INVESTIGATING THE INTERACTION BETWEEN THE TOPOLOGY OF BUS TRANSPORT NETWORKS AND REGIONAL DEVELOPMENT IN GREECE

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Abstract

Bus companies are transport operators that support the demand in local markets for transport and at the same time promote regional development. This paper studies the topological and geographical characteristics of the Greek Bus Transport Network (GBTN) of the Joint Reciepts Fund of Buses (KTELs) of five regions of Greece in relation to their socio-economic environment, aiming at studying the effectiveness of the GBTN in comparison to the inter-regional road transport network in Greece. For this purpose, we apply complex network and econometric analysis to delve into the interaction between the topology of bus transport networks and regional development, focusing on the case of Greece. The methodological approach promotes the analysis of complex spatial networks, as a modeling tool in spatial planning. Overall, this paper highlights and evaluates the contribution of the interurban network to the overall road network of the country and the support and promotion of the economic profile of local markets.

Keywords: public transport; regional and local economy; network science; spatial networks; network analysis.

JEL classification: R41, R42, R1

1. Introduction

The purpose of transport is to transcend space, which is shaped by a variety of human and physical constraints such as distance, time and administrative boundaries (Rodrigue et al., 2013). The main purpose of transportation systems is to move people, goods and information from source to destinations (Ducruet & Beauguitte, 2014). Transport networks in general and road networks in particular are the backbone of a city and directly affect its productivity and survival. The road network has been the main land transport network in Western world countries since the 1950s to the present day and exhibits complex topological properties (Tsiotas, 2021). It allows for extensive dispersion of travel in space and relatively easy accessibility to areas with complex geomorphological topography (Rodrigue et al., 2013; Tsiotas, 2021). In Greece, the road mode of land transport is the main mode of transport, given that the country's rail infrastructure lags far behind that of other European countries (Colak, 2015; Perovic and Golem, 2015; Constantin et al., 2021; Polyzos, 2019, 2023) and its main transport infrastructure is the road network (Tsiotas, 2017, 2021). This complements both sea and air and rail transport (Tsiotas and Polyzos, 2015a,b). Greece's road network consists of motorways, national and provincial roads. Two of the main roads in mainland Greece are the Patras - Athens - Thessaloniki - Evzoni (PATHE) axis and the Egnatia Odos, which crosses Greece from west to east, from the port of Igoumenitsa to the Turkish border. The Greek inter-regional road network is 35,860km long (Tsiotas, 2021) and connects a variety of mountainous, land and coastal areas.

An extremely important part of road transport is public transport, which is a collection of modes of transport available to the public regardless of ownership (White, 2002; Dionysopoulou et al., 2021). Historically, most public transport networks have evolved over time based on the past experience of planners, simple guidelines or requirements from local communities (Mumford, 2013). The evolution of a city's public transport system is closely related to the development of the city itself and is therefore influenced by many factors of historical, geographical and social origin (Gioti-Papadaki et al., 2017; Tsiotas et al., 2021). In sparsely populated areas, the aim is to meet basic transport needs, while in larger cities the aim is to reduce congestion and improve the environment (Goula et al., 2015; Polyzos, 2023). At the regional scale, the purpose is to create opportunities for education and increase the labor market. Several studies (Crane and Scweitzer, 2003; Titze et al., 2008; Van Acker et al., 2013; Zhang et al., 2017; Yu et al., 2019) have examined the association between public transport and the built environment, as well as socioeconomic characteristics. These studies quantitatively measured the impact of local built environment factors (density, diversity, design, transit distance, and destination accessibility) on public transportation. Most assumed that public transport travel choice is only influenced by local factors within the same spatial unit (e.g. traffic analysis zones) and most relied on empirical observations and surveys of the local spatial unit. However, the city is composed of a set of actions, interactions and transactions (Batty, 2013; Liu et al., 2015) and studies need to take into account dynamic spatial interactions in relation to space and time (Nasri and Zhang, 2014).

