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Assessing the Impact of Multimodal Transportation on Economic Growth: A Machine Learning and Cointegration Approach in 28 Countries

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Abstract

In this study, the effect of freight and passenger transport in different modes on economic growth is determined for 28 selected countries. The Westerlund cointegration test is used to reveal the long-term relationship between freight and passenger transportation and growth. According to the cointegration analysis, all transportation modes (road, rail, and air) are cointegrated with growth. Additionally, machine learning models were used to predict growth based on each transportation mode for each country for the upcoming four years and to determine the importance of the input parameters. According to the importance of the parameter analysis, for the entire panel, rail transport is the most effective transport mode for economic growth. On a country-by-country basis, the findings differ. Rail transport is the strongest transport mode for growth in high-income countries. However, although it is not the dominant mode, the relative impact of air passenger transport is strong. In upper middle-income countries, there generally is not a dominant mode of transport, but in general, freight transport is important to economic growth. In passenger transportation, air passenger transport is the most prominent mode in these countries. In lower middle-income countries, rail freight is the strongest transport mode for economic growth.

1 Introduction

A developed economic structure requires an effective transportation infrastructure, therefore developments in the transportation sector play a determining role in economic development. Transportation provides countries with a competitive advantage in international trade and affects economic life through many channels. In addition, the impact of the transportation sector on development is not unidirectional, and economic development directly affects the developments in the transportation sector (Nikolaou, and Dimitriou, 2024; OECD, 2004). For example, Zhang and Garaham (2020) discussed this relationship in the context of air transportation with e-supply-chain effects, spillover effects, and feedback effects. The main mechanism in the supply chain effect is that air transportation is a direct component of employment and economic activities. In addition, this sector affects economic growth by affecting related sectors such as hotels, car rental, and tourism. In the spillover effect, air transportation provides locational advantages to metropolitan areas in many ways by reducing distances. In this context, it positively affects indicators such as employment and commercial life, which are determinants of economic growth, with different interactions. In the feedback effect, capital supply and demand channels come to the fore.

Transportation affects a country's economy many channels, for example, transportation reduce trade costs (Zheng D, Kuroda, 2013); decreased costs increase the country's trade volume and FDI Samir ve Mefteh, 2020), and also lead to changes in consumer spending through the savings channel (Weisbrod and Reno, 2009) and offer companies the opportunity to benefit more from economies of scale and innovation (Lakshmanan, 2011). Transportation infrastructure, which directly affects the competitiveness of countries in international markets (Weisbrod and Reno, 2009) increases total productivity (Antle, 1983) and makes a significant contribution to urban development (Aljoufie et al, 2013; Li et al. 2013). It reduces the population pressure in some regions by contributing to the spread of settlements to wider geography (Verhoef, 1997); in some regions, it positively affects employment with job opportunities (Button et al. 1999). And increasing job opportunities directly affect participation in the workforce, which indirectly feeds the relationship between employment and economic growth (Babar, 2024; Shinwari, and Zahid, 2024). So, the sector, which affects the development of different regions with different channels, so plays a direct role in increasing/reducing regional imbalances.

Developments in the transportation sector directly affect the dependent sectors, and also lead to positive externalities on different sectors. For example, the increase in trade also affects the demand for land and plays an important role in the real estate sector (OECD, 2004) In addition, transportation networks increase road safety, and this has a positive effect on health transformation and schooling (Brenneman and Kerf, 2002; Rietveld, 1989). Therefore, it is very difficult to reach the goals of “universal education and health care for all” without providing transportation infrastructure (Pradhan and Bagchi, 2013). On the other hand, improvements in schooling and health cause individuals to be more productive and increase the savings tendency of households (Bajar and Rajeev, 2015). In addition, transportation is one of the mechanisms that can determine smart cities, whose effects on national economies have been frequently emphasized in recent years. (Shinwari, and Ashna, 2024). Considering all these effects, it is clear that well-developed transport infrastructure plays an important role in economic development (Khan et al. 2018).

Considering the effects of transportation on world economies, it is seen that investments made in transportation systems (highways, railways, and canals) in various parts of the world in the 19th century directly affected the development of countries (OECD, 2004). Because a developed transportation infrastructure both increases the mobilization of existing resources and expands the production capacity of countries by affecting the efficiency of these resources. In this framework, transportation infrastructure is directly involved in the production process and mostly functions as a production factor; it also increases the efficiency of existing inputs. For example, a well-designed route allows goods to reach the market in a shorter time and this reduces the transportation cost in the production process. In addition, transportation infrastructure can be a magnet for regional economic growth by attracting resources from other regions with its supportive role to the cluster (Pradhan and Bagchi, 2013).

In order to better understand the effects of inadequate transportation infrastructure on the national economies, the effect of inefficient transportation infrastructure on costs is important in terms of revealing the importance of the sector. Brazil is a good example in this regard. Brazil is a country with large geography with a complex and inefficient transportation system. Problems related to the transport sector in the country form the core of the "Brazil Cost". Brazilian cost, in the most general sense, refers to the increasing operational costs in Brazil. At this point, the weaknesses that may occur in the transportation system cause loss of earnings based on trade and negatively affect the productivity in other sectors (Azzoni and Guilhoto, 2008).

In the USA, transportation costs come second after housing expenditures. Especially the poorest 20% of society spend 40.2% of their net salary on transportation expenses. In this context, developments in the sector will lead to a decrease in fuel consumption and the need for vehicle maintenance due to bad road conditions, and an increase in the accessibility of public transportation systems and all these will allow Americans to spend less money on transportation. Therefore, the decrease in transportation costs means an increase in the welfare of the household in a sense (National Economic Council and the President's Council of Economic Advisers, 2014; Surface Transportation Policy Project, 2003).

Although transportation contributes to the country's economy in many ways, it can also lead to some negative consequences. One of them is related to the costs of financing provided to the sector. In this context, the increase in taxes or an increase in interest rates due to the government's borrowing from the capital market for financing will have a negative impact on consumption or investments. In addition, developments in the sector may lead to negativities such as congestion in transportation, accidents, accident costs, noise, and environmental pollution (Verhoef et al. 1997; Hu and Liu, 2010). Similarly, Transportation has a positive effect on labor force participation, which in turn increases work-associated emissions. In this context, increasing environmental pollution can weaken economic growth through costs, renewable energy, fossil fuel consumption (Hussain, 2024; Aqib and Zaman, 2023; Nazir, 2023;) or increasing environmental pollution can create a burden on the economy by both increasing health expenditures and negatively affecting human health (in terms of productivity) through the health channel (Imran et al. 2023).

In addition, the transportation sector both provides the development of other sectors through positive externalities and directly affects growth. At this point, one of the issues that should be emphasized is which transportation modes affect which sectors and in what direction. Because different modes of transport can affect certain industries with different coefficients. For example, while road transport has a greater impact on the manufacturing and construction industries, investments in ports have a stronger impact on the agricultural sector (Holmgren vd.2017)

One of the issues regarding the effects of transportation, which has been discussed in many ways in the literature, is economic growth. The studies on this subject emphasize different transmission channels. One of them is that the developing transportation networks provide a competitive advantage with the freight transportation channel. In this context, cost advantage provides total profit to producers and total benefit to consumers, affecting social welfare and can affect economic growth both directly and indirectly. In addition, the developed transportation system can also enable regional development. If transportation contributes to the development of other sectors through positive externalities, its impact on growth may be stronger. Another important transmission channel is the benefit it provides to the workforce as a factor of production. An advanced public passenger transport system, which provides more job opportunities to households living in rural areas with limited job opportunities, can positively affect growth through the labor productivity channel. However, transportation infrastructure, which sometimes leads to inefficient use of public resources, is expected to negatively affect economic growth. Again, the burden of transportation on economies through pollution is one of the topics of discussion. In this context, the debate on the impact of transportation on economic growth, which affects socio-economic life in many ways, continues to be an important topic of discussion today.

The structural conditions of countries play a critical role in the transportation growth relationship. Therefore, when working with a country panel group, the fact that the effect of each sub-transportation mode on economic growth may differ may make it difficult to obtain an optimal result. In this context, the question of whether the prominent modes of countries in freight and passenger transportation explain growth as expected forms the basis of the study.

In fact, there are many studies in the literature discussing the relationship between transportation and growth. The relevant literature mostly consists of studies dealing with limited country groups and modes of transport. This study diverges from the existing literature by examining the growth effect of different modes of transport for large groups of countries. In addition, studies examining sub-transportation modes in the context of both freight and passenger transportation are quite limited. Another important contribution of the study to the literature is that, in addition to the general findings, it ranks the economic growth impact of sub-transportation modes on a country basis by using the machine learning method in order of importance. To the best of our knowledge, there is no study investigating the relationship between sub-transportation modes and growth in this context.

In this study, the effect of different transportation modes on growth is determined in selected 28 countries. The plan of the study is as follows: in section 2 following the introduction, the literature is examined, data and models are presented in section 3; the analysis findings are determined in section 4 and then the conclusion is given.

2 Literature

In studies discussing the relationship between transportation and economic growth, the general view is that transportation increases economic growth. In this context, when the literature is examined, it is seen that the focus is mostly on the role of general transportation or that several sub-transportation modes are used. The effects of sub-transportation modes differ in these studies. For example, Park et al. (2019) suggests that maritime transportation is stronger, but Pradhan and Bagchi (2013) emphasize the strong effect of road transport. For the rail transport, Otu and James (2015) suggested that the effect of rail transport on economic growth is negative, but according to Khan et al. (2018) rail freight transport increases economic growth in low- and low-middle-income countries. In addition, Ozer et al. (2021) and Tong and Yu (2018) suggested that rail transport does not affect growth. Park et al. (2019) found that maritime transport is the primary transport mode for growth. For air transportation Arvin et al. (2015), who argue that air transportation, which has a critical role especially in passenger transportation, is a stronger mode of transportation, but Hong et al. (2011) claim that air transportation is weaker. While studies generally emphasize that the effect of air transportation on growth is positive (Ali et al., 2023; Balsalobre-Lorente et al. 2021; Abraham et al., 2015; Mukkala and Tervo (2013), but there are also studies suggesting that this effect is negative (Lean et al. 2014).

