Research Article

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INTELLIGENT TRANSPORT SYSTEMS MANAGEMENT AND REGIONAL CONNECTIVITY IN TRANSPORT INFRASTRUCTURE DEVELOPMENT

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Background. This study highlights the importance of analysing and assessing various aspects of regional connectivity in the context of integrating ICT into infrastructure and related facility management. In Bulgaria and the Balkans, there is a significant deficit in regional transport connectivity, which hinders the formation of a single spatial-economic and transport-geographical community. This creates an urgent need for improved governance and the implementation of ICT solutions to strengthen regional transportation connectivity.

Purpose. This study aims to analyse and evaluate alternative approaches to modelling regional connectivity in the context of modern, innovative governance, and to outline opportunities to improve connectivity in the Balkans.

Findings. The results of this study demonstrate that an intelligent interconnected model integrating Internet of Things (IoT) technologies, mobile communication systems, and sustainability principles provides an effective basis for comprehensive infrastructure monitoring and management. Simultaneously, the study reveals structural problems in infrastructure management, particularly excessively long project preparation times (averaging around 3 years) and the lack of bypass roads around major urban centres. To develop North-South connectivity in the Balkans, it is necessary to construct a fifth route through Bulgaria. The study found a strong relationship between road network density and regional economic growth. The average road network density in Bulgaria is 0.1800 km of road per km², and the average regional GDP per capita is 12,899.85 EUR.

Implications. The incorporation of e-government into regional development can enhance the effectiveness of implementing transport connectivity policies across different modes of transport and their adaptability to the European Union. However, several infrastructure and transportation problems need to be addressed (project delays, lack of bypass roads, and poor rail connectivity). The modernisation of motorways, construction of the rail network, and major infrastructure projects on the Danube (multimodal terminals and bridge facilities) and the Black Sea will shape connectivity patterns. Moreover, this will create preconditions for increased investment in and strengthening of the existing road networks.

Keywords: Connectivity Model, Innovative Governance, Transport, Infrastructure, Intelligent Transport System.

1. Introduction.

Connectivity is at the core of European integration, linking countries and peripheral regions to the European Union (EU). Connectivity is an opportunity to reduce the speed gap between regions in the European Union. For countries such as Bulgaria, connectivity embodies a profound human dimension and a way to integrate several mountainous, semi-mountainous, peripheral, and remote regions into the national market.

The European Union continues to expand by setting new priorities for effective and stable connectivity among its member countries and regions in the context of border control management under the Schengen Borders Code. From a research perspective, connectivity is seen as a complex process that requires the use of a set of management tools to achieve maximum efficiency and create a new consumer market, with a focus on risk analysis and the use of regional development tools as factors in the development of the national territory.

Infrastructure is one of these tools and, under the concept of Integrated Border Management (IBM), is considered a central measure for preventing and combating cross-border crime. Thus, a major challenge for regional development is infrastructure connectivity, which is a key factor in European integration and the formation of a common market. This objective requires the construction of Trans-European Transport Networks (TEN-T) covering projects of common interest for the creation of new transport infrastructure or the modernisation of existing infrastructure, filling in missing links, eliminating bottlenecks, and removing technical barriers to transport flows. This is another argument for improving connectivity across all modes of transport so that access to markets and goods enables us to improve integration within municipalities and expand access to markets and services.

Thus, the role of the nation-state is to implement targeted regional development policies that encourage the construction of different types of transport infrastructure and connectivity models (Yankov, 2020).

For countries such as Bulgaria, the new north-south approaches necessitate reforms and a serious redefinition of the country's transport flow. This approach to development requires redesigning roads, constructing new infrastructure, and developing models for regional development (Negenborn & Hellendoorn, 2010).

These policies are based on spatial models of particular economic activities (Persyn et al., 2022). For example, the need for railway lines in rural areas has created opportunities (Vilotijević & Vukićević, 2018). Simultaneously, interurban railways contribute to urban population concentration.

This study examines the need to combine the construction of road routes (roads, railways, and infrastructure facilities) with the creation of an intelligent accompanying system to manage processes in this new environment for the development of large spaces. In addition to these challenges, Bulgaria faces other challenges.

These are related to the shared European vision for the significant modernisation of railway infrastructure, which directly supports improvements in the environmental conditions. All European Union strategic documents support the development of freight and passenger rail transport, which should play an increasingly important role in creating a greener Europe.

The situation is similar in neighbouring Romania, which is important because it can encourage the implementation of larger infrastructure projects to improve connectivity in the European Union. This will accelerate regional connectivity for north-south traffic in Southeast Europe.

It is important to note that connectivity is not just about construction but also about maintaining a high level of regional economic development. When infrastructure is functioning, the economy develops more rapidly. The condition of rail freight and passenger transport, an increasingly important component of a greener Europe, is deteriorating. In this regard, the European Union's efforts to modernise rail transport are evident in improving efficiency (Bal et al., 2025).

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The importance of transport infrastructure, including rail, river, air, and road, will become increasingly necessary for better mobility and connectivity in approximately 281 regions in Europe, posing a major challenge for the EU to overcome regional disparities. This can be achieved by introducing intelligent transport management systems and implementing new regional development models in the future.

At present, given the substantial volume of information available, it is necessary to assess the analysis of information at a high level, both at the level of state institutions and to define the framework for the infrastructure network that should be developed, applying a professional analytical process that provides both the most accurate and timely forecasts and assessments, as well as possible solutions to management and organisational problems in the formation of a new north-south direction.

A significant problem for regional development is the lack of infrastructure connectivity, a key factor in advancing European integration and forming a single, common market (Copeland & Taylor, 2017).

The construction and development of regional connectivity in both the EU and the Balkans should be seen in the context of the formation of digital communities and economies, learning regions and their specialisation, and the construction of cross-border links and infrastructure (Anguelov & Petkov, 2022; Burgess et al., 2020; Dolchinkov, 2025; Greenstein, 2020; Lee et al., 2020; Redding & Turner, 2015; Redding & Rossi-Hansberg, 2017).

This study aims to outline sustainable and stable connections across at least four priority areas. The first is to upgrade new routes along the unfinished parts of the European transport corridors, which will allow good connectivity in South-Eastern Europe in the North-South and West-East directions, as well as on the new TEN-T network. Second, there is a need to work on gasification and high-speed Internet access to stimulate innovation, digital trade, and the provision of critical infrastructure in border and rural regions.

2. Literature Review.

In recent years, connectivity has been understood as market access for economically active individuals. A similar study on understanding connectivity to international markets was conducted as a systematic review (Calatayud et al., 2016; Giljum & Eisenmenger, 2004). A review of the normative and regulatory framework for policymaking shows that the academic community has not only highlighted the problems.

Despite this, the public sector also recognises connectivity as an essential element of the modern state's overall development and growth. Another problem is that, depending on the type of transport, it has often been defined differently, acquiring different meanings in the process. For example, urban transport systems significantly influence the growth and development of cities (Gonzalez-Navarro & Turner, 2018).