The analysis of public transport networks using Network Science allows the use of a common platform in which we can understand and decipher the intrinsic network characteristics encoded in the topological properties (Tsiotas and Polyzos, 2018). In graph theory, a network is typically represented as a graph consisting of a set of nodes interconnected by a set of edges. This field of study continues to attract enormous research interest in the last two decades (Barabasi, 2016). Although many complex real-world systems have been analyzed using graph theory, little attention has been paid to the field of public intercity road networks which is an active research area. Intercity bus services are an integral part of the overall public transport system that responds to the demand for long-distance travel. It plays a vital role in connecting large cities with each other and small towns and rural settlements. Intercity buses help communities achieve sustainability goals (Polyzos, 2019; Polyzos and Tsiotas, 2020, 2023).

In Greece, there are sixty-two operators providing public intercity passenger transport services using buses under the name of Common Bus Collection Funds (KTEL) with their headquarters and operating area in their regional unit. The definition of bus and coach undertakings also refers to the boarding stations of these buses and coaches. Bus and coach operators serve the whole country, with approximately 180 million passengers per year. The public long-distance road transport network serves the permanent travel needs of the public, with scheduled services to which everyone has access for a fixed fare. In the context of this complexity, in this paper, we conduct a case study on the public long-distance road bus network (GBTN) of five regions of Greece (Eastern Macedonia and Thrace, Central Macedonia, Western Macedonia, Thessaly and Epirus), using 24 bus stations (analysis zones). During our analysis, various network parameters are introduced to explore the impact of topology on transport and its connection to the socio-economic context of the network. The various local and global properties are evaluated as part of the topological analysis and provide a common platform for understanding and deciphering the intrinsic network characteristics that are partially encoded in their topological properties. In addition, a comparison is made between the topology of two networks, the public interurban road transport network (GBTN) and the interregional road transport network in Greece (GRN) as studied by Tsiotas (2020), expressing a spatial infrastructure network.

2. LITERATURE REVIEW

2.1. Transport, Transport Networks and Spatial Development

Human mobility serves the intrinsic need for mobility and continuously affects the social and economic development of societies at national, regional and local levels (Polyzos, 2011; Rodrigue et al., 2013; Polyzos and Tsiotas, 2020, 2023). The existence and efficient operation of a transport system and the corresponding infrastructure is an essential prerequisite for development both at national, regional and local levels. According to Behrens and Thisse (2007), transport contributes over time to linking individual land uses and promotes the production process and the realisation of trade through the creation of trade flows (Polyzos and Tsiotas, 2020, 2023). Moreover, transport implies the development of economies at the local level, reducing inequalities between regional units and spatial asymmetry in general, while enlarging national economies and promoting international economic transactions (Alexiadis et al., 2011; Polyzos, 2011; Xanthos et al., 2011). The operation of transport networks contributes to regional development (Alexiadis, 2020; Polyzos and Tsiotas, 2020, 2023), as transport intensifies productive activities (contributing to the exploitation of the comparative advantages of regions), facilitates and develops interregional trade reducing travel costs and time (Shimamoto, 2019), expands the tourism sector contributing to the tourist development of remote areas (Caca et al., 2016), increases the degree of social cohesion (helping to address the phenomena of isolation and demographic weakening of regions), and improves the quality of life (contributing to the development of regional economies).

2.2. Public transport and regional development

Providing public transport requires significant organizational efforts, careful planning, financial contributions from the public and coordination between millions of passengers and staff members in large systems. The existence and operation of efficient transport networks and related infrastructure involves a key economic dimension that affects both the level of service to the public interest and the national economy and the level of encouragement of private initiative and enhancement of entrepreneurship (Polyzos and Tsiotas, 2020). Several studies have conducted extensive reviews of economic and policy issues related to public transport (Berechman, 1993; Gwilliam, 2008), others summarize previous developments in optimizing public transport capacity for social improvement (Jara-Diaz and Gschwender, 2003a,b), others review the pricing literature in a multimodal context (Jara-Diaz and Gschwender, 2005; Tirachini and Hensher, 2012; Jansson et al., 2015), while there are studies that review the optimization problems in public transport with a strong orientation towards operational research (Desaulniers and Hickman, 2007).