Some studies (Khan et al. 2018; Arvin et al., 2015; Beyzatlar et al., 2014) emphasize that the development levels and structural conditions of countries have critical importance in the effect of transportation on economic growth. The basic view emphasized in these studies is that this effect is stronger especially in developing countries. However, Kaya and Aydın (2024) suggested that this effect is weaker in underdeveloped countries due to inadequate infrastructure.

Although there are different emphasis points in the literature on the mechanisms by which transportation affects economic growth, the general view is employment and production (Mukkala and Tervo, 2013), tourism and infrastructure (Ali et al., 2023), foreign direct investment and trade volume (Abraham et al., 2015), cost advantage and dissemination of information (Bozkurt et al. 2017).

In general, the prominent view on the effect of transportation on economic growth is that this effect is positive. Yang et al. (2024) investigated the relationship between transportation and socio-economic development in 31 provincial administrative regions in China. According to the authors, an efficient transportation system not only directly increases economic growth but also makes a positive contribution to the country's economy by improving social welfare and quality of life. Shafique et al. (2021) found that the transportation sector (freight and passenger transport) contributes to economic growth in 10 Asian economies. Bozkurt et al. (2017) revealed that transportation increases growth in some economies in Eurasian countries. According to the study, this effect is determined by the fact that the developments in transportation provide a cost advantage and positively affect the dissemination of information. Arvin et al. (2015) discussed the impact of transportation on growth in G-20 countries. According to the study, passenger transport density increases growth in developing G-20 countries, and this effect is especially stronger in air passenger transport. Lean et al. (2014) argued that transportation in China provides both time and cost savings and that the sector has a positive effect on growth both through these channels and other transmission channels, but the effect of air transportation on growth is negative. According to Hu and Liu (2010) and Zhou et al. (2007), the transportation sector boosts growth in China both directly and through positive externalities.

The development levels of countries can be decisive in the relationship between transportation and economic growth. Because, transportation is seen as one of the important sources of growth, especially in developing countries. For example, Khan et al. (2018) discussed the impact of transportation on per capita income in countries with different levels of development. According to the study, in low- and low-middle-income countries, rail freight transport has a positive effect on per capita income and negatively in upper-middle and high-income countries. Arvin et al. (2015) in their study, in which they examined the effect of transportation on growth in G-20 countries, found that passenger transport density affects growth positively in developing G-20 countries, but there is no statistically significant relationship between the two variables in developed G-20 countries. They based this result on the developed countries on the saturation point of these countries in transportation. The World Bank (2015) suggested that the impact of transportation on China's 2007 growth figures was approximately 6%. According to Easterly and Rebelo (1993), who hold a similar view, the effect of public investments in transportation and communication (T&C) on growth is stronger in developing countries. However, taking the opposite view, Beyzatlar et al. (2014) discussed the relationship between transportation and GDP in 15 EU countries. According to the study, there is a bidirectional relationship between freight transportation and GDP in relatively more developed countries. On the other hand, there is unidirectional causality in some of the relatively low-income countries and there is no causal relationship in some of these countries. Although there are different opinions in the literature, the general trend is that the effect of transportation on growth is stronger in developing countries. However, the efficiency of investments in the transportation sector is as determinative as to the development level of the countries. For example, according to Devarajan et al. (1996), apparently productive expenditures can become unproductive when overused. Therefore, as Banister and Berechman (2001) emphasized, it is important to improve the transportation infrastructure in quality rather than quantity in ensuring economic growth.

Despite the strong positive effect on the effect of general transportation, this effect can be more differentiated in transportation sub-modes. The most frequently discussed of these modes of transport is air transport. According to Raihan et al. (2024), air passenger transport in Malaysia feeds the sectors and creates employment in both the short and long term, thus air passenger transport positively affects GDP. Uçar et al. (2023) investigated the effect of air transportation on economic growth in BRICS-T countries. Accordingly, air freight transportation positively affects economic growth, but air passenger transportation negatively affects economic growth. The occurrence of significant economic crises (1997 Asian; 2008 global financial crisis) and the pandemic (COVID-19) during the sample period may be decisive in the negative relationship between passenger transportation and economic growth. And, Balsalobre-Lorente et al. (2021) found that air transport positively affects economic growth in Spain. There are similar results in studies on causality and cointegration relationships. For example, Kaya and Aydın (2024) examined the relationship between air transportation and economic growth in 91 countries. According to the cointegration test, economic growth affects air transportation in the long run, and according to the causality analysis, air transportation causes economic growth in 11 high-income, 10 middle-income and 2 low-income countries. Lack of infrastructure in underdeveloped regions is effective in these results. Nguyen et al. (2023) investigated the relationship between air freight and passenger transportation and economic growth among regions in Asia. The authors found bidirectional causality in most regions of Asia. In addition, they found a causal relationship from economic growth to air freight transportation in West Asia and Central Asia, and from economic growth to air passenger transportation in South Asia. In the regions where the causal relationship exists, short-term and long-term effect coefficients were also found to be significant. Air transportation is especially prominent in long-distance and light/valuable goods transportation. When the growth elasticity differences between countries are associated with this relationship, the differences in air and economic growth are better understood. Another factor that stands out in these results is that the former Soviet countries have good road/rail networks. In countries such as India, Pakistan and China, domestic air cargo transportation is strong and most commodities are in the group of sensitive goods in terms of income. Therefore, air cargo transportation has a high economic growth elasticity.

Similarly, Ali et al. (2023) examined the relationship between air transportation and economic growth in BRICS countries. The authors found a unidirectional causality from both air passenger transportation and air cargo transportation to economic growth. Because air transportation increases commercial activities, feeds the tourism sector and increases employment, enables the development of infrastructure, and all these play a role in economic growth. Law et al. (2022) found bidirectional causality between air passenger traffic and economic growth in the long run for Cambodia, Laos, Myanmar, and Vietnam (CLMV countries) in Mainland Southeast Asia. And, Hakim and Merkert (2016) found that there is a uni-directional causality relationship from growth to air passenger traffic and air freight volumes in South Asian countries. Abraham et al. (2015) found a unidirectional relationship from air transportation to economic growth in Nigeria. In addition, the effect of air transportation on economic growth is positive. Tourism, foreign direct investment and trade volume are the prominent parameters in this relationship. Mukkala and Tervo (2013) investigated the relationship between air traffic and economic growth using data from 13 countries and 86 regions in Europe. Both air passenger and air freight transport were used as variables. The causality relationship is from regional growth to air traffic. There is causality from air traffic to economic growth in peripheral regions. According to the study, air traffic in peripheral regions can minimize the negative effects caused by long distances. This allows economic activities, especially investments, to be concentrated in these regions and positively affects economic growth through transfer channels such as employment and production.

For road freight transport the transport growth relationship is mostly positive. For example, Suproń and Łącka (2023) studied the relationship between economic growth, CO2, fuel consumption and road freight transport in the Visegrad Group of countries. In Slovakia, there is a long-run relationship between economic growth, road freight transport and CO2 emissions. In Poland, Hungary and the Czech Republic, there is a short-run relationship between growth and road freight transport. Zhu et al. (2021) investigated the relationship between road transport and economic growth in 31 provinces and municipalities in China using causality analysis. They found bidirectional causality between variables in general. There is a unidirectional causality from road transport to growth in Shanghai, Beijing and Heilongjiang, while there is no causality relationship in Tibet.

Railway passenger transport is of critical importance in passenger transport, both developing and developed countries. For example, according to Khan et al. (2018) rail freight transport increases economic growth in low- and low-middle-income countries, but this effect negative for upper-middle and high-income countries. Similarly, Kulshreshtha et al. (2001) found bidirectional causality between economic growth and railway freight transport in India. Ben Jebli (2016) found this results for that railway passenger transport. Author claim that railway passenger transport increases economic growth in Tunisia. However, Ozer et al. (2021) argued that the impact of railway freight transport on growth was insignificant. Similar findings for railway transport were reached by Tong and Yu (2018) for China.

When we look at the studies that highlight the distinction between freight and passengers in transportation, Uçar et al. (2023) found that the effect of air freight transportation on economic growth ise positive but the effect of air passenger transportation is negative in BRICS-T countries. Iqbal et al. (2022) found that air freight transport, technological innovation and foreign direct investment positively affect economic growth in BRICS-MT countries. There is also a one-way causality relationship from air freight transport to economic growth. And Ma et al. (2020) focused on the relationship between freight transportation and economic growth in China. There is a bidirectional causality between GDP and freight turnover in the northeastern economic regions. In the Circum Bohai-Sea, the Pearl River, Middle Part, Southwest, and Northwest regions, there is a unidirectional relationship from freight turnover to economic growth. However, no causality relationship was found between the variables in the Yangtze River economic region.

