteria and provides a monetary value to all the benefits and costs of the investment during its lifetime. Due to the time value of money, these values are discounted to the present time, which is calculated as the Economic Net Present Value (ENPV) [23].

If the economic life of HSR is N(year) and the time value of money (MARR, WACC) is i during the economic life, the ratio of benefit to cost (B/C) is stated as in (18).

$$\frac{B}{C}=\frac{\text{The discounted value of earnings to date t for N year}}{\text{The discounted value of costs to date t over N years}} \quad (18)$$

- *Discounting Yearly Benefits to Date T*

The economic benefits of HSR are due to improved accessibility, shorter travel times, more comfort, and being environmentally friendly. The main challenge is to gain commercial benefits from HSR services.

The ticket price ($t_p{}^{(j)}$) for the year j is defined by the linear regression model as in (19).

$$t_p^{(j)}=\gamma_0+\gamma_1+P^{(j)}+\gamma_2\times e^{(j)} \quad (19)$$

Where

$(\gamma_{0+}\gamma_{1+}\gamma_2)$ are real coefficients. $P^{(j)}$ is USD/TRL parity for j. year.

$e^{(j)}$ is the domestic inflation rate for year j, and given in (20).

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$$e^{(j)} \approx \frac{e^{(j)}_{UFE} + e^{(j)}_{TUFE}}{2} \quad (20)$$

Where

e_{UFE} : product price index

e_{TUFE} : consumer price index

If the average passenger number during N(year) is represented n_{pass}, the discounted value of annual ticket sales to date t can be formulated as in (21).

$$Benefit_{ticket} = \sum_{j=1}^{N} tp^{(j)} x\, n_{pas} x (1+i)^{-j} \quad (21)$$

The value of salvage value discounted to date t is stated as (22).

$$Benefit_{salvage\ value} = \beta \times M_{total} \times (1+i)^{-N} \quad (22)$$

Where

$\beta x\, M_{total}$ is salvage value and β is stated as below as in (23).

$$\beta = \frac{Salvage\ value}{M_{total}} \quad (23)$$

βis the range of 0.0-0.10. Therefore, benefits can be defined totally as in (24).

$$Benefit = Benefit_{ticket} + Benefit_{\ salvage\ value} \quad (24)$$

- *Reducing Annual Costs to Date T*

The operation costs for the year *j* consist of maintenance, repair, employee, insurance, lighting, climate, heating, and depreciation costs [26]. The operation cost for the year *j* is stated annually and $M_{operation}$, j can be defined with a regression model (empiric relation) as in (25).

$$M_{operation,\ j} = \sigma_0 + \sigma_1 \times P^{(j)} + \sigma_2 \times e^{(j)} \quad (25)$$

Where

σ_0 , σ_1, σ_2 are real coefficients.

$$M_{operation} = \sum_{j=1}^{N} M_{operation,\ j} \quad (26)$$

The discounted value of all annual operating costs to date t can be expressed with the regression equation [27]. The cost of revision that should be made each ρ year, and the value for the year j can be given as in (27).

$$M_{rev} = \tau_0 + \tau_1 \times P^{(j)} + \tau_2 \times e^{(j)} \quad (27)$$

Where τ_0, τ_2, τ_1 are real coefficients. The discounted value to date t of all revision costs over N years is stated as in (28).

$$M_{rev} = M_{rev,\ 1}{}^{x}(1+i)^{-\rho} + M_{rev,2}{}^{x}(1+i)^{-2x\rho} + M_{rev,3}{}^{x}(1+i)^{-3x\rho} + \ldots \quad (28)$$

- *Reducing to Date T of Construction Cost*

The relationship between $Credit_{USD}$ which is received in the year t_1 for HSR construction, and annual uniform repayment credit $_{USD}$ is given as in (29).

$$Credit_{USD} = \frac{Credit_{USD}}{i_{USD}} \left[1 - \frac{1}{(1+i_{USD})^{n_{USD}}}\right] \quad (29)$$

Where

i_{USD} is the credit interest rate and n_{USD} is the loan term.

If credit $_{USD}$ starts from year y not year 1, The right-hand side of the equation must be multiplied by $(1+i)^{-y}$, (y >1). The reduced value of the $Credit_{USD}$ received in the year t to the date of the inauguration of the HSR is given in (30).

$$Credit'_{USD} = Credit_{USD} \times (1+i)^{t-t_1} \quad (t_1 < t) \quad (30))$$

The relationship between Credit $_{TRL}$ received in t_2 year and credit $_{TRL}$ which is annual uniform repayment for it is stated as in (31).

$$Credit_{TRL} = \frac{Credit_{\ TRL}}{i_{TRL}} \left[1 - \frac{1}{(1^{+} i_{TRL})^{n_{TRL}}}\right] \quad (31)$$

Where

($n_{\ TRL}$) is loan maturity of TRL credit and i_{TRL} is TRL credit interest rate.