At EU level, the private car dominates over all other modes of transport (Eurostat, 2020). This fact, to the extent that it is linked to congestion on the arteries of the public transport network, not only has a significant impact on the environment (increased levels of air pollution) and on the quality of life of the populations of large urban centers (road accidents), but also has a negative impact on the mobility (in terms of time and cost) of goods and people transported to and from large urban centers, with consequences for their productivity and the overall efficient management of their time. In Greece, despite the fact that through privatizations and public-private partnerships (PPPs) the share of state control of transport, especially in the land transport sector, has been significantly reduced over the last decade, many transport hubs and transport service infrastructures are still owned by state operators. Investment in public transport affects the flow of money as well as job creation in the economy (Polyzos, 2019; 2023). Several researchers have found a close relationship between infrastructure investment and the economic development of a region (Tsiotas and Tselios, 2023). Transport infrastructure, among the different types of infrastructure, is considered one of the most important by policy makers, since transport costs are very important for the choice of location for businesses and thus the economic development of a region (Polyzos, 2019; Cao, 2021). Improved mobility, time and cost savings provided by investment lead to wider economic growth resulting from changes in business productivity, household disposable income and market access (Karras, 2010; Polyzos, 2019; 2023). There are public policy interests in both elements of economic impact (Polyzos, 2019; 2023; Tsiotas and Tselios, 2023).

2.3. Public Transport in Greece

The KTEL (Common Bus Collection Funds) constitute a separate operational structure in the Greek transport sector. They are public limited companies which are responsible for the execution and operation of intercity and urban passenger transport services. The historical development of KTEL dates back to 1896, when the first French-built bus of only 14 seats appeared on the Athens - Thebes line. Each bus was an independent private enterprise and the owner, at his discretion, without the supervision of the state, could use it in any area and on any route. The fare was freely determined according to the number of passengers or any competition. In 1920-25, the first provisions regulating the circulation or movement of buses appear, such as Legislative Decree 24812 of September 1922, and Presidential Decree 715 of October 1925. In 1937-40, the fundamental provisions were adopted and the first joint urban and intercity bus directorates were established. Consequently, 1937 can be regarded as the starting point for public bus passenger transport. At that time, the joint directorates for urban and interurban buses were created, which was the first essential step in the organization of passenger transport. This process was halted by the Second World War. In the year 1939 the total number of intercity buses in the country was 1635 buses with 27,767 seats. After the end of the war, the reconstruction of bus transport began again and saw a rapid rise due to the fact that the railways had been destroyed and served few areas of the country, there were no airports and the car was essentially the only land-based means of transport. The KTELs were established by Law 2119/1952 "On bus transport by car", one for each island and for each prefecture (a total of 104 common funds were created, of which 59 were intercity and 45 urban). The intercity bus companies had a fleet of 3311 buses with 79,464 seats. By decision of the Ministry of Transport, in 1967-68, all the KTELs were merged into 8 KTELs (Joint Reciepts Fund of Buses). The 6 urban KTELs of Attica were merged into 1, the 45 intercity KTELs of the mainland and Crete were merged into 8 KTELs, and the remaining 53 maintained their independence. However, this system proved to be problematic and Legislative Decree 102/1973 'On the organization of buses, cars and public passenger transport services' reverted to the previous system. Under Law 1437/1984, a process of separation of the urban and interurban bus companies was initiated under Article 24. Law 1437/1987 "Regulation of issues of passenger cars for public use and other provisions" ensured their definitive separation into intercity and urban, while Law 2963/2001 "Organization and operation of public passenger transport by bus, technical inspection of vehicles and transport safety and other provisions" transformed them into joint-stock companies providing transport, commercial and tourist services.