When looking at the findings of studies focusing on more than one sub-transport, Özer et al. (2021) discussed the impact of maritime and railway container transport on economic growth in Turkey and found that this impact was statistically insignificant for railway freight transport. The reasons for this are that railways are under public monopoly and, as a result, the profit motive is in the background and they are not modernized enough. Ochei, and Mamudu (2020) found that road transport, air transport, postal and courier services increase economic growth in Nigeria. However, this effect is negative for maritime transport and transportation services. The external impact may be decisive in these results. But Park et al. (2019) suggested that maritime transport has a stronger effect on economic growth than land and air transport in OECD countries and some non-OECD countries. The decisive factor here is that large ports play an important role in global trade. In addition, it has been argued in the study that air and land transportation mostly have an insignificant or negative effect on economic growth in developing countries. Otu and James (2015) revealed that there is a positive relationship between road, airway, and maritime growth in Nigeria, but rail transport has a negative effect on growth. According to Hong et al. (2011), maritime and land transport in China positively affects growth and the effect of air transport is weak compared to other modes of transport. Besides, land transportation has a stronger effect on growth, maritime transport increases growth only after a certain investment level threshold is exceeded. According to the study, the fact that road transport in China is at the forefront is decisive in obtaining these findings. One of the studies that revealed similar findings for China belongs to Tong and Yu (2018). According to the study, while rail transport is not effective for growth, road transport increases economic growth. Pradhan and Bagchi (2013) examined the impact of road and rail infrastructure on growth in India. They found that there is a unidirectional causality relationship from rail transport to economic growth and there are bidirectional between road transport and growth. According to the study, one of the prominent reasons for obtaining these findings is that road transport is one of the main inputs of the production process in India.

Mostly panel data analysis has been used in the literature. However, transportation, which is a part of structural and cultural life, affects socio-economic indicators with a different transportation option in each country. The study is important in the context of showing which transportation mode has an effect on economic growth in each country in the sample and in what order. In addition, all transportation modes except maritime transportation were separated as both freight and passenger in the study and ranked in the context of economic growth. In this sense, the study aims to contribute to the literature.

3 Methodologies

In this paper, the relationship between transportation modes and growth was examined. In this context, a cointegration test was conducted to reveal the long-term relationship between freight and passenger transportation with GDP per capita. STATA 14.2 package program was used for Cross-Sectionally Augmented Im-Pesaran-Shin (CIPS) and Cross-section Dependence (CD) testing, and Gauss 6.0 package program was used for Westerlund (Westerlund, 2008) cointegration analysis.

Table 1. Description of variables

Variables	Description	Source
LGDP	GDP Per Capita (Constant 2015 US$)	World Development Indicators (WDI)
LROADG	Freight Transport (million ton-km)	OECD, WDI
LROADPSG	Passenger transport (Road, Million Passenger-kilometers)	OECD, WDI
LRAILG	Railways, goods transported (million ton-km)	OECD, WDI
LRAILPSG	Railways, passengers carried (million passenger-km)	OECD, WDI
LAIRG	Air transport, freight (million ton-km)	World Development Indicators
LAIRPSG	Air transport, passengers carried	World Development Indicators

Note: L indicates that the natural logarithm of the variables is taken.

In Model 1 and Model 2, analysis was made for selected 28 countries by considering the period of 1995-2019. The following models were used to determine the cointegration relationship between the series.

Model 1

$$\mathrm{LGDP}_{it} = \beta_{0it} + \beta_1 \mathrm{LROADG}_{it} + \beta_2 \mathrm{LRAILG}_{it} + \beta_3 \mathrm{LAIRG}_{it} + \varepsilon_{it} \tag{1}$$

Model 2

$$\mathrm{LGDP}_{it} = \beta_{0it} + \beta_1 \mathrm{LROADPSG}_{it} + \beta_2 \mathrm{LRAILPSG}_{it} + \beta_3 \mathrm{LAIRPSG}_{it} + \varepsilon_{it} \tag{2}$$

in the equation, i is the unit (country) index, t is the time index, β_{0it} is constant parameter and $\beta_1, \beta_2, \beta_3$ are slope parameters. LGDP_{it} is represents dependent variable, LROADG_{it}, LRAILG_{it}, LAIRG_{it} are independent variables for Model 1. $\mathrm{LROADPSG}_{it}, \mathrm{LRAILPSG}_{it}, \mathrm{LAIRPSG}_{it}$ are independent variables for Model 2. ε_{it} is error term. GDP per capita is used as a growth indicator.

In order to determine which type of unit root test will be used in this study, first of all, the cross-sectional dependence was tested. If there is a cross-section dependency in the series, unit root tests that take this into account should be used in the analysis. After determining the cross-sectional dependence, unit root test was performed. The unit root test was applied to all variables and the stationarity level of the variables was determined. After determining the stationarity levels, whether there is a long-term relationship between the series for Model 1 and Model 2 was examined by cointegration test. After the cointegration (long-term relationship) was determined, forecasting was generated for the GDP of each country for the upcoming four years with artificial neural network methods. Then, the most effective variables on economic growth were determined for the transportation modes. In essence, by integrating unit root tests, cointegration analysis, and machine learning methods into our research framework, we were able to comprehensively analyze the dynamics of the variables, identify long-term relationships, and develop robust forecasting models to anticipate future economic growth trajectories.

In this study, firstly whether there is a correlation between cross-sections was determined by using the CD test which developed by Pesaran (Pesaran, 2004). This method developed to test cross-sectional dependence, in other words, cross-section correlation, is a simple test that uses ordinary least square (OLS) residuals derived from the Augmented Dickey Fuller (ADF) regression. Each unit represents a country. The equation used to test the cross-sectional dependence for the balanced panel is as follows:

$$\mathrm{CD} = \sqrt{\frac{2\mathrm{T}}{\mathrm{N}(\mathrm{N}-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho_{ij}}\right) \tag{3}$$

In this equation, T represents the time dimension and N represents the country dimension. ρ_{ij}: i represents the correlation coefficient of residual j (between the residual of countries i and j). i and j indicate country indices. In this equation, N is the country dimension and (N)*(N-1) correlations are calculated. The null hypothesis of the CD test shows that there is no cross-section dependence. The probability value is calculated and if the value is less than 0.1, 0.5, 0.01, the basic hypothesis is rejected at 90%, 95%, and 99% confidence levels. This test can be used for small T and large N.

Subsequently CIPS unit root test was used to test the stationarity of the series transport. This test developed by Pesaran (Pesaran, 2007) eliminates cross-section dependence asymptotically. The first differences and cross-sectional averages of the individual series were added as factors to the standard ADF regression. Therefore, in this test, the lagged cross-sectional averages of the ADF regression are used, and the first-order difference of the regression eliminates the correlation between the units. The cross-section extended CADF regression is as follows.

$$\Delta y_{it} = \alpha_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + d_i \Delta\bar{y}_t + e_{it} \tag{4}$$

Here y is dependent variable, i is countries, t is the time variable, e_{it} is error term for country-spesific, α_i, b_i, c_i are fixed effect coefficients. $\bar{y}_t$ is the average of all N observations at time t, calculated by the equation of $\Delta\bar{y}_t = \frac{\sum_{i=1}^{N}\Delta\bar{y}_{it}}{N}$. It is decided whether there is a unit root in the panel by taking the arithmetic average of the CADF values calculated separately for each section. The CIPS statistic is obtained by taking the arithmetic average of the CADF statistics found for each country, as shown in equation 6. Therefore, the developed CIPS test specific to the cross-section is used. The CIPS test can be considered as a cross-section extended version of the IPS test in equation 5 (Das, 2018).

$$\mathrm{CIPS}\ (\mathrm{N},\mathrm{T}) = \mathrm{t}-\mathrm{bar} = \mathrm{N}^{-1}\sum_{i=}^{N}\mathrm{t_i}(\mathrm{N},\mathrm{T}) \tag{5}$$

$$\mathrm{CIPS}\ (\mathrm{N},\mathrm{T}) = \mathrm{N}^{-1}\sum_{i=}^{N}\mathrm{CADF_i} \tag{6}$$

The existence of a long-term relationship between the variables in the set models was examined with the cointegration test developed by Westerlund (2008) which takes into account the cross-sectional dependence. This test allows the series to be stationary of different levels. Westerlund (Westerlund, 2008) Durbin-Hausman test is defined as follows.

$$\mathrm{DH_p} = \widehat{S_n}\left(\tilde{\phi}-\hat{\phi}\right)^2\sum_{i=1}^{n}\sum_{t=2}^{T}\hat{e}_{it-1}^2 \tag{7}$$

$$DH_g = \sum_{i=1}^{n} \widehat{S_i}\left(\widetilde{\phi_i} - \widehat{\phi_i}\right)^2 \sum_{t=2}^{T} \hat{e}_{it-1}^2 \quad (8)$$

DH_pshows the panel statistic while DH_g shows the group mean statistic. i is the countries and T represents the time dimension. $\widehat{\phi_i}$ is show estimated by OLS of ϕ_i in equation of $e_{it} = \phi_i e_{it-1} + v_{it}$, and the $\widehat{\phi}$ is the pooled OLS estimation in equation. $\widehat{e_{it}}$ is error term and consistent estimate of e_{it}. The corresponding individual and pooled instrumental variable (IV) estimators of ϕ_i, denoted $\widetilde{\phi_i}$ and $\widetilde{\phi}$, respectively, are obtained by simply instrumenting $\widehat{e_{it-1}}$ with e_{it}. The null hypothesis and alternative hypothesis for the panel test are as follows [39].

$$H_{0:}\ \phi_i = 1 \quad i = 1, \ldots.\ , n \quad (9)$$

$$H_{1:}\ \phi_i = \phi \text{ and } \phi < 1 \quad i = 1, \ldots \ldots\ , n \quad (10)$$

The null hypothesis states that there is no cointegration and the alternative hypothesis states that there is cointegration. It is assumed that the common values for the autoregressive parameters are the same under the null hypothesis and the alternative hypothesis for this test. Therefore, if the basic hypothesis is rejected, it is decided that there is cointegration for all cross-sections. The main hypothesis and alternative hypothesis for the group mean test are defined as follows (Westerlund, 2008).

$$H_{0:}\ \phi_i = 1 \quad i = 1, \ldots.\ , n \quad (11)$$

$$H_{1:}\ \phi_i < 1 \text{ at least a unit (country)} \quad (12)$$

The autoregressive parameters for the group mean test are not assumed to be the same for cross sections. Therefore, the autoregressive parameters differ between the cross-sections. The null hypothesis for this test is that there is no cointegration relationship. If the basic hypothesis is rejected, it is decided that there is a cointegration relationship for at least one unit (Westerlund, 2008).