These concerns affect large geographical areas or extended areas of activity, are global issues, and require national action. This requires studying trends in the evolution of phenomena that may affect the object of study, market evolution, demographic aspects, fiscal policies, the country's economic development or regression, legislative stability, and its relations with other countries. This underscores the need for systematic use of data, information, and knowledge to demonstrate the need to develop border regions and connect individual cities and regions that are called upon to develop within a single territory and space.

Connectivity is important for the overall European vision of creating a single market. This requires the construction of Trans-European Transport Networks (TEN-T) covering projects of common interest for the creation of new transport infrastructure or the modernisation of existing infrastructure, filling in missing links, eliminating bottlenecks, and removing technical barriers to transport flows. This is another argument for improving connectivity across all modes of transport, enabling access to markets and goods, thereby improving integration within municipalities and expanding access to markets and services (Komornicki & Goliszek, 2023; Man et al., 2015).

Thus, the role of the nation-state is to implement targeted regional development policies that encourage the construction of different types of transport infrastructure and connectivity models (Yankov, 2020).

For Bulgaria, the new north-south approaches necessitate reforms and a serious redefinition of transport flows. This new approach to development requires redesigning roads, constructing new infrastructure, and developing models for regional development in the country. This connectivity model is a prerequisite for developing a new transport model for the country, emerging in the North-South direction. The West-East connectivity must also be maintained. The ultimate goal is to build a network model of transport connectivity and stability of regional development (Tsonkov & Petrov, 2023).

The pressure of tourist flows to the Black Sea, the Aegean Sea, and the Middle East necessitates improving the level of connectivity of countries such as Bulgaria, Greece, and Turkey, northward to Romania, Hungary, Slovakia, Poland, the Baltic States, and Finland, and after the end of military operations, certainly to Ukraine and Moldova (Persyn et al., 2022). It is necessary to create a reliable information environment that ensures traffic safety. Figure 1 illustrates the proposed research model. In line with widely accepted theoretical concepts, it has been argued that transport connectivity impacts economic development, as reflected in the GDP (Ejiogu et al., 2020; Harmatuck, 1996). A strong link exists between infrastructure provision and regional development (Iskandar, 2023; Muntean, 2024; Tsonkov & Petrov, 2025).

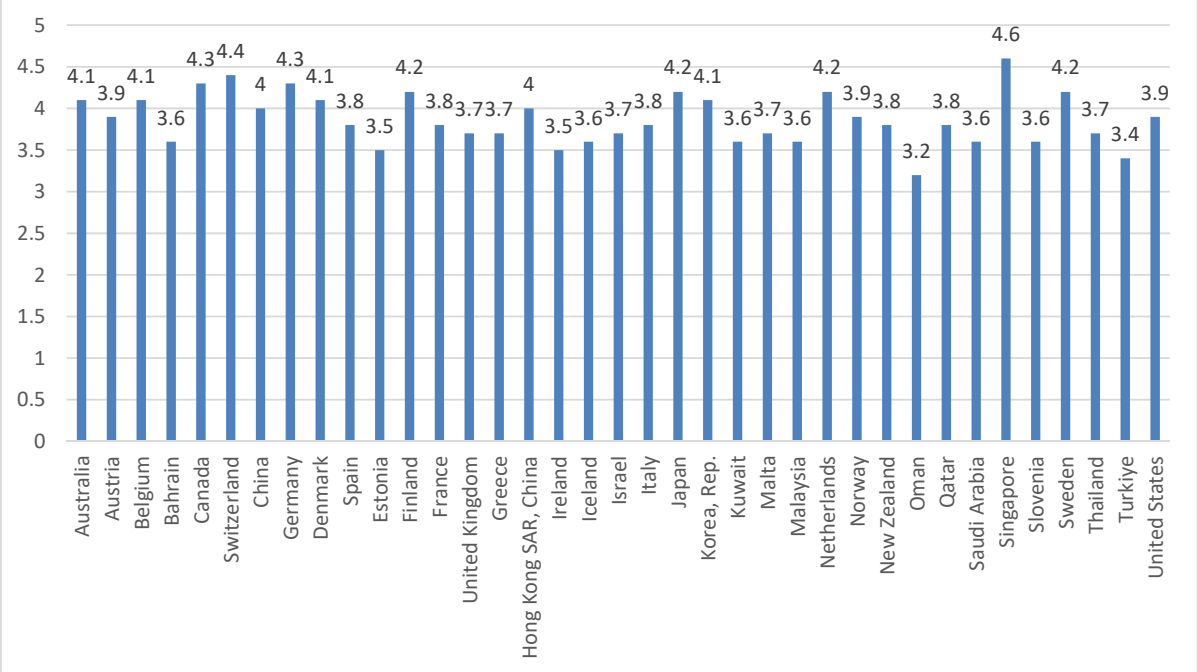

Fig. 1. Leader State by World Bank Logistics Index (Infrastructure Indicator), 2023.
Source: based on World Bank Data (2023).

The denser the road and rail network, the greater the connectivity. A high level of territorial saturation with transport infrastructure influences economic development, trade, people's mobility, connectivity between communities, and, as a result, regional development (Bröcker & Rietveld, 2009; Magazzino & Mele, 2021; Moljevic, 2016; Sebayang, 2020; Solina & Abramović, 2022). There is a discussion on the correlation between road infrastructure and economic growth across regions. Many studies consider infrastructure a prerequisite for economic development and growth (Bom & Ligthart, 2014; García et al., 2017; Straub, 2008).

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The theoretical framework adopted emphasises the importance of road infrastructure in generating increased mobility of people and goods (Ke et al., 2020; Maciulyte-Sniukiene & Butkus, 2022; Ma'rifah, 2022; Ng et al., 2017; Ng et al., 2019; Zhang & Cheng, 2023). This creates new job opportunities and stimulates the local economies. In recent years, the results of the European Union's cohesion policy have been measured by regional connectivity. Regional connectivity improves transportation. Transportation encompasses three main types of connectivity: physical connectivity through infrastructure, informational connectivity, and connectivity among individuals and communities (Li & Qi, 2016).

The World Bank (OECD, 2021) has contributed to the methodology for infrastructure assessment. This report highlights the importance of infrastructure provision and the challenges of infrastructure development. A methodology was proposed based on a logistics index, which is an indicator of infrastructure development in the region. Experts developed this index using World Bank (2019) data, and infrastructure is one of the six dimensions of the supply chain. A relationship exists between a country's infrastructure and its economic development. In this case, resource-rich countries have a high index because they invest in the infrastructure required to transport goods and raw materials.

It is necessary to discuss the objective links and interactions among infrastructure, its condition and quality, regional connectivity, trade, logistics networks, and ultimately, economic and regional development. The implementation of transport policy, including trans-European networks, is aimed at facilitating the single EU market, in line with Article 3(2) of the Treaty on the European Union and Article 26(1)–(2) of the Treaty on the Functioning of the European Union (European Union, 2012). Transport policy also stems from the pursuit of economic, social, and territorial cohesion and the harmonious development of the entire European Union (EU) (Article 3(3) of the Treaty on the European Union; Article 174 of the Treaty on the Functioning of the European Union).