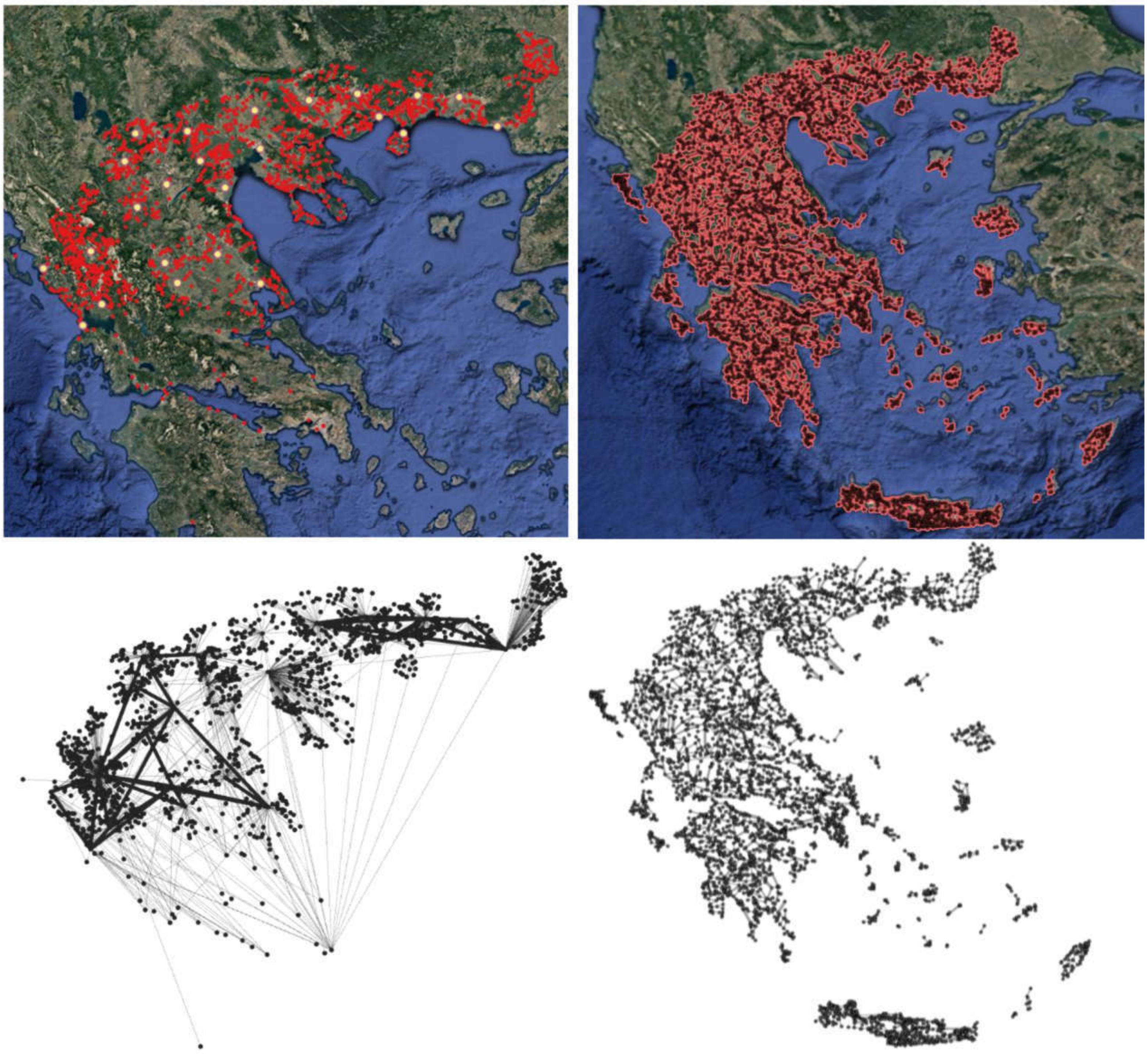
Today, there are sixty-two KTEL operating in the form of limited companies with a fleet of around 4,199 buses. Although they are private companies (not directly subsidized by the State, as is the case with urban transport), they continue to be, in essence, public utilities, under the direct supervision of the State, which sets the fare (ticket prices) and offers the highest social good of public transport. In different countries, depending on the spatial structures, alternative transport services and regulations, there are huge differences in market shares. In fully deregulated countries such as the UK, the USA and Sweden, intercity buses operate without subsidies, while, in partially deregulated countries such as Norway and Spain, long-distance buses are operated with subsidies as a result of competitive tendering (Augustin et al., 2014). The supervisory bodies of the bus operators are the relevant Region and the Ministry of Infrastructure and Transport. Intercity bus stations owned by the State or other public sector bodies or public-private partnerships are part of the public intercity passenger road transport network.