Value of the loan received in t_2 is discounted to the date t of commissioning of the HSR given as in (32).

$$Credit'_{TRL} = Credit_{TRL} \times (1+i)^{t-t_2} \quad (t_2 < t) \quad (32))$$

The amount of equity used for the construction of the HSR is given in (33).

$$Equity\ capital = M_{total} - (Credit'_{USD} + Credit'_{TRL}) \quad (33))$$

Thus, the B/C related to the date t of commissioning of the HSR is written as follows.

$$\frac{B}{C} = \frac{Benefit_{ticket} + Benefit_{salvage\ value}}{M_{operation} + M_{rev} + Credit'_{USD} + Credit'_{TRL} + equity\ capital} \quad (34)$$

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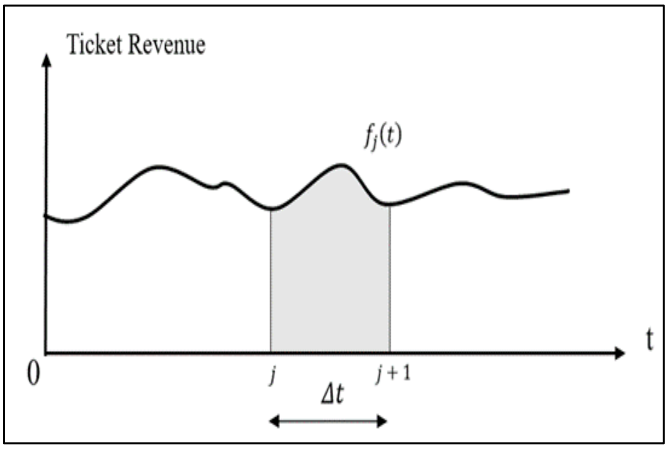

Fig 1 The Dynamic Model for High-Speed Train Ticket Revenues

$$\mathbf{P_j = \int_0^1 f_j(t) e^{-r \times t}\, dt} \tag{35}$$

$$P_0 = P_j \times e^{-r \times j} \tag{36}$$

Where r is the annual nominal interest rate. If the period of Δt time is selected as a month, p_j revenues will be calculated 12 times a year and discounted to t= 0.

For each Δt period, the monthly nominal interest rate is approximately r/12.

➢ *Method for Freight Trains Cost Estimation*

Train services that run through the corridor have to be taken into consideration. Unlike passenger trains, data for freight trains are not available. Therefore, the approach for freight trains is set according to the following data:

- The average number of freight trains per day/week that runs through the corridor
- The number of wagons necessary to operate the program is determined in step one
- The share of the cost of freight trains for the corridor.

The necessary data for freight trains cannot be available; therefore, average values can be used for km/trip. Average values of freight trains can be obtained yearly and daily. The fleet size for the freight trains can be calculated in two-step; time/trip and the number of locomotives. The fleet size can then be calculated as in (37).

$$N_{FL} = 2 \times h_{TL} \times N_p \times \left(1 + \frac{R_{Maintenance}}{100}\right) \tag{37}$$

Where

N_F: Number of locomotives/fleet for the line,

h_{TL}: time/trip in h for locomotive,

N_p: number of trains/direction/hour,

$R_{Maintenance}$: maintenance reserve.

The number of wagons is determined as in (38).

$$N_{Fw} = 2 \times h_{Tw} \times N_p \times \left(1 + \frac{R_{Maintenance}}{100}\right) \tag{38}$$

Where

N_{FW}: number of wagons /fleet for the line,

h_{TW} : time/trip in h for the wagons,

N_p : number of trains/direction/hour,

$R_{Maintenance}$: maintenance reserve

➢ *The Cost Share of Freight and Passenger Trains*

The share of the cost of the trains using the same infrastructure can be determined by the ratio of km used by services (regional, HSR, freight) and the total length of each service as in (39).

$$C_s = \frac{Km_s}{Km_T} \times 100 \tag{39}$$

Where

C_s is the share of the cost for the relevant km,

Km_s is service km

Km_T is the total service km

➢ *Auxillary Costs*

Freight trains operating intercountry have to pay tolls, access costs to infrastructure, and finance charges for the rail system infrastructure. Access costs to the railway infrastructure for the freight trains of different mass groups in different countries are given in [28]. Access costs change from 0.9 Euro/train-km to 13 Euro/train-km for 6000-tonne trains in different countries. Financial charges values are provided per train km incurred by different railway companies. They have payments from 0.9 Euro to 3.0 Euro/train km. The container transit price has been fixed at 0.23 Euro per kilometer for a loaded 40-foot container [29].

IV. CBA OF ANKARA-SIVAS HSR

The upcoming Ank-Siv high-speed railway line will reduce travel time between Ankara and Sivas from 12 hours to just 2 hours and 51 minutes, making it the second-longest HSR line in Turkey. The length of the current railway between Ankara and Sivas has been cut from 603 kilometers to 400 kilometers [28]. The Ank-Siv Project specifications are given in Table 1. [24]. The Ankara–Kırıkkale conventional line has been upgraded for 140 km/h running, and then the new alignment from Kırıkkale to Sivas is suitable for 250 km/h [30]. Ank-Siv HSR CBA is carried out by CBA to deduce the net present value (NPV) of the project depending on the equations given in part 2.