The entire EU transport network is divided into a core and a comprehensive network, which are interconnected. The first is to be completed by 2030, and the second by 2050.

This network must cover all modes of transport: road, rail, air, maritime, and inland waterways, as well as hubs and intermodal platforms. From this perspective, the new concept and theoretical foundations for the chronological development of geographical processes and the imposition of new concepts of spatial development indicate that the countries of Eastern Europe will orient themselves toward the North-South (Laruelle & Rivera, 2019).

It is worth emphasising that strengthening these linkages is achieved by creating opportunities for transport accessibility, thereby improving the flow of people, goods, and information. In this regard, prerequisites are being established to facilitate the development of new transport routes. Traditionally, in the EU, as in most European countries, the connectivity model has been oriented towards the East.

The concept of North-South connectivity has been increasingly consolidated in recent years. The importance of the North-South transport axis, which served as a hub of systematic trade for several centuries, has not been sufficiently acknowledged.

This study aims to analyse and evaluate alternative approaches to modelling regional connectivity in the context of modern, innovative management and to outline opportunities to improve connectivity in the Balkans, particularly in Bulgaria.

3. Methodology.

Modelling regional connectivity is a multifaceted process in which regional differences and local economic development are significant factors affecting the quality and accessibility of transport infrastructure. Ensuring the quality of connectivity in a particular economic area or space depends on the quality of the individual types of stable transport systems and their adequacy in relation to ongoing socio-economic processes and the stability of local government.

In this regard, the philosophy of development is based on the correct setting of development goals in the context of spatial planning and natural conditions, which presupposes connectivity across all types of space.

Traditionally, within the European Union since 1973, as well as in most European countries, the connectivity model embodies the possibility of achieving a common market based on the free movement of people, goods, and capital (de Melo & Tsikata, 2014), as well as the right to establish businesses.

This approach is expressed through the creation of a typical institutional and informational environment and the provision of infrastructure at the meso- and macro-levels. In the meso-spatial approach, the subject of study should be the spatial relations of social groups/communities at the local and regional levels (neighbourhood, village, town, regional community).

In the macro-regional approach, the subject of study may be the spatial relations within large communities/systems at the state and supranational levels (states, regional unions, federations, empires, economic and political unions, and the world).

Thus, the integration process also raises new challenges at the meso and macro levels. This means that regional policy and its manifestations at the regional level within the European Union, clearly require the implementation of regional development policies to be effective.

In practice, this approach involves the formation of a conceptual framework that defines the supranational context in a north-south direction and is targeted at the economic situation in countries towards the creation of a national, and subsequently a typical European, market for goods, services, and investments.

3.1. Research Objectives.

The main objective of this study is to outline the problems of connectivity by reducing time and opportunities to build infrastructure that will contribute to the security of the provision of goods, people, services and investments. This process is recognised by the European Union (EU).

Bulgaria's location in Southeast Europe and the Balkan Peninsula gives it a significant role in European connectivity in both the West-East and North-South directions. Fulfilling Bulgaria's new role in meeting connectivity needs requires the construction of new regional and national facilities and infrastructure to enable the country to realise these intentions.

This study aims to identify and outline significant deficits in regional connectivity along the North-South axis in Bulgaria (in the context of the Balkans and Central Europe). Moreover, connectivity implies the formation of a complex infrastructure network with exit links to Romania and Greece as part of the European Economic Area (EEA).

This predetermines the search for ways and forms of regional economic integration between Northern and Southern Bulgaria, with clearly defined connecting transport routes and territorial directions of national, regional, and local character.

3.2. Research Type and Design.

The study is conceptual, descriptive, analytical, and conjunctural, using factor analysis and spatial-economic analysis with data and macroeconomic indicators. Along with the geo-economic analysis, an assessment of Bulgaria's natural and geographical location indicates harmonious development not only in the West-East but also in the North-South directions. In this way, the study takes an interdisciplinary approach to identify problems in establishing connectivity and the real needs for implementing regional development policies.

Furthermore, it is analytical and descriptive, as it defines the possibilities for future route construction to identify priority scenarios for the regional development of Bulgaria within the European Union and other Balkan countries.

Statistical information and a network approach are used to identify territorial and socio-economic problems affecting the current state of the territories and to generate processes and phenomena that can be transformed or implemented through policies to improve regional connectivity.

3.3. Specific Methods Used.

Analytical, comparative, mapping, and GIS analyses were used to compare the East-West transport orientation with emerging North-South demand and to contrast Bulgaria, Romania, and Serbia. In terms of assessing connectivity, space is the result of action. Simultaneously, spatial structure actions or spaces can both restrict and enable action. Therefore, statistical measures and hierarchical comparative analyses are required.

This involves comparing the transport status of the existing network with the development potential and functionality of the East-West and North-South orientations. In this regard, the importance of infrastructure in relation to neighbours must be assessed at the national, regional, and local levels. Next, border areas should be identified as opportunities for the deployment of certain high-speed inter-state roads and logistics centres to relieve the mega-urbanised areas within the national territory.

For this analysis, purely geographical and statistical approaches were applied, supplemented by a spatial economic analysis. Given the study's primary focus on Bulgaria and the Balkans and the lack of large-scale, targeted research on the topic, it used methods such as assumptions and case studies to assess and address the specific issues. Such an approach is mainly interdisciplinary, similar to studies conducted in other parts of the continent (Cvetković et al., 2013).

The study incorporates expert assessments and foregrounds comparative extrapolation or evaluation processes for transportation systems through mathematical experiments. To a large extent, this approach can lead to additional questions that may not adequately address the quality of the analysis of transport orientation and its significance for urban areas.

It should be noted that Bulgaria's East-West orientation stemmed from its social system until 1990. In contrast, the new North-South orientation is imposed mainly by the country's membership in the European Union. In addition, it is unclear what transnational policies North Macedonia, Serbia, and Turkey can implement.

Meanwhile, the pace of integration of Romania and Greece, and their integration into the European single market, is delicate. Territorial, geographical, and network approaches were applied to identify connectivity gaps and propose five specific routes (for example, Vidin-Thessaloniki and Ruse-Alexandroupolis).

This study focuses on the need to upgrade connectivity and build new routes using spatial, chronological, and geographical approaches. This requires us to consider the indirect significance of the conditions for developing and optimising the demographic potential, as well as the possibility of migration pressure in the country.

This approach highlights regional security and the potential to meet the consumer needs of the population. Thus, connecting Bulgaria with neighbouring countries along the North-South axis and the meridional routes should generate the necessary level of security and absolute local economic stability. In this regard, the built environment requires physical, informational, and human connectivity to allow ongoing processes to be viewed from different perspectives. In addition, this study reviewed the literature to examine existing models for assessing connectivity (Li & Qi, 2016).

In such comparisons, spatial characteristics are used to assess the correlation between road network density and regional economic growth. Petrov and Tsonkov (2025) used a simplified model that combined several measurements, including population, regional GDP, regional GDP per capita, area, road infrastructure length, and road infrastructure density. The study should return to the relevant territory or natural-geographical scope by applying network or cluster analysis to assess the importance of each transport route (such as Vidin-Thessaloniki, Ruse-Alexandroupolis, Constanţa-Varna-Burgas-Malko Tarnovo, and Silistra-Shumen-Yambol-Lesovo).