The KTELs cover the basic road transport connections between local and municipal units and the administrative and economic centers of the urban areas of Greece. As far as the region of Attica, excluding the regional unit of islands, and the regional unit of Thessaloniki are concerned, the planning of the interurban road passenger transport network concerns only the interurban lines within their geographical boundaries, as well as the interurban line Athens - Thessaloniki. In addition, the bus services shall take into account the specific needs of pupils or trainees for travel to education centers and workers for travel to work. The contribution of KTEL to the regional economy is considered to be considerable, as it serves the mobility of many workers and connects remote areas of Greece with regional and national centers, serving to promote regional and local development in various ways, such as by improving accessibility for tourists. Moreover, the importance of KTEL as the main provider of long-distance transport services in Greece is evident from the fact that it covers areas where there are no alternative (ferry, rail or air) transport services at a national level (Tsiotas and Polyzos, 2015a,b; Alabanos and Theodoropoulos, 2017). In addition, several KTELs have set up tourism offices, organizing excursions to destinations inside and outside Greece, and operate routes between Greek urban centers and urban centers in neighboring countries. In order to carry out their transport work, the KTELs may undertake studies relevant to the organization and operation of their work and may carry out any transport project, subject to compliance with the relevant conditions of the regional unit, by setting up special transport companies to carry out this work. Given that the structure of the existing networks is characterized by a high degree of complexity, the study of bus networks in terms of complex network analysis is expected to be enlightening both in terms of economic geography and regional policy. A complex network is a network characterized by unusual topological properties (i.e. properties not found in simple networks or random graphs), but which occur in 'real world' networks (Barthelemy, 2011). The analysis of transport systems as complex networks can be an effective methodological tool for their investigation (Tsiotas and Polyzos, 2015a,b; Tsiotas, 2017, 2021). From a network science perspective, transport infrastructures correspond to networks and transport to the flows that take place within networks. The particular structure, form or function of transport networks may vary depending on current historical, economic and social conditions. It has been observed that the emergence and expansion of transport networks is a pole of attraction for economic and social activities in adjacent areas (Tsiotas and Polyzos, 2018). As a rule, therefore, the formation of areas (hubs) characterized by high accessibility implies an increase in the overall demand for the establishment of activities and, therefore, the creation of a comparative advantage in relation to other competing areas.