After cointegration analysis, machine learning models which are Gaussian process regression (GPR) and artificial neural network are used. GPR model is nonparametric kernel-based probabilistic models. Consider the predictor group x, which consists of d variables. A common machine-learning method's goal is to "learn" the functional connection between the d-dimensional predictor $x \epsilon R^d$ and the target variable y, R symbolizes real space.

$$y=f(x), \quad (13)$$

While f denotes the unknown function, the following linear combination of basic functions provides a discrete approximation of the unknown function f.

$$\hat{f}(x, W) = \sum_{j=1}^{M} W_j \emptyset_j(x) \quad (14)$$

Where $\{\emptyset_j(x)\}_{j=1}^{M}$ is a set of linear or nonlinear basis functions; $W=[W_1,\ldots,W_M]^T$ is the unknown weight vector; and M is the number of basic functions used to approximate f. We have the following model if we assume additive model error.

$$y = \sum_{j=1}^{M} W_j \emptyset_j(x) + \varepsilon, \quad (15)$$

In here $\varepsilon \sim N(0, \sigma^2)$ denotes the error term, the error variance σ^2 and the coefficients β are estimated from the data, the unknown weights W can be calculated using a set of training data that includes N predictor observations, $X = \{x_i\}_{i=1}^{N}$ (i.e., each row of the d-column matrix X represents an observation of x), and co-observed predicted values, $y=[y_1,\ldots,y_N]^T$. Basis function is a broad formula that applies to a variety of linear and nonlinear regression algorithms, including artificial neural network (ANN), and kernel-based methods. The role of the basis function $\emptyset(x)$ in the latter situation can be thought of as a transformation that transforms x from the original input space into a high-dimensional feature space. However, as will be shown later, the actual shape of the basis function is not require (Seeger, 2004). GPR is built on the assumption of Gaussian priors for (transformed) function values, as previously stated (Rasmussen and Williams , 2006). As a result, a GP is totally defined by its second-order statistics.

$$f(x) \sim GP\big(m(x), k(x, x')\big) \tag{16}$$

Where the mean and covariance function of f are $m(x)$ and $k(x, x')$, respectively. Any finite subset of a GP has a joint Gaussian distribution by definition. As a result, if $f = \{\hat{f}(x, W)\}_{i=1}^{N}$ indicates the model outputs for the input dataset X,

$$\hat{f}(x, W) = \sum_{j=1}^{M} W_j \emptyset_j(X_i), \qquad i = 1, \ldots\ldots, N \tag{17}$$

or basically,

$$f = \Phi W \tag{18}$$

the previous distribution of f is then Gaussian.

$$p\big((f|X), \theta\big) \sim \mathcal{N}(0, K) \tag{19}$$

A collection of kernel parameters or hyper parameters, θ is frequently used to parameterize the covariance function $k(x, x')$. To explicitly emphasize the dependence on θ, $k(x, x')$ is frequently written as $k(x, x'|\theta)$. While training the GPR model, this model calculates the basis function coefficients, β the noise variance, σ^2, and the hyperparameters of the kernel function from the data. The basis function, kernel (covariance) function, and parameter initial values can all be specified. Because a GPR model is probabilistic, the prediction intervals can be computed using the trained model (Sun et al, 2014).

Another important machine learning model is ANN which are computational model built on linked units or neurons in a specific architecture. Signals are used by neurons to communicate with one another (Isik et al., 2020; Sahin et al, 2021; Bayraktar et al. 2022; Ozyilmaz et al. 2022). Every neuron executes calculations using training algorithms that have been developed. We use both the extreme learning machine and back propagation learning techniques in this study. The most frequent method for training ANN models is the back propagation learning algorithm. The propagation and updating of weights are the two steps of this approach. The inputs are supplied to the network in the initial phase, and they propagate forward through the network until they reach the last layer. The network's output is compared to the desired output in the last layer, and the error value is calculated. The incorrect value is subsequently propagated backwards through the network, updating all of the neurons' weights. According to Nian et al. (2014), Huang et al. (2006a, 2006b), ELM was created with a single hidden layer for neural networks. Because ELM does not require iterative parameter adjustment, it may calculate outcomes faster than traditional learning methods.

For M random samples (x_i, t_i), where $x_i = [x_{i1}, x_{i2}, \ldots, x_{in}]^T \in R^n$ and $t_i = [t_{i1}, t_{i2}, \ldots, t_{im}]^T \in R^m$, the neural network with N hidden nodes and activation function g(x) with can be described as follows

$$\sum_{i=1}^{N} \beta_j g_j\big(X_j\big) = \sum_{i=1}^{N} \beta_j g(w_i x_j + b_i) \qquad j = 1, \ldots\ldots, N \tag{20}$$

Where $w_i = [w_{i1}, w_{i2}, \ldots, w_{in}]^T$ is the input-to-hidden node weight vector, $\beta_i = [\beta_{i1}, \beta_{i2}, \ldots, \beta_{in}]^T$ is the weight vector between the output and hidden nodes, and β_i is the ith hidden node's threshold.

The importance of the training data by linear regression is determined with the tree ensemble variable method (Ozyilmaz et al. 2022). The mean squared error (MSE) of a tree in the forest is the most commonly used measure in the random forest approach for determining the relevance of a parameter. One of the most useful by-products of the random forest method is the determination of parameter relevance. The parameter significance is calculated by adding the changes in MSE caused by parameter splits and dividing the total by the number of branch nodes. Each parameter in the dataset used to train the random forest tree has one measure of relevance. The mean squared error is calculated as node error and weighted by node probability at each node. The difference between the MSE for the parent node and the total MSE for the two children is used to calculate parameter importance for this split. If surrogate splits are used, the sequence of parameters has no bearing on the determination of parameter relevance. If surrogate splits are not used, however, it is dependent on the order. If surrogate splits are used, parameter significance is assessed before pruning or combining leaves to decrease the random forest tree. Parameter importance is determined before the random forest tree is lowered by clipping or combining leaves if surrogate splits are not used. According to the findings, pruning the tree reduces the parameter importance for non-surrogate split trees but has no effect on parameter importance for surrogate split trees. As a parameter relevance indicator, Gini significance was used. This parameter importance measure assigns a ranking to the following parameters: The Gini impurity measure is used to find the ideal number of splits at each node within the binary trees of the random forest. It's calculated using the formula in Eq (21).

$$\mathrm{GI} = 1 - \sum_{\mathrm{i}} \mathrm{p}^2(\mathrm{i}) \tag{21}$$

In here *p(i)* denotes the observed fraction of classes that reach the node. The Gini index is a measure of impurity in nodes.

$$\Delta_{\mathrm{i}} = \mathrm{GI} - \mathrm{p(L)p(R)} \left(\sum_{\mathrm{i}} |\mathrm{L(i)} - \mathrm{R(i)}| \right)^2 \tag{22}$$

In the equation p(L) and p(R) are the left and right split fractions of observations, respectively. The reduction in Gini impurity as a result of this optimal split is recorded and accumulated for all nodes in all trees in the forest. When compared to other variables, a variable with a higher significance score implies that the variable is more significant for categorization.

4 Analysis Results and Discussion

The CD test which is developed by Pesaran (2004) was used to determine the cross-sectional dependence between units. This test gives good results in case of N>T. When CD test results are examined, it is seen that there is a correlation between units in all variables. Therefore, the CIPS unit root test was used. This test was developed by Pesaran (2007) and takes into account cross-section dependence. The results of the CD test and CIPS unit root test are shown in Table 2.

Table 2. CD Test, CIPS unit root test and westerlund cointegration test results

	CIPS Unit Root Test			
Variables	Cons	Cons+Trend	1st Diff.	CD Test
LGDP	-2.887***	-3.156***	-2.970***	85.11***
LROADG	-2.825***	-2.579*	-4.145***	42.65***
LROADPSG	-2.360***	-2.617*	-4.339***	29.37***
LRAILG	-2.075*	-2.230	-3.744***	9.93***
LRAILPSG	-1.274	-1.804	-3.977***	6.60***
LAIRG	-1.651	-2.169	-4.795***	8.14***
LAIRPSG	-2.271**	-2.594*	-4.558***	61.26***
	Westerlund Conintegration Test			
	Dh_g	Dh_p		
Model 1	5.699***	1.210		
Model 2	4.615***	8.105***		

*** and ** indicate the rejection of the null hypothesis at the 1% and 5% levels, respectively.

According to CD test results, there is cross-section dependency in all variables. Therefore, the CIPS unit root test, which takes into account the cross-sectional dependence, was used to test the stationarity of the variables. According to the CIPS unit root test results, LRAILPSG and LAIRG variables were found I(1) series, while LROADG, LROADPSG, LRAILG, LAIRPSG variables were found stationary at the level. Westerlund (2008) cointegration test was preferred in the cointegration analysis since these series are stationary in different levels. The cointegration analyzes of the defined models (Model 1 and Model 2) test results are presented in Table 2. According to the Westerlund cointegration test results, it is seen that there is a cointegration relationship for panel and group averages in Model 2, whereas in Model 1, there is only a cointegration relationship for the group. Westerlund test results show that all variables have a long-run relationship with economic growth.

After determining the cointegration relationship between modes of transport and growth, the coefficients were estimated using the linear regression method to determine the effect of transportation modes on economic growth. According to the model to determine the importance of parameters, the growth of the given countries are predicted by using transportation modes as an input. With the help of R^2 Score and Root Mean Square Error (RMSE), the model's performance was evaluated. The primary performance measures employed in performance assessments of regression models are those mentioned above. The statistical indicator R^2 indicates how closely the data resemble the fitted regression line. RMSE, and R^2 values of used models are given in Table 3. Both models are given satisfactory results. The general structure of the proposed system is given in Figure 1.