However, Bulgaria is geographically located such that most of the North-South and East-West transport corridors between Western Europe and Asia, the Scandinavian countries, and the Global South pass through it.

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The importance of the North-South transport axis, which has been the site of systematic and significant trade for several centuries, has not been sufficiently acknowledged.

Thus, the research toolkit covers a complex of territorial networks and combined territorial or socio-economic analysis, as well as an assessment of a significant part of the specialised literature.

The methods used to compare the East-West transport orientation with the emerging North-South demand and to contrast Bulgaria with Romania and Serbia are clearly interdisciplinary.

The second methodological step involved estimating the road network density in the three study areas before and after the construction of new roads. Road network density was calculated using a standard formula widely applied in the literature (Tsonkov & Petrov, 2025).

$$D_{i,t} = \frac{L_{i,t}}{A_i} \quad (1)$$

where:

$D_{i,t}$ – road network density for area *i* at time *t* (before or after construction);

$L_{i,t}$ – total road length (km) in area *i* at time *t*;

A_i – area of territory *i* (km²).

Subsequently, statistical methods are employed to analyse the relationship between road network density and gross domestic product per capita (GDP per capita). Statistical data were used to analyse the correlation between regional GDP per capita (in BGN) and road network density (in km) at the NUTS 2 planning region level.

The calculations were performed at the NUTS 2 planning region level in the Republic of Bulgaria. The general scope of the study covers the planning regions in Bulgaria, which are composed of separate territorial and administrative units, the country's districts. The general population is covered by statistical data at the NUTS 2 planning region level.

The indicators include population, regional gross domestic product per capita, regional area, length of the road network by region, and road network density.

3.4. Data Sources.

This study collected and used statistical data from the National Statistical Institute of the Republic of Bulgaria (NSI) and the World Bank/OECD (e.g., logistics and mobility indices). For the analytical and comparative analysis, EU documents, including the TEN-T strategies and Trans-European Transport Corridors, were used. This study used official statistical information from the respective open data sources.

4. Results.

4.1. North–South Connectivity in Bulgaria: A Balkan Regional Perspective.

Bulgaria is a key country in the Balkans for advancing the common Balkan market and regional connectivity. This can be explained geographically, given Bulgaria's location as a connecting link between several Balkan countries: Romania, Greece, North Macedonia, Turkey, and Serbia.

It is essential to analyse the degree of connectivity and homogeneity of the Bulgarian territory within the regional connectivity of the Balkans. In practice, Bulgaria is divided by the natural barrier of the Stara Planina Mountain Range. The mountain range divides the national territory into Northern and Southern Bulgaria. Several mountain passes connect the two regions of the country.

However, analyses show significant socio-economic differences between the two regions. As shown in Table 1, there are significant differences between the two parts of Bulgaria due to their limited connectivity. This deficit creates unfavourable conditions for the development of regional cooperation and connectivity.

Table 1. Socio-Economic Indicators and Regional Disparities in Northern and Southern Planning Regions of Bulgaria.

Region	Population	Average Annual Salary (Euro)	Regional GDP (million Euro)	GDP per Capita (Euro)	Total Road Network Length (km)	Highway Length (km)	Road Network Density (km/km²)	Area (km²)
Bulgaria (total)	6,437,360	10,999.76	83,040.96	12,899.85	19,986	845	0.1800	110,994
North-West	655,430	9,724.77	5,722.89	8,731.33	3,442	16	0.1800	19,070
North-Central	673,331	9,679.27	6,043.98	8,976.24	2,976	0	0.2001	14,815
North-East	826,742	10,728.95	8,306.96	10,047.82	2,697	111	0.1820	14,781
South-East	952,383	10,152.72	10,437.51	10,959.36	3,322	223	0.1680	19,799
South-Central	1,306,492	9,874.58	10,849.61	8,304.39	4,108	193	0.1840	22,369
South-West	2,022,982	15,838.29	41,680.00	20,603.25	3,441	302	0.1690	20,306

Source: based on the National Statistical Institute of the Republic of Bulgaria (2024).

GDP in Northern Bulgaria is significantly lower than in Southern Bulgaria. The density of the road network is relatively high across the six areas, but this is due to the length of first- and second-class roads and the differences across regions. Regional product and population size are significantly affected by the lack of motorways and expressways in Northern Bulgaria.

Figure 2 shows the relationship between road network density and regional product output. A higher density creates conditions for greater economic activity and growth, which is reflected in higher regional products values (Tsonkov & Petrov, 2025).

Figure 2 illustrates the relationship between regional GDP and road network density (RND). The process of regional connectivity formation involves several stages. An essential part of this process is strategic planning and connectivity modelling, as infrastructure corridors are planned and designed. Another aspect of modelling involves creating an effective model for the intelligent monitoring and management of infrastructure, transportation, and logistics. These activities also include the innovative management of multimodal terminals, logistics platforms, and connectivity among the system elements.

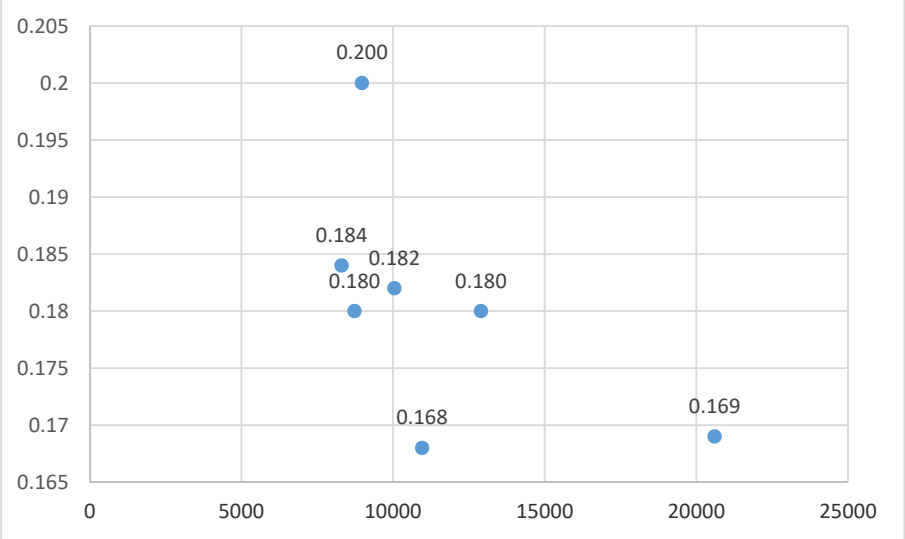

Fig. 2. Relationship Between Road Network Density and Regional Product Output.

High-quality transport infrastructure is the real instrument of connectivity through which a country can participate in geopolitical relations and processes. Bulgaria has ports on both the sea and rivers. By establishing intermodal terminals, Bulgaria should become an "intermediate route" or a "logistics centre" for trade with the EU. Notably, several Bulgarian projects remain conceptual, which is not a good indicator of effective public governance.