3. METHODS AND DATA

The methodological framework applied for the analysis of the public interurban road transport network (GBTN) consists of three distinct steps. The first is the graphical modeling of the GBTN (public long-distance road transport destinations and origins). In the second, important topology and geometry measures related to the structure and efficiency of the GBTN are calculated and compared with the corresponding measures of the inter-regional road transport network in Greece (GRN) as studied by Tsiotas (2021). The third step contains the empirical analysis which is carried out on a set of network and socio-economic variables for each regional unit, analyzing the results on the socio-economic performance of the GBTN topological structures both from a computational and empirical point of view. Initially, GBTN is modeled on a geo-referenced initial graph (Tsiotas, 2021), taking into account the spatial integration of 24 public long-distance road transport networks (KTEL) for the regions of Eastern Macedonia and Thrace, Central Macedonia, Western Macedonia, Thessaly and Epirus. The graph is represented in the space L, called the stop space (Kurant and Thiran, 2006; Von Ferber et al., 2009), where a bus stop is treated as a node and a pair of nodes are connected by an edge if there is at least one route serving the two stops consecutively. Multiple edges between nodes are not considered in order to display the actual physical connectivity of the network (Tsiotas and Polyzos, 2015a). In GBTN the L-space representation consists of bus stops and the presence or absence of connectivity between stops regardless of the number of routes between stops. Figure 1(a) shows the spatial locations of GBTN bus stops and the final network structure. Each sub-network node is connected to a central point (origin node), having point-to-point connectivity. The sub-network centers (KTELs) are shown in yellow and are indicated as bus starting points in the capital cities of the regional units (with the exception of the KTEL of Chalkidiki, where the starting point is defined as Thessaloniki). The digitization was carried out using QGIS, an open source geographic information system software that allows the creation, visualization, processing and analysis of geospatial data. Google Earth was used to visualize the spatial location of the bus stops and Gephi (Bastian, et al., 2009) for visualization and topological analysis. Also, Figure 1(b), illustrates the spatial locations of roadway intersections and the GRN structure (Tsiotas, 2021).

Fig.1. Spatial location of (a) GBTN bus stops (destinations and origins) (1486;1663) and (b) GRN road route intersections (stops) (4993;6847)



(Source: Own editing ; Tsiotas, 2021)

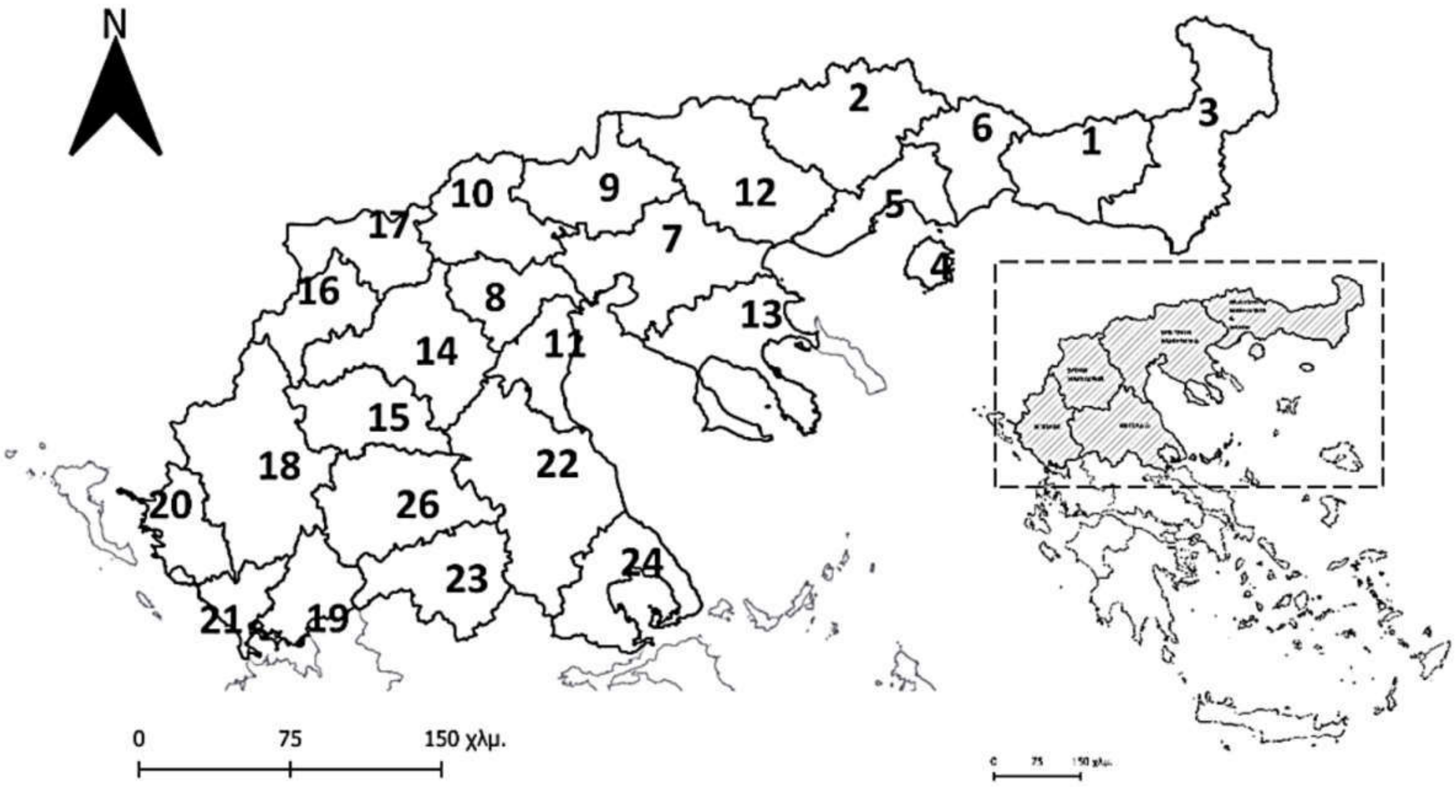
The bus network data for GBTN used in this study were obtained from the official websites of the twenty-four local bus transport organizations, and the institutional frameworks of the competent authorities (Directorate of Transport and Communications) and local authorities (see Annex). The information available for each long-distance line included the list of stops and the list of routes (sequence of stops) operated by the operators. A stop or station is a designated place available for picking up or dropping off passengers and a route (stop sequence) is a route followed to reach the destination from a source along intermediate stops. The key assumptions followed in the article to extract the datasets to extract meaningful information are summarized as follows:

- Destinations (places of arrival) are considered to be intermediate stops (settlements) and the final destination (settlement), even if they are round trips
- If the stop is outside a settlement (e.g. at a junction), the nearest settlement is taken as the stopping place
- Routes which are operated only when the school is in operation are considered as permanent routes (destinations)
- No separation of winter and summer routes (destinations)

In this framework, the GBTN was constructed as an undirected graph G(V,E), with spatial weights, consisting of n=1486 nodes (vertices) and m=1663 edges (links). The set of nodes V corresponds to the origins and destinations (place of arrival) of the GBTN, while the set of edges E, represents the road routes between origin and destination. The positions of the nodes are located at the exact geographical coordinates (longitude, latitude) of the GBTN buildings, while the edges are drawn as lines and not in their natural (to scale) form. The weights of the edges represent the geographical distance (in km) and the time distance (in minutes) between two nodes. The geographical location of waypoints along road links between consecutive stops and the travel time of the whole route were not available from all operators of the routes, so an approximation had to be made for each route. The assumption made was to take as distances the minimum kilometric distance, within a radius of more than 10 km from the center of each sub-network (origin), and the minimum time distance between the origin stop and the destination stop, even if they do not correspond to the same road route. Because this assumption is constant in space and time across all sub-networks, its effect does not affect the results. The GBTN emerged non-connected network (Tsiotas & Polyzos, 2015a), having 25 subnets as components.

In the next stage of the empirical analysis of GBTN, a correlation analysis is applied to a set of road network infrastructure, spatial, economic, demographic and tourism variables. To apply the correlation analysis, the variables were reduced to the scale of a regional unit, as the network nodes do not have any additional exploitable physical or economic importance. The variables involved in the analysis were drawn from relevant literature (ELSTAT, 2011; Tsiotas and Polyzos, 2015a,b;. Tsiotas