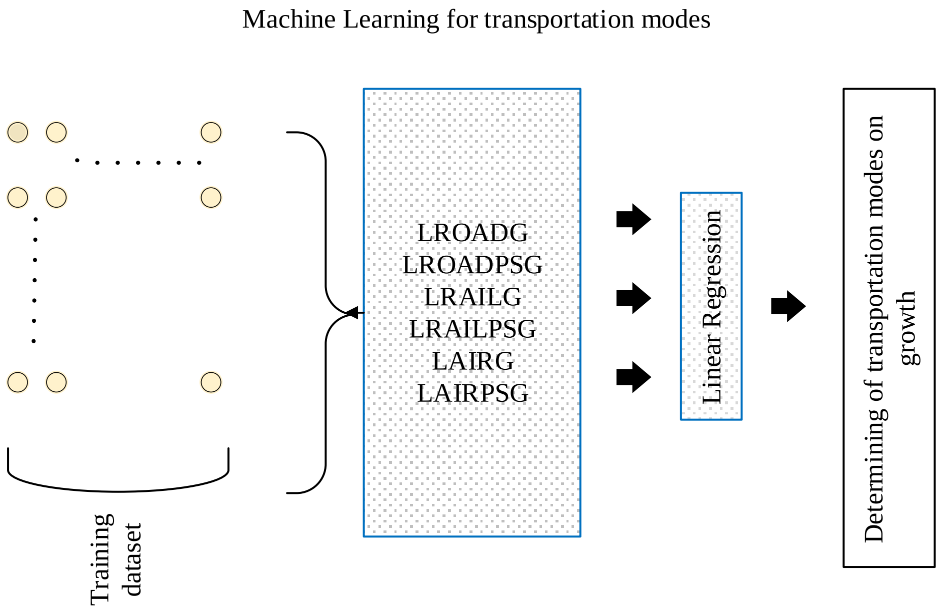

Figure 1. The general structure of the system

Table 3. RMSE, R2 and MSE values of used models

RMSE	R^2	Model
0.059984	0.997	Gaussian Process Regression
0.060	0.998	Artificial neural network

The dataset was divided into training (80%) and testing (20%) subsets to ensure the models were trained and evaluated on independent data. Additionally, k-fold cross-validation (k=5) was employed to validate the model's performance and minimize the risk of overfitting. The high R^2 values reflect the strong predictive power of the models for the given dataset. These values, coupled with low RMSE values indicate that the models effectively capture the relationship between transportation modes and economic growth, with minimal residual errors. To address the risk of overfitting, regularization techniques were applied in the ANN model. These methods reduce the likelihood of the model memorizing noise in the training data. Furthermore, the Gaussian Process Regression model's hyperparameters were optimized to balance complexity and accuracy (James et al. 2013; Huang et al. 2024; Alam et al. 2024: Tariq et al. 2024: Tanweer et al. 2023). All the transportation mode variables are used as inputs and LGDP is used as output for the both models. Therefore the variable number shown on the x-axis of the figures showed all the input data used in the analysis, while the y-axis showed the output LGDP as shown in Figure. 2,_both axis are unitless. Since the data for each country has values close to each other, and different from the other country, and therefore, although it seem like a scattered shape, each cluster actually represents a country. The most important point is that true and predicted values gave almost the same result with a very small error rate. According to both models, all data are predicted with a small residual with a value of about ± 0.2. All of the predicted results and their errors are also shown in the red line. All the predicted and real data had almost the same value shown below the figures.

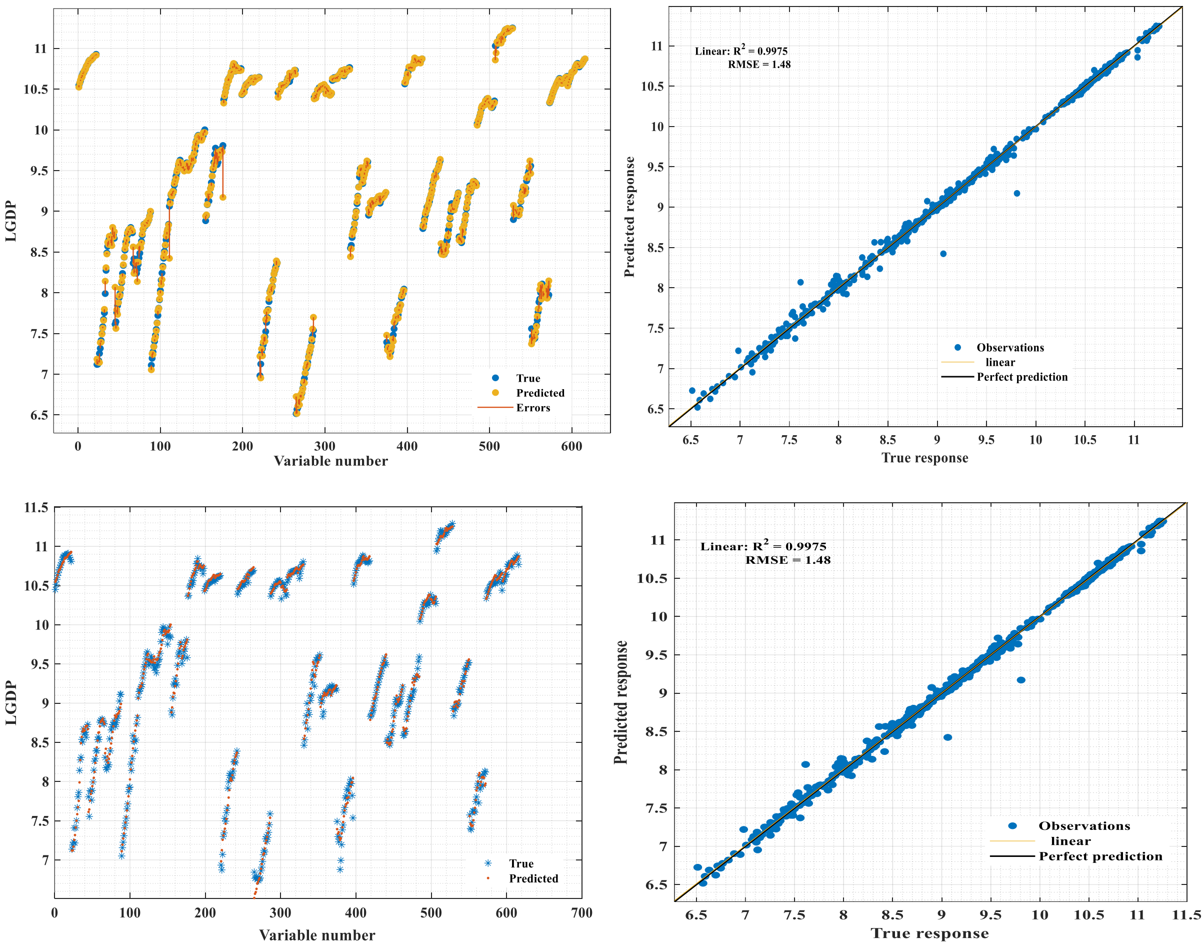

Figure 2. *LGDP values of the predicted and real data and their predicted response variations by using (a) Gaussian Process Regression and (b) Artificial neural network.*

In many applications, determining parameter relevance is a significant difficulty in interpreting data and comprehending the underlying phenomena. The importance of each input parameter is depicted in Table 5. The information covers variables that predict a country's growth in terms of transportation options. All of the variables are categorical. It's a vector of parameter significance values that's 1-by-6. Greater values indicate parameters that have a greater influence on predictions. The LRAILPSG is the most critical parameter in the experiments, followed by the LRAILG. When the literature on growth factors is evaluated, it is discovered that the majority of them likewise impact the LRAILPSG and LRAILG. It is known that especially developed countries have developed transportation railway networks.