For instance, significant work remains to be done on projects in Bulgaria, particularly by accelerating construction on the Ruse-Biala and Veliko Tarnovo–Dimitrovgrad-Makaza sections. Ring roads around major cities should be designed, with those around Sofia, the capital of Bulgaria, and Plovdiv, the second-largest city, being the first to be completed. Therefore, it is important to intensify efforts on railway projects through tunnels under the Balkan Mountains in the North and South directions.

High-speed rail routes through Bulgaria are a particular priority. Their role is to transport large numbers of passengers and goods safely and reliably across the country. Depending on its design, a high-speed rail corridor in Bulgaria could serve at least 300,000 passengers per day between the major cities of Sofia, Plovdiv, Pernik, Blagoevgrad, Pazardzhik, and others.

This would reduce daily private car use and provide traffic relief on roads and at airports, particularly for short- and medium-distance journeys. In addition, rail corridors are much less affected by bad weather than road or air transport, allowing them to continue providing services even in conditions that would paralyse road and, especially, air operations.

This process has its shortcomings in Bulgaria, as new railway stations are not currently being designed in major cities, nor are new facilities being built in the outlying districts or suburbs of Bulgaria. Such new transport points aim to position them as local and transport hubs that provide transport services and connect to national transport networks, gradually becoming permanent transport hubs that support the varied use of urban transport networks, especially public transport.

In the context of civilisational realities, the imposition of intelligent information systems is becoming a leading paradigm in all spheres of human activity. An intelligent system is a meaningful system with a core purpose, sense, and actuator. Currently, e-development can be introduced through e-governance. In practice, a set of tools is required to coordinate and manage the implementation of relevant programs and projects.

Therefore, e-governance means not only equity in meeting current needs while also reflecting a more comprehensive notion of fairness across generations. Given that intermodal terminals are operated more efficiently than those in the private sector (with better operating conditions, staffing, costs, and modern handling technology and equipment), careful planning is required.

Intermodal terminal projects must be launched from a real market need, on a commercial basis, offering operators and customers flexibility in financing and location, in line with the development needs of the European Union economy and, respectively, the formation of a regional economy across different sub-national regions.

The conditions for providing infrastructure for information systems for traffic regulation and regional economic zones will set a new trend in the geo-economic development of European space and determine its pace. It is important to note that information technology is essential in this approach, enabling us to monitor the condition of transport means, their movement, and their efficiency in implementing market mechanisms.

It is witnessing the significant impact of modern communication and information technologies on the region's economy and governance. Regional governance must be viewed in the context of intelligent development, renewable energy, and mobility systems. Mobility implies connectivity and electrification, which refer to infrastructure and regional connectivity, respectively. In this respect, connectivity is regarded as the integration of all facilities and infrastructure into a single system, together with intelligent control systems (ICSs).

However, Internet connectivity is required for vehicles, major transport and infrastructure sites, and cars.

All of this is changing the nature of logistics networks, infrastructure, and transport connectivity through the integration of IoT, Internet coverage and access, and communication and information technology. These are combined with the use of autonomous means of transport, new energy sources, handling goods and services, and freight flow and management.

All these require the use of new technologies to improve the management of transport and logistics networks and corridors (Kyriakides, Polycarpou, 2014). A specific indicator was developed for this purpose. The Organisation for Economic Co-operation and Development uses a mobile connectivity index (OECD, 2021). The index measures countries' performance across the primary factors driving mobile Internet adoption: infrastructure, accessibility, user readiness, content, and services. According to this index, many countries in the Middle East and North Africa were considered transit countries in 2019. In this sense, mobile infrastructure and Internet coverage are also essential to the development of North-South transport corridors, which need to be managed more rationally and efficiently using information technology. For most cities in Bulgaria, creating belts or bypass roads to eliminate heavy traffic flows from and around cities remains a priority. The finalisation of belts reduces heavy traffic on important roads, significantly improving traffic safety, reducing pollution, and improving the quality of life in areas freed from it.

The complexity of infrastructure development in the national territory necessitates the allocation of sufficient time and resources to prepare for the construction of national sites. There is an ongoing debate in regional development about the significant issues of various natures that may arise during its implementation. The experience of previous programming periods has shown that effective preparation for a project to be implemented under a programming framework should begin at least 3 years before its commencement.

By the time the financing agreement and the economic contracts under it are signed, the procedures for expropriation and obtaining the necessary approvals and permits to commence implementation of the works are completed. The risk management concept for the development of these corridors (projects) includes some specific measures to be considered to ensure sustainable mechanisms for the implementation of the activities and the qualitative development of connectivity, namely:

1. A study of the corridor (project) implementation options and minimisation of the technical, economic, and environmental risks of the technical solutions.

2. The selection of tenders, submission deadlines, and timing of work should allow sufficient time to develop quality tender documents. Using the lowest price criterion for awarding contractor and consultancy contracts, along with increased professionalism among tender evaluation committees, does not always yield positive results for the government. Therefore, consideration could be given to introducing criteria relating to more extended warranty periods (15-20 years).

3. Increase the primary beneficiaries' technical expertise and participation (know-how and ownership) by creating and imposing responsibilities on the project units.

4. An integrated approach to construction management is related to the combination of construction with the laying of fibre-optic highways, telecommunications links, the construction of quality supporting infrastructure, and opportunities to use alternative routes.

These requirements should define a new approach for the development of infrastructure routes and connecting roads, given the dependence on construction, information technology, and road transport. Several shortcomings affect the development of infrastructure at the desired pace, including reduced permit issuance and approval times. Factors external to the construction of roadways, shortages of both basic and specialised labour, and increased material and labour costs are among the factors affecting investment.

In this regard, the national state should work towards establishing national routes; within Bulgarian territory, it was proposed to form five such routes in a north-south direction. It covers essential parts of Bulgaria's regional economy and, in practice, gives impetus to the development of North-South relations in Bulgaria, thereby helping to form a Balkan Economic Community.

The central thesis is that North-South railway transport should be developed. This will connect the Danube ports with the Mediterranean and Adriatic, and in the other direction, with the Baltic region. Rail connectivity is key to ensuring efficient North-South logistics corridors. Therefore, it is essential to build a rail link along the Black Sea coast from Georgia to Greece and Turkey. In this respect, the construction of intermodal and multimodal river terminals is crucial. The Danube and Black Sea are vital.

The spatial-economic analysis and assessment of the construction of new transport and infrastructure links in the Balkans in the North-South direction via Bulgaria raise significant reservations about the project. According to the National Statistical Institute of the Republic of Bulgaria (2024), in 2023, the number of ports from Bulgaria to third countries decreased by 2.9% compared with 2022.