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Table 1 Ank-Siv HSR Project specifications

Terminals	Ank-Siv
Average commercial speed	250 km/h
Boarding time	15 minutes
Route length	406 km
Estimated journey time	2 h and 50 min
Train frequency	24 pairs of train /day
Train capacity	330 passenger /hour/direction
Commencement date	2008
Estimated completion date	2018
Project Timeline	30 years
Construction period	10 years
Operation period	40 years
Passenger traffic	3 Million passengers/per year
Ticket price	27.4 Dollar
Construction costs	2.26 billion Dollar
Pollution reduction	600 ton NOx, 160,000 tons CO2/year
Growth of international collaboration /year	5%

The infrastructure costs of a new HSR are comprised of the building, site acquisition, and external charges. Infrastructure accounts for fifty percent of the project's total cost [30]. High-speed rail infrastructure is extremely costly. On average, the lines cost 25 million euros per km (excluding the more expensive tunnel costs). Infrastructure costs can rise over time depending on the accuracy of estimations. Ankara-Sivas HSR line construction phase is estimated ten years. The anticipated overall cost of infrastructure is $2.260 billion [22].

➢ *Operation Costs*

De Rus defined the operations costs of HSRs to be 67,840.16 $/seat/year and the maintenance cost of 40,742.64 /km/$ year and the rolling stock maintenance cost is 5,432.35 $/seat/year. According to De Rus, the 1000-passenger external cost of HSR is 14.13 dollars/year[31]. According to Ank-Siv specifications given in Table 1, cost values were given in Table 2.

Table 2 Ank-Siv HSR Costs

Costs	Million $ /Year
Operation	559.68
Infrastructure maintenance	16.54
Rolling stock maintenance	44.82
External cost	42,548.962
Total (NPC)	663.56

➢ *Benefits*

In addition to ticket revenue, social benefits include reducing journey time, reducing environmental pollution, increasing reliability, and improving safety [32]. Gines De Rus gave the data about travel time benefit, 17.11$ /passenger/hour[23]. For Ank-Siv travel time decreased from 12 hours to 2.59 hours. Time-saving is 9,153.99 $/per passenger for the Ank-Siv journey time. Pollution reduction in CO_2 and NOx emissions costs an average of 33.95 $/ton and 7,741.10 $/ton, respectively [33]. The value of travel time savings is related to reliability improvement, which is 13.7% of it.

The value of accident reduction and life savings is given at 2.54 million$/per life-saving and 0.45 million $/per serious injury. According to the road traffic accident statistics report, the annual number of accidents outside urban areas is 78,005, the annual number of injured people is 70,803, and the death number is 1488 [34]. The calculated benefit values of Ank-Siv are given in Table 2.

Table 3 Ank-Siv HSR Benefits

Benefits	Million $
Ticket revenue	82.50
Travel time saving	461.97
Pollution reduction	9.896
Reliability improvement	60.017
Safety improvement	35.640
Cumulative present value	650.023

NPV value is calculated as 13.48 million Dollars for passenger analysis. This corridor gives also services to freight trains. Ank-Siv corridor used 33 million tonnes (Mt) of freight trains in 2019. The market share will be increased to 5% in 2023 and increasing 22% in 2053, traffic volume is expected 55 Mt yearly [45]. Freight tariff rates from Lianyungang, China to Turkey, are priced at $5,485.00 /24 tons/axle via the middle corridor. Customs formality fees are 10 euros/wagon for loaded containers, and 5.50 euros/ton. In addition, 20 euros for each wagon will be assessed for crossing the Marmaray [36].

V. CONCLUSION

HSR systems are generally used for passenger transport. However, the acceleration of freight transport has removed the need to use the fast train infrastructure for freight shipments too. In polycentric countries like Turkey, HSR lines may be economically unfeasible and network effects have to be considered. This paper investigated the economic analysis and impacts of a new high-speed railway as part of a new silk iron road corridor between Europe and Asia and attempted to quantify the costs and benefits realized from rail investment.

The proposed holistic methodology has been applied to evaluate the investment and operating costs of freight and passenger transport services using the Ank-Siv HSR as a part of the middle corridor. In this context, Ankara–Sivas HSR has been assessed specifically by using the BCA method. The Ank-Siv HSR line is a trade corridor and has the potential to contribute to regional economic integration. Investing in HSR along the most important corridors can be accepted as a target to foster regional development even with the lower traffic demand. The operation revenues would not be sufficient, but HSR investments may be justified by the macroeconomic benefits and regional developments.

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The approach is based on approximation due to the lack of detailed numbers of freight trains. Therefore, the real situation cannot be represented. However, the approach can be adapted to special cases. Other benefits are not captured in this approach. The method, however, be adapted to the comparison of other functionalities as well. The paper proposes an articulated methodological approach for the estimation of freight and passenger railway investment and operating costs.

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