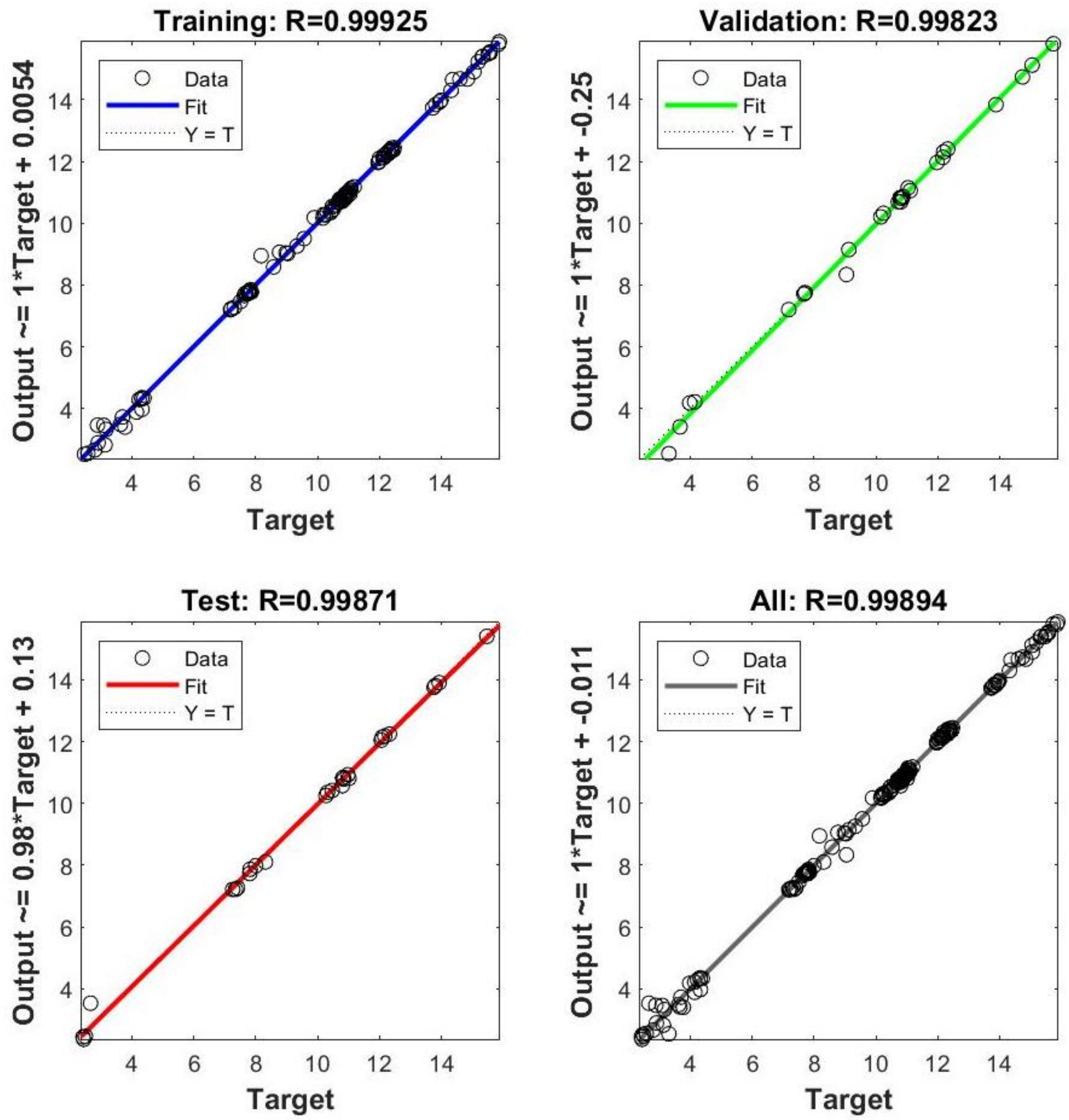

Figure 3. The performance results for the forecasting.

To illustrate the efficacy of our forecasting methodology, Figure 3 shows training and validation results. The training results depicts the performance of the ANN model during the training phase, showcasing the convergence of the model's predictions with the actual GDP values over the historical data period. This graph provides insights into the model's learning process and its ability to capture the underlying patterns in the data. Additionally, the validation results graph demonstrates the performance of the ANN model on unseen data, validating its predictive accuracy and generalization capabilities. Furthermore, to provide a comprehensive overview of the forecasting results, Table 4 shows the predicted GDP values for each forecasted year. The presented results highlight the varying impacts of different transportation modes on the GDP of various countries, categorized by income levels and regions. Using an artificial neural network model, GDP forecasts were generated for the years 2020 to 2023, with separate analyses for road freight (LRoad), rail freight (LRail), and air freight (LAir). In high-income countries, air freight generally shows a stronger correlation with economic growth, potentially due to the higher value and efficiency associated with air transportation. For upper-middle-income countries, air freight also frequently emerges as the most significant predictor of GDP growth, reflecting its role in facilitating international trade and high-value goods transport. Lower-middle-income countries present a more varied picture, suggesting that the impact of transportation modes on economic growth is influenced by a range of factors, including infrastructure development and economic policies.

Table 4. Forecasting results of LGDP according to the each transportation mode for each country

Country	Region	Income	Year	LGDP-LRoad	LGDP-LRail	LGDP-LAir
Australia	Non-AB	High-Income	2020	10.9942	10.99504	11.03869
			2021	11.00421	11.00495	11.05465
			2022	11.01422	11.01485	11.07061
			2023	11.02423	11.02475	11.08657
Czech Republic	AB	High-Income	2020	9.896961	9.906043	9.937936
			2021	9.915643	9.925797	9.962343
			2022	9.934325	9.945552	9.98675
			2023	9.953007	9.965307	10.01116
Estonia	AB	High-Income	2020	9.874929	9.949469	10.02604
			2021	9.892985	9.983807	10.06558
			2022	9.911042	10.01815	10.10513
			2023	9.929098	10.05248	10.14468
Finland	AB	High-Income	2020	10.70202	10.72638	10.80186
			2021	10.70254	10.73237	10.81637
			2022	10.70306	10.73835	10.83088
			2023	10.70358	10.74434	10.84539
France	AB	High-Income	2020	10.54792	10.5635	10.57695
			2021	10.5532	10.57221	10.58602
			2022	10.55848	10.58091	10.5951
			2023	10.56377	10.58961	10.60418
Germany	AB	High-Income	2020	10.69219	10.69307	10.69218
			2021	10.70513	10.7063	10.70539
			2022	10.71808	10.71952	10.71859
			2023	10.73103	10.73274	10.7318
Italy	AB	High-Income	2020	10.31781	10.3421	10.36702
			2021	10.31152	10.34114	10.36726
			2022	10.30523	10.34017	10.3675
			2023	10.29893	10.33921	10.36774

Japan	Non-AB	High-Income	2020	10.51543	10.51091	10.49254
			2021	10.52701	10.52151	10.49947
			2022	10.53858	10.53211	10.50639
			2023	10.55016	10.54271	10.51331
Latvia	AB	High-Income	2020	9.690054	9.733817	9.820775
			2021	9.719763	9.775342	9.868468
			2022	9.749471	9.816866	9.916162
			2023	9.77918	9.858391	9.963856
Netherlands	AB	High-Income	2020	10.76452	10.76943	10.81077
			2021	10.77017	10.77615	10.82287
			2022	10.77583	10.78286	10.83497
			2023	10.78148	10.78958	10.84707
Spain	AB	High-Income	2020	10.23921	10.23921	10.24847
			2021	10.2526	10.2526	10.25825
			2022	10.26599	10.26599	10.26803
			2023	10.27937	10.27937	10.27781
Switzerland	AB	High-Income	2020	11.38758	11.3808	11.40023
			2021	11.39656	11.389	11.41084
			2022	11.40555	11.3972	11.42145
			2023	11.41453	11.40541	11.43206
United Kingdom	Non-AB	High-Income	2020	10.75022	10.78449	10.78955
			2021	10.75685	10.79853	10.80128
			2022	10.76347	10.81257	10.81301
			2023	10.77009	10.82661	10.82474
United States	Non-AB	High-Income	2020	10.99867	11.02141	11.02232
			2021	11.0086	11.03642	11.03521
			2022	11.01852	11.05142	11.0481
			2023	11.02845	11.06642	11.06099
Azerbaijan	Non-AB	Upper-Middle	2020	8.869309	8.585067	9.052142
			2021	8.924361	8.586239	9.133307
			2022	8.979412	8.587411	9.214473
			2023	9.034463	8.588583	9.295638
Belarus	Non-AB	Upper-Middle	2020	8.942318	8.78614	9.01809
			2021	8.987521	8.804265	9.073124
			2022	9.032725	8.82239	9.128158
			2023	9.077928	8.840514	9.183193
Bulgaria	AB	Upper-Middle	2020	9.061188	9.016816	9.072853
			2021	9.094566	9.043474	9.108648
			2022	9.127943	9.070132	9.144444
			2023	9.161321	9.09679	9.18024
China	Non-AB	Upper-Middle	2020	9.394647	9.344566	9.403914
			2021	9.476855	9.418059	9.487581
			2022	9.559064	9.491552	9.571248

			2023	9.641272	9.565045	9.654915
Croatia	AB	High-Income	2020	9.539687	9.526564	9.591831
			2021	9.555881	9.543498	9.614588
			2022	9.572075	9.560431	9.637344
			2023	9.588268	9.577365	9.660101
Georgia	Non-AB	Upper-Middle	2020	8.558241	8.51963	8.630311
			2021	8.610305	8.564954	8.692311
			2022	8.66237	8.610277	8.75431
			2023	8.714434	8.6556	8.81631
India	Non-AB	Lower-Middle	2020	7.633988	7.650362	7.608079
			2021	7.686227	7.706717	7.657039
			2022	7.738467	7.763072	7.705999
			2023	7.790706	7.819427	7.754959
Mexico	Non-AB	Upper-Middle	2020	9.222966	9.224981	9.227202
			2021	9.231728	9.234111	9.236266
			2022	9.24049	9.243241	9.245331
			2023	9.249252	9.252372	9.254395
Moldova	Non-AB	Upper-Middle	2020	8.148669	8.160721	8.141052
			2021	8.188719	8.203228	8.181431
			2022	8.228768	8.245734	8.22181
			2023	8.268818	8.288241	8.262189
Poland	AB	High-Income	2020	9.646527	9.625599	9.65292
			2021	9.684852	9.660209	9.691964
			2022	9.723177	9.694819	9.731009
			2023	9.761502	9.729429	9.770054
Romania	AB	Upper-Middle	2020	9.317578	9.294081	9.349808
			2021	9.352545	9.324691	9.39048
			2022	9.387511	9.355302	9.431153
			2023	9.422478	9.385912	9.471825
Russia	Non-AB	Upper-Middle	2020	9.272403	9.205181	9.371466
			2021	9.294854	9.215471	9.408041
			2022	9.317304	9.225761	9.444616
			2023	9.339755	9.23605	9.481191
Turkey	Non-AB	Upper-Middle	2020	9.464578	9.449112	9.423447
			2021	9.502855	9.484547	9.456059
			2022	9.541132	9.519981	9.488672
			2023	9.579408	9.555416	9.521284
Ukraine	Non-AB	Lower-Middle	2020	7.71813	7.741079	7.937497
			2021	7.711383	7.741003	7.964566
			2022	7.704635	7.740926	7.991636
			2023	7.697887	7.740849	8.018705

The importance of each input parameter is presented for each country. The higher value is depicted the higher parameter importance in the table. Negative variable importance means that the error estimate was higher and this would imply that utilizing the permuted values resulted in a lower error estimate (e.g., RMSE) than using the original values of the predictor variable. Randomly permuting the values of a variable that was barely predictive of the outcome but was still chosen for some splits may cause some observations to follow a path in the tree that turns out to produce a more accurate predicted value than the path and predicted value that would have been obtained with the variable's original ordering. The model was analyzed for each country individually to see the impact of each country's transportation modes on growth. When the effect of transportation modes on growth is analyzed separately for each country, it is seen that railway transportation is the most important mode for 15 countries in general. And also, road passenger transportation mode was not the most important parameter for any of the studied 28 countries. It is seen that road passenger transport does not contribute to the LGDP of these countries used in the analysis. The estimation performances of each countries of the developed models were calculated using RMSE, and the R^2 scores and the results were 0.008226 and 1, respectively for the country based analysis.