Bulgaria's international trade is primarily concentrated with Turkey, the United States, China, Serbia, Ukraine, North Macedonia, and Egypt, which account for 50% of its exports to third countries. Imports of goods into Bulgaria from third countries in 2023 decreased by 19.7% compared to 2022, to BGN 38.766,8 billion (Zhelyazkov, 2025). The most significant volumes of goods imported were from non-EU countries. In addition, Bulgaria's trade in 2022 was €8 billion with Romania, 5.9 billion EUR with Greece, and very little with Albania (190 million EUR). The statistics for economic and trade turnover indicate a North–South imbalance. According to official data, imports declined by 19.7% in 2023. Furthermore, Bulgaria's trade volume with Albania is low (190 million EUR) compared to that with Romania (8 billion EUR).

Despite the above-mentioned trade turnover with the Balkan countries, the potential for developing trade with them is substantial. In total, the formation of a single Balkan space by bridging borders through more cross-border and intra-regional infrastructure projects would ensure the structuring of a regional market encompassing more than 120 million people. From the above data, the potential construction of trans-Balkan corridors will contribute to the positive development of these countries.

First, the building itself adds value to the territories through which the route passes and increases gross domestic product (GDP). Regional connectivity ensures the formation of efficient economic links between large agglomeration areas. Theoretically, their gravity zone would contribute to the development of territories within a 60-100 km radius. Second, the formation of regional connectivity would create conditions for structuring a unified space in Bulgaria and the Balkans. Third, by connecting the North and South regions, trade and people's mobility will be stimulated, leading to a cumulative effect across all countries, not only Bulgaria.

It is also necessary to maintain connectivity in the West-East direction, mainly through the construction of expressways in the direction of Sofia-Pirdop-Karlovo-Kazanlak-Sliven-Aitos-Burgas (Gauge G-20), a four-lane Danube expressway Vidin-Lom-Nikopol-Svishtov-Ruse-Silistra (G-20), the construction of a high-speed train in the direction of Alexandroupolis-Kardzhali-Dimitrovgrad-Yambol-Burgas, as well as expressways from Svilengrad-Topolovgrad-Yambol-Sredets-Burgas to develop regional cooperation and fast access to the Black Sea.

This means that work must also be done to build a modern port of Burgas, which would enable a larger cargo flow and allow the port to open with fast transport connections to Poti, Trabzon, Batumi, Sukhumi, and Istanbul. In this regard, Bulgaria needs to complete the Hemus motorway, which will connect Sofia with Varna and create new investment opportunities in Northern Bulgaria. It is difficult to outline all the priorities.

From an analytical point of view, the Bulgarian state as a whole moves very slowly and has difficulty financing important strategic projects that remain to be implemented for years rather than the relatively short 4-5-year terms. This deficit can be overcome as a member of the European Union, especially after entry into Schengen, after which several projects that do not yet meet the readiness criteria will need to be completed quickly. These positive changes will affect the gross domestic product, and in the long run, social and economic regional inequalities will be resolved.

4.2. Key Findings and Implications for Strategic Transport Infrastructure Planning in the Balkans.

Close connectivity and regional economic integration imply that the conditions are in place for the creation of stable and effectively functioning regional economies in which a functioning regional consumer market can be established. Access to information and decisions to reduce production costs and implement new technological solutions using more modern methods to assess and analyse current processes are becoming increasingly important for the development of connectivity processes.

The Internet of Things (IoT) enables ubiquitous real-time data collection using embedded sensor technology. Increasingly, artificial intelligence can be used with appropriate caution, offering techniques for the autonomous analysis of large volumes of urban data from the Internet of Things. When combined effectively, modern approaches can generate more data and information to support an adequate assessment of infrastructure, enabling decisions to optimise operations and improve the citizen experience. A natural extension of this technology is radio frequency identification (RFID).

This is one of the methods for automatic identification and data collection, specifically for identifying remote objects. In practice, RFID technology has been available in commercial networks in one form or another since the 1970s. Another important issue is the assessment and analysis of ongoing processes for their reliability and security.

This brings digital infrastructure to the forefront, supporting both user-oriented applications and internal automated processe (Vuković et al., 2025). In regional development, there is a need for a comprehensive digital infrastructure strategy that integrates various technological domains within a unified framework.

After 2020, however, the requirements are greater because the integrated system must support both current operations and future growth, or have the capacity for rapid, effective upgrading. Each component plays a key role in creating a sustainable, large-scale (spatial) infrastructure that can adapt to changing business requirements.

Against this backdrop, countries such as Bulgaria are introducing digital solutions only partially, leading to delays or incomplete implementation of projects that could promote connectivity and improve infrastructure management.

For example, statistics from Bulgaria show that approximately 45,478 passenger cars will be registered for the first time in 2025. Every day last year, 135 new passenger cars were delivered to customers (National Statistical Institute of the Republic of Bulgaria, 2025). This shows that in recent years, the number of cars has been growing, which means that the state must provide funds for the construction of new roads, parking lots, etc., especially since the share of car trade within the European Economic Area (EEA) has been increasing.

Another example in this direction over the last 10 years is the real estate market in Plovdiv, which is relatively stable and shows a clear upward trend. Real estate transactions (including parts of properties and agricultural land) range from 15,000 to 16,000 per year, with prices and the number of new properties rising significantly (National Statistical Institute of the Republic of Bulgaria, 2025). The reason is that Plovdiv is the second-largest city in Bulgaria and, thanks to its well-developed industrial zone, technology companies, and international investments, it offers a stable business and professional development environment.

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This naturally leads to an increased demand for housing and rental properties, making real estate investments extremely promising. This meant that the ring road was to be built with four lanes, but after 2023, the renovated road retained only two lanes and is now the country's busiest.

The state has committed to a new Plovdiv ring road measuring 25 km. It will start at the Tsaratsovo junction on the Trakia motorway, pass through the existing ring road route, through the Asenovgradsko Shose roundabout, and reach the Skobeleva Majka overpass. The future road will be 42 m wide, with two lanes in each direction and two local one-way lanes on each side. These will handle traffic for businesses on both sides of the routes.

The speed limit on the Ring Road, which will have eight roundabouts and overpasses, will be 80 km/h (ArcGIS, 2025). This new infrastructure needs to be integrated with IoT technologies, primarily to address infrastructure management issues, such as delays in preparing traffic management projects, the construction of buffer parking lots and charging stations, and the provision of alternative routes.

These examples are primarily related to urban regions. However, at the national level, connectivity between northern and southern Bulgaria also requires important decisions to divert traffic away from large cities, ensure optimal entry points, and enable logistics and commercial activities by optimising time use.

Thus, five strategic transport corridors were proposed to improve north-south connectivity (Figure 3). Assuming that Kom Peak is the westernmost point in Northern Bulgaria and Cape Emine is the easternmost point in Southern Bulgaria, the distance between them is approximately 650 km. This suggests that, on average, every 120-130 km, it is feasible to build a route with a gravity of 50-65 km to the east and the same to the west in Bulgaria.

It is optimal to build five national infrastructure corridors of international importance connecting the north and the south. The first direction was established in 1997 as a route along European Transport Corridor No. 4, in which the ports of Lom and Vidin are of key importance, as is the second bridge between Bulgaria and Romania at Vidin.

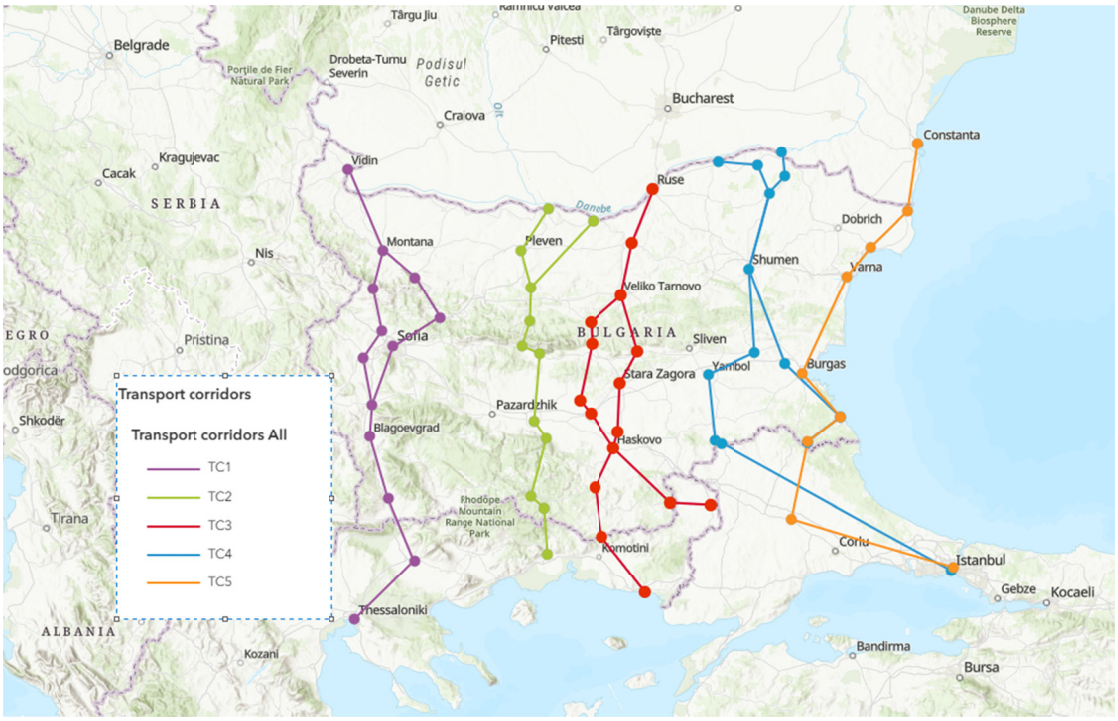

Fig. 3. Major Routes in the Balkans, North-South Direction.
Source: based on ArcGIS (2025).

The route includes Vidin (Lom) – Montana (Petrohan-Kostinbrod-Pernik) – Vratsa –Botevgrad – Sofia – Lyulin – Dupnitsa – Blagoevgrad – Sandanski – Syr – Thessaloniki (enclosed corridor). This route has two branches: the key branch is before the city of Vratsa, as the western route passes through the Petrohan Pass and shortens the distance to Sofia by nearly 60 km. The Eastern route continues past Vratsa and joins the Hemus Motorway in Botevgrad. This route aims to build not only a motorway but also a railway link, in which Sofia plays a key role as an intermediate centre. Cities such as Vratsa, Pernik, and Blagoevgrad serve as primary logistics hubs.

Realistically, this is the shortest route between the Danube and Thessaloniki, but due to several problems in Bulgaria, the route is still under construction and has yet to be completed.

A connection with Kyustendil would create a real opportunity for good connectivity with North Macedonia, Kosovo, and Albania. Furthermore, the Vidin-Lom-Thessaloniki route may also have a railway dimension, which could affect the transport of goods from the Mediterranean to Hungary, Romania, Slovakia, the Czech Republic, and Poland. Of course, rail links must have their own infrastructure, and funds must be allocated in the period 2028-2034 for a high-speed, double railway line Lom-Boychinovtsi-Vratsa-Mezdra, as well as for Vidin-Brusartsi, with the construction of a large logistics distribution centre for Northwestern Bulgaria around the Brusartsi station.

It is also necessary to consider a new railway link between Kostinbrod and Novi Iskar, which will be doubled and extended to Pernik, where a large logistics and transport centre will be built. Turning the city of Pernik into a vital rail transport hub will require identifying opportunities to build a rail link from Pernik to Radomir, Kyustendil, Gyueshevo, Deva Bair, and Kriva Palanka (North Macedonia). This project has been contemplated for a long time, but remains unimplemented. The road to Blagoevgrad and Thessaloniki passes through Pernik, indicating that Bulgaria plans to build a high-speed railway line from Sofia to Pernik, Sandanski, Serres and Thessaloniki.

The second national corridor would start from the town of Svishtov (the other branch being Nikopol – Pleven) – Lovech – Troyan – Karnare – Karlovo – Plovdiv – Asenovgrad – Smolyan – Rudozem – Xanthi (Mizia-Thrace Corridor). It provides an opportunity to develop the Plovdiv-Pleven axis and further enhance connectivity between Bulgaria, Romania, and Greece in geo-economic terms, thereby creating conditions for the development of the regions through which the route passes.

This route could include a new bridge over the Danube at Svishtov (there is currently a ferry between Svishtov and Zimnich), as well as work on the construction of the Pleven – Lovech – Troyan – Karnare – Karlovo – Plovdiv, which would have a tunnel in the direction of Troyan-Karnare and would reach Rudozem in the Rhodopes via a new road. Within this framework, opportunities can be sought for the construction of a road connecting Plovdiv – Asenovgrad – Cherven – Tri Mogili – Vishnevo – Dolna Dryanka – Srednogorci – Rudozym – Elige – Xanthi, or Plovdiv – Kuklen – Lyaskovo – Chepelare – Proglad – Levochevo – Ustovo District – Rudozem – Elige – Xanthi.

If built, each of these routes will provide opportunities for regional development in the Rhodopes and will be of significant importance for the revival of the regional economy. Concerning the settlements in Northern Bulgaria, it will be possible to create an alternative for their socio-economic development, provide opportunities to establish new industries, and profile their territory by attracting investment and developing a new spatial organisation of the agricultural sector.

The third route starts at Corridor No. 9, beginning in the city of Ruse, continuing to Byala, and ending in Veliko Tarnovo, where it splits into two branches: one branch goes to Gabrovo – Shipka – Bratia Daskalovi – Chirpan – Haskovo – Ivaylovgrad – Orestiada (Greece); the second route passes through Gurkovo, Stara Zagora, Dimitrovgrad, Haskovo (Knizhovnik – Chiflik – Skalishte – Vishegrad), Kardzhali, Makaza, and Alexandroupolis (Vertical Corridor).

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The second route is part of Corridor No. 9, which should include, in addition to the motorway, a rail link in this direction, given the growing importance of the Port of Alexandroupolis and the opportunities to implement the Three Seas Initiative. This route is strategically important because it offers opportunities for geo-economic development in both the northern and southern parts of the country and provides a reliable link between Bucharest and the Aegean Sea. This corridor could significantly increase the importance of the Bulgarian region, given its geographical location and the fact that its northern neighbour, Romania, has significant functional links with its neighbouring countries.