Table 5. Forecasting results of LGDP according to the each transportation mode for each country

Country	Region	Income	LROADG	LROADPSG	LRAILG	LRAILPSG	LAIRG	LAIRPSG	Result
Panel	-	-	1.337	0.939	2.553	1.148	1.108	0.710	LRAILG
Australia	Non-AB	High-Income	0,097	0,000	0,598	0,218	0,082	0,063	LRAILG
Croatia	AB	High-Income	0,221	0,000	0,225	0,068	0,612	-0,056	LRAILG
Czech Republic	AB	High-Income	0,0461	0,000	0,315	0,044	0,174	0,083	LRAILG
Estonia	AB	High-Income	-0,089	0,000	0,496	0,427	-0,044	0,097	LRAILG
Finland	AB	High-Income	0,066	0,000	0,599	0,033	0,148	0,135	LAIRG
France	AB	High-Income	0,148	0,000	0,414	0,048	0,060	0,193	LRAILG
Germany	AB	High-Income	0.018	0.000	0.854	0.159	0.060	0.501	LRAILG
Italy	AB	High-Income	0.148	0.000	0.213	0.044	0.076	-0.063	LAIRG
Japan	Non-AB	High-Income	0.270	0.000	-0.056	0.120	-0.037	0.370	LAIRPSG
Latvia	AB	High-Income	0.587	0.000	0.136	0.109	-0.018	0.016	LROADG
Netherlands	AB	High-Income	0.046	0.000	0.398	0.054	-0.045	0.189	LRAILG
Poland	AB	High-Income	0.179	0.000	0.398	0.045	0.081	0.195	LRAILG
Spain	AB	High-Income	0.041	0.000	0.435	0.166	-0.060	0.270	LRAILG
Switzerland	AB	High-Income	0.061	0.000	0.153	0.107	0.076	0.531	LAIRPSG
UK	Non-AB	High-Income	0.291	0.000	0.321	0.085	-0.010	0.284	LROADG
US	Non-AB	High-Income	0.222	0.000	0.303	0.045	0.109	0.565	LAIRPSG
Azerbaijan	Non-AB	Upper-Middle	0.349	0.000	0.215	0.130	0.087	0.177	LROADG
Belarus	Non-AB	Upper-Middle	0.092	0.000	0.283	0.200	0.160	0.761	LAIRPSG

Bulgaria	AB	Upper-Middle	0.379	0.000	0.374	0.000	0.057	0.006	LROADG
China	Non-AB	Upper-Middle	0.616	0.000	0.383	0.045	0.111	0.006	LROADG
Georgia	Non-AB	Upper-Middle	0.147	0.000	0.772	0.143	-0.045	0.252	LAIRPSG
Mexico	Non-AB	Upper-Middle	0.567	0.000	0.296	0.000	0.144	0.355	LROADG
Moldova	Non-AB	Upper-Middle	0.296	0.000	0.845	0.084	0.087	0.303	LRAILG
Romania	AB	Upper-Middle	0,045	0,000	0,380	0,178	-0,069	0,091	LRAILG
Russia	Non-AB	Upper-Middle	0,102	0,000	0,377	0,000	0,131	0,190	LRAILG
Turkey	Non-AB	Upper-Middle	0.405	0.000	0.289	0.000	0.079	0.139	LROADG
India	Non-AB	Lower-Middle	0,172	0,000	0,336	0,166	0,196	0,264	LRAILG
Ukraine	Non-AB	Lower-Middle	0.139	0.000	0.185	0.005	-0.053	0.076	LRAILG

According to analysis findings, road freight transport is the most powerful mode of transport on growth in Latvia, UK, Azerbaijan, Turkey, China and Mexico. Road passenger transport is the second most effective mode of transport on growth in the all of the countries. Rail freight transport affects growth the most in Germany, Japan, Poland, Spain, Romania, Australia, Russia, Estonia, India and France. Air freight transport is the most powerful mode of transportation growth only in Finland and then Italy. The strongest mode of growth among the analyzed countries is rail freight transportation. This mode is the most powerful mode of transportation on the growth both country based and the general analysis. The second most important mode is road freight transport. The third most important mode in general analysis is rail passenger transport. Air freight transport is the weakest mode of transport on growth in Estonia, Japan, Netherlands, Latvia, and Georgia. Rail passenger transport is the weak mode of transport on growth in Turkey, Mexico, Bulgaria, and Russia. Air freight transport is the weakest mode of transport on growth in Estonia, Italy, Japan, Ukraine and Georgia. Air passenger transport is the weakest on growth in Croatia, and Italy.

On the other hand, road freight transport affects the growth with the highest coefficient in China. Road passenger transport has no impact on growth in any country. Railway freight transport affects growth the most in Germany, Rail passenger transport has the highest impact on growth Estonia. Air freight transport affects Croatia's economic growth the most. The country in which air passenger transport affected the growth with the highest coefficient is Belarus. The prominent countries in each mode of transport are summarized below in the Figure 4, the road passenger mode has no effect on the growth therefore it not shown in the figure.

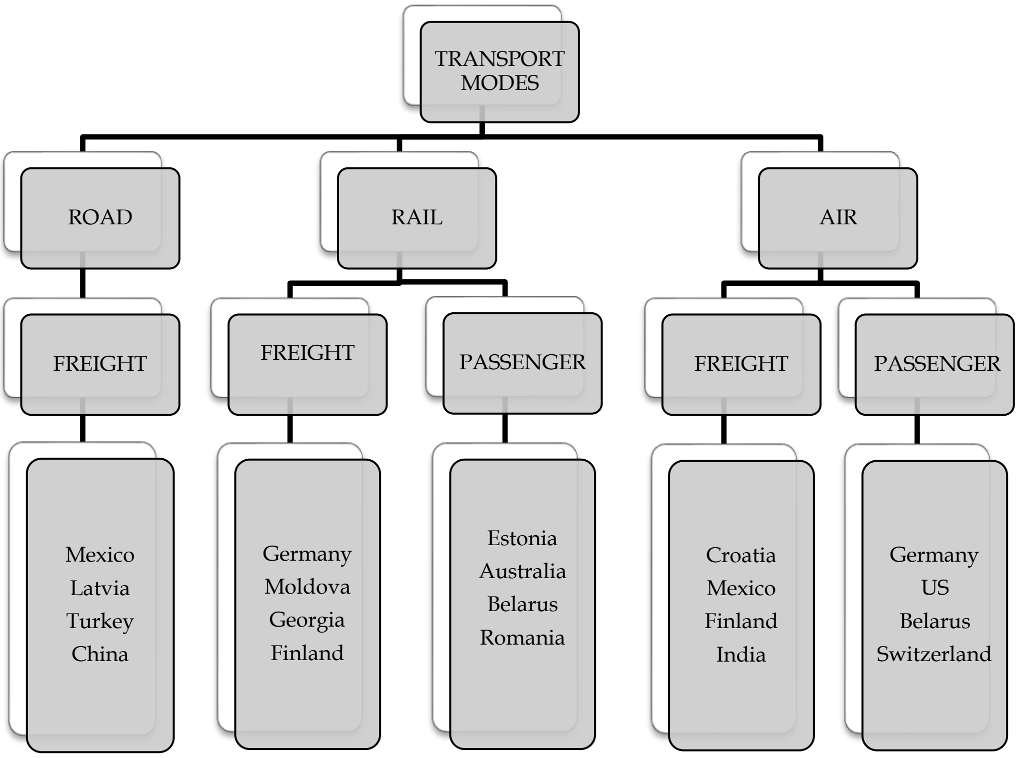

Figure 4. The most effective modes of transport on growth by country.

In general, although freight transport is mostly the focus of discussions in studies on the transport-growth relationship, passenger transport is also of critical importance for economic growth. While cost, competition, and foreign trade channels come to the fore in freight transportation, passenger transportation can reduce production costs through channels such as labor productivity and working time. For example, in their study for Australia, Ma and Ye (2019) emphasized that passenger transportation is directly related to labor productivity.

When evaluated in the context of transport modes, road transport constitutes the majority of transport, especially in countries with large geographical areas such as the USA, Japan, and Canada. Since road transport is a flexible mode and is used with other modes of transport, it comes to the fore in freight transport in the world (European Commission, 2022; Noussan et al. 2020). For example, 75% of total freight transport in EU countries is road freight transport. Although air passenger transport is the most decisive mode of economic growth for the USA, road and rail freight transport in terms of ton-km constitute 78% of total freight transport (OECD and ITF, 2022; Smyk, 2010). As a matter of fact, in the analysis findings, it is seen that road freight transport is important for growth, especially in countries with a wide geographical area and in most EU countries.

Despite the importance of road freight transport, road passenger transport is not significant on growth in all countries in the sample. Although the focus is mostly on the positive effects of transportation on growth through trade and labor channels, the transportation sector can be a burden to the country's economies through the pollution channel. At this point, road passenger transport is the mode of transport that should be discussed the most. Because two-thirds of all external costs consist of passenger transportation and one-third is freight transportation (European Environment Agency, 2021) considering the traffic factor, it is unlikely that road passenger transport will positively affect economic growth through labor productivity.

According to the analysis findings, air transport is determinant on economic growth in most of the countries. In general, air passenger transportation is one of the increasing modes of transportation in the world. For example, between 1970 and 2003, air passenger transport in the USA increased 328%, almost twice the GDP growth rate during this period. In the EU, this increase was over 1200% in the same period European Environment Agency, 2021). By volume, air transport accounts for less than 1% of world trade, but has about 35% by value. In this context, the value of goods transported by air is estimated to be over $6.7 trillion in 2019 (IATA, 2020). In this context, air passenger transportation, which comes to the fore in national and international passenger transportation, not only leads to an increase in social welfare, but also plays an important role in national and regional development with parameters such as access to the world market, encouraging foreign direct investments, strengthening local industries and facilitating labor mobility. In addition, with passenger transportation, entrepreneurs and companies can gain faster access to new business connections. Another transmission channel is tourism. Considering the determinant role of tourism on economic growth, it is expected that air transport will make a significant contribution to economic growth through tourism. Therefore, air transport is gaining more and more importance for national economies with both freight and passenger transport channels (Ali et al. 2023; Brugnoli et al. 2018; Noussan and Hafner, 2020).

In the study, countries such as China, USA, Finland, Italy and Turkey come to the fore in air transportation. Air passenger transport rather than air freight transport is more important for growth in all these countries. One of the determining parameters in this is the position of countries in air transportation, being tourism destinations, having a significant share in world trade, and strong domestic transportation channel depending on population sizes. For example, USA has the most profitable airline companies in the world such as American Airlines, Southwest Airlines, United Airlines, Delta Air Lines. Similarly, China Southern Airlines and China Eastern Airlines, which are Chinese airlines, are the world's leading airline passenger transportation companies. In addition, the USA and China are the top countries in domestic air passenger transportation (Pande, 2022; Rodrigue et al., 2020; IATA, 2020). On the other hand, the fact that countries such as Finland, Italy and Turkey are important tourism destinations and that air transport is also important in domestic transportation in these countries may be determinant in these findings.

Rail transport has played an important role in economic development in countries such as Japan, Western Europe and the USA, especially in the industrialization process. However, rail transport has been weak in competition with road transport, which has been at the forefront with its flexibility in recent years (Noussan, and Hafner, 2020). Because rail transport, although cheaper per ton-kilometer transported, often brings additional costs. In addition, the flexibility of rail passenger transport is low. For example, the demand for rail transport can often be limited to bulk goods over long distances. Rail transport is widely used mainly in several Eastern European countries, the Russian Federation, Australia and Canada. Especially in these countries with a wide geographical area, railway transportation has an important share in freight transportation. For example, the share of railways in freight transport in Australia is 56%. In addition, the Russian railway network is one of the largest in the world, and with a cargo volume of 3,000 billion tons per year, it accounts for about 30 percent of the world's rail transport. And the share of rail freight transport in Russia is 60%, excluding road freight transport. A similar trend exists in Eastern European countries. One of the main reasons why the railway is important in these countries is that these countries were former Soviet Unions and some structural conditions still remain partially. For example, in Lithuania, one of the countries of the former Soviet Union, road and rail freight transportation has an important share in the country's transportation system (OECD and ITF, 2022; Noussan, and Hafner, 2020; United Nations Economic Commission, 2020; Comité National Routier, 2020). In summary, it is seen that rail freight transportation is important in economic growth in former Soviet Union countries such as Latvia, Estonia, Belarus and Moldova, especially Australia and Russia.

However, one of the points that should be emphasized is that the dominant mode of transportation in a country does not have a primary role in the economic growth of that country. For example, although road freight and passenger transportation is the most prominent mode of transportation in the world, its importance in growth is not as strong as expected.

5 Conclusion

Transportation as one of the most important factors affecting economic growth depends on many different parameters. In this study, the effect of different modes of transportation on economic growth is determined in 28 selected countries. In this context, both freight and passenger transport data were used in road, rail and air transport. Firstly, the Westerlund Cointegration test is used to reveal the long-term relationship between transportation and growth. According to the cointegration analysis, all transportation modes (road, rail, and air) are cointegrated with growth. In addition to this analysis, the machine learning model was also used to predict the data and also determine the importance of the input parameters. The random forest method was used to obtain the relative importance of the input variables. According to, for all panel, rail transport is the most effective transport mode for economic growth. On the basis of country, the findings differ. Rail transport is the strong transport mode on growth in high-income countries. For example, in Britain, rail freight is critical to supply chains, and is prominent in transport services in sectors such as food, construction and pharmaceuticals. In addition, it reduces the need for trucks in bulk cargo and large quantities of containerised transport. (Network Rail Limited, 2023). In addition, since the railway infrastructure in developing countries is not sufficiently developed, the return on investments may be long. However, since developed countries have more developed railway transportation, the development of the existing efficiency infrastructure can yield more optimal results (Alotaibi et al. 2022). In literature, Khan et al. (2018) suggested that rail freight transport increases economic growth in low- and low-middle-income countries. Similarly, Kulshreshtha et al. (2001) found bidirectional causality between economic growth and railway freight transport in India. In another study for India, Pradhan and Bagchi (2013) suggested that there is a unidirectional causality from rail transport to economic growth. Ben Jebli (2016) found that railway passenger transport has a positive effect on economic growth in Tunisia. Alotaibiet for similar results for railway in in the Kingdom of Saudi Arabia.

Road passenger transport is has a slight effect on growth in high-income countries. The fact that these countries are tourism destinations and the use of more air transport and railway for travel are determinative in obtaining the findings. In upper middle-income countries, generally do not have a dominant mode of transport, but in general, freight transport is important to economic growth. In passenger transportation, the most prominent transport mode is air passenger transportation in these countries. In lower-middle-income countries, rail freight is the strong transport mode for economic growth. In addition, road passenger transport is has a slight effect on growth in both upper-middle-income and lower-middle-income countries. McKinnon (2007) also argued this trend in his study. According to the author, between 1997-2004, GDP growth and road freight transport growth have been significantly separated. The increasing economic growth has not been at the same rate for road freight transport. The decrease in the freight market share of road freight transport has an important role in these findings. A similar argument was made for Finland by Tapio (2005).

When the effect of transport modes on growth is analyzed by country, road freight transport has a strong effect on economic growth in Latvia, Mexico, China, Turkey, Poland, Georgia, Bulgaria, and Azerbaijan. The majority of these countries are Eastern European countries. According to Harkava et al. (2024), road transport has shown significant development in Eastern European countries. Poland, in particular, has a significant share in road transport revenues in the countries of this bloc. Similarly, Similarly, Berrones-Sanz (2020) emphasized that road freight transport is the main mode of transportation in Mexico and is of critical importance in employment and GDP. Road passenger transport has no impact on growth in all the countries.

The countries where rail freight transportation is strong on growth are Germany, Mexico, Romania, Australia, and Russia, but for passengers, these countries are Bulgaria, China, Japan, Romania, and Australia. Road and rail transportation networks are strong in Russia and former Soviet countries (Nguyen et al., 2023). Similarly, Germany has a very special railway transportation system (Seidenglanz et al. 2015). In addition, In Austria, rail passenger transport increased by 11,2% between 2003 and 2011 (Molemaker, and Pauer, 2014). Japan is one of the leading countries in the world in terms of quality and quantity compared to the number of railway passenger/freight kilometers. Germany, US, Belarus, Switzerland and India are among the countries where air passenger transport has a strong effect on growth. The prominent countries in air freight transportation are Croatia, Mexico, Finland, and India. In this context, the strong impact of air passenger transport on economic growth is seen especially in developed countries. And, Arvin et al. (2015) revealed that the economic growth impact of air passenger transport is strong in G-20 countries. In addition, air transportation is also of critical importance in India. According to IATA report (2019), US, Mexico, and Germany are the leading countries in air transportation

In the study, although rail is an important mode in high-income countries, the relative impact of air passenger transport is stronger. The fact that these countries are relative tourism destinations and host large airline companies are decisive in obtaining these findings. In this context, fiscal reforms aimed at the growth of this sector in these countries could further strengthen air transport. On the other hand, it is seen that rail freight transportation is the prominent mode of transportation on growth in low-income countries. The relative cost of road transport and the fact that air transport exceeds the economic conditions of these countries increase the importance of rail freight transport in these countries. Therefore, the public development of railway infrastructure can be a driving force in the economic growth of these countries. The high cost of investments in transportation infrastructure requires the public to take responsibility in this regard. When all modes are evaluated in general, all transport modes except road passenger transport are important on economic growth. Therefore, public incentive policies for railways and airlines in passenger transport can be determinative in the transport growth relationship. In freight transportation, on the other hand, it is necessary to create public policies for the optimal type of transportation, taking into account the public interest, without ignoring the structural conditions of the countries.

The most important limitation of the study is that maritime transport is not included. This is due to a significant lack of data. In future studies, it will be important to include maritime transport in all sub-transport modes in order to make comparisons. Also in the future studies, the Cross-Panel Data (CPD) technique developed by Zaman (2023), which allows the comparison of policy decisions taken in one country with the results in another country, can be used to reveal the impact of transportation mode policies in another country.

Contributor Statement

Isik, Ozyilmaz and Olgun has participated in the paper conceptualization, writing, developing the applied methods, and obtaining the fundings supporting the research. Bayrakrar, Toprak and K. Senturk have participated in the investigation process and reviewing and editing the paper. All authors have participated in reviewing the paper.

Confict of interest (COI)

All authors declare that no confict of interest exists.

Ethical approval

Not applicable.

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