The fourth route starts in the city of Tutrakan – Sito (the second starting point is the city of Silistra-Alfatar) – Dulovo – Shumen – with a branch to the Aytos Pass – Kameno – Tsarevo – Malko Tarnovo – Turkey, and the second route through the Rishki Pass – Karnobat – Yambol – Lesovo Border Crossing Point – Hamzabeyli – Istanbul (The Middle Corridor). This corridor is of strategic importance to countries such as Moldova, Ukraine, Romania, and Northeastern Bulgaria because it is the shortest route to Istanbul and offers opportunities for connectivity with Asia Minor and, from there, with the Persian Gulf.

However, the region in Bulgaria is one of the least developed, with mostly satisfactory road infrastructure. Within the framework of the Three Seas Initiative and rail connectivity, this part of the country will have the opportunity to stimulate its development. The middle corridor could be the lifeline for the development of the local economy in the Shumen-Targovishte regional area, which has begun to increase its commercial role in recent years, as well as for the Danube ports of Silistra, Tutrakan, Yambol, and Sliven in southern Bulgaria. The middle corridor is not only the fastest, cheapest, and most direct route between Asia and Europe but also between Europe and Asia. In December 2025, Bulgaria, Greece, and Romania will accelerate the development of a transport axis south of the Danube.

From a geo-economic perspective, the Danube is the backbone of Europe. This living organism connects regions, markets, and ambitions, and while the river is a border, it should not be an obstacle to trade. The middle corridor was designed to turn European infrastructure into a real contributor to local economic development by strengthening the single market, ensuring military mobility, and making the North-South axis operational.

The fifth direction: Constanta – Durankulak – Balchik – Varna–Dyulinski Pass – Burgas – Tsarevo – Malko Tarnovo – Lyule Burgas – Istanbul (Black Sea Corridor) is a strategic transport route that can be implemented through the development of the Varna-Durankulak expressway and the Varna-Lyule Burgas motorway (Black Sea Corridor). It is a strategic transport route that can be implemented through the development of the Varna-Durankulak expressway and the Black Sea motorway, as well as a new route for the Burgas-Marinka-Yasna Polyana-Tsarevo-Malko Tarnovo expressway. This is essentially the Black Sea route and is of considerable strategic importance for development, but its implementation is relatively slow and laborious; on the other hand, it could have a significantly positive impact on the regional development of the Dobrich, Varna, and Burgas areas.

Bulgaria, Greece, and Romania have agreed to foster common transport infrastructure development to connect the Aegean and Black Seas. This is based on a signed Memorandum of Understanding. This document serves as a framework for the Black Sea–Aegean Sea Corridor Platform, promoting cross-border cooperation among the Balkan states. The uncertainties surrounding the development of cooperation in the Black Sea give Bulgaria and Romania reasons to consider alternative options. In practice, maritime transport continues to face threats from floating mines and jamming technologies, which affect maritime transport and regional energy security. A possible alternative is the construction of a road from Galati, Constanta, Varna, Burgas, Malko Tarnovo, and Istanbul to protect the regional economy and transport corridors, as well as the trade flows that are essential to Europe.

5. Conclusions.

Given its geographic location, infrastructure development, and energy significance, Bulgaria can be a central player in building the Central Asia-Caucasus-Europe economic corridor. Investments in ports, transport, and energy, together with close cooperation with the countries of the Caucasus and Central Asia, will turn Bulgaria into an essential gateway between these regions and the EU. It is important to emphasise that there is a specific deficit in the development of the Bulgarian state in maintaining a modern electronic infrastructure and implementing e-government at all levels. There are also positive outcomes from the inclusion of e-government in regional development.

However, this requires us to seek results and begin measuring its effectiveness. In reality, this can be achieved by implementing transport connectivity policies across various modes of transport and ensuring their alignment with the European Union standards. Unfortunately, there are still open questions and several information, infrastructure, and transport problems to address to create a foundation for developing technologies and, from there, the security of the processes involved. The modernisation of motorways, construction of the railway network, and major infrastructure projects on the Danube River (multimodal terminals and bridge facilities) and the Black Sea will shape the connectivity model.

This, in turn, will create the conditions for more investment and the strengthening of the existing road network, and, why not, a new road network that will be an alternative to the existing one. For example, measures are needed for railway sections in the TEN-T corridor plans and programs, where speeds of more than 160 km/h can be achieved. There are problems, mainly related to limited space and ageing rolling stock. An upgrade will increase average commercial speeds, and travel speeds will be higher. The average commercial speed of passenger trains on the Bulgarian railway network is 46 km/h, indicating a lack of competitiveness and lag behind other modes of transport.

This leads to an unattractive and uncompetitive mode of transport that requires structural interventions to improve its quality, efficiency, and interoperability.

Public road transportation also faces several concerns. Therefore, any investment in the transport sector must be inclusive and respect the principles of equal opportunity. Thus, when implementing large infrastructure projects, Bulgaria must ensure partnerships in the programming and management of EU funds, as well as support for working and socially responsible businesses. This is a prerequisite for developing solid program documents based on the priorities established at the European, national, and regional levels to implement effective economic, social, and territorial policies that are efficient, have a positive impact on citizens, and reduce disparities in development at the European Union level.

Southeast Europe is undergoing a period of strategic reconfiguration in which cooperation between Member States is becoming essential for mobility, competitiveness, and security. A significant obstacle to implementing North-South regional connectivity is the lack of financial resources and support procedures.

Until now, funding has been provided by national and European budgets. In several countries, good practices in public-private partnerships and the use of private funding for infrastructure projects have been observed. In this way, several challenges can be overcome by building regional North-South connectivity. One of the most important difficulties is the lack of a coordinated vision at the administrative level of the government.

Although the law does not require the development of strategies for infrastructure development and road management (passportization), many corridors or first-class roads lack such plans or implement them inefficiently, thus facing difficulties in management and rehabilitation. Another important barrier is the high initial costs. Investments in green belts, noise barriers, or blue-green systems may seem expensive compared to traditional solutions, but they are effective and should be implemented.

As the analyses have shown, modelling involves the use of accurate tools to assess infrastructure and its future value to a region and the country. Simultaneously, this process should encourage ICTs to improve the management of transport and logistics flows directly related to infrastructure and its condition, and ensure a high degree of connectivity and mobility.

As an EU member, Bulgaria should jointly build new infrastructure that can provide other European countries with greater freedom of action and more opportunities for trade in energy and the transfer of digital data. Connectivity is an important priority of European integration. The path to developing connectivity lies in investing in roads, airports, and ports to secure a prominent position among the European nations.

Initiatives developed in partnership with residents are more effectively adapted to real needs and receive continued support. Public participation actively increases the sense of belonging to and responsibility for urban spaces. Cooperation among administrations, experts, and citizens is vital for turning challenges into opportunities and ensuring a future in which nature and economic development can coexist.

Conflict of Interest Statement.

The authors declare that there is no conflict of interest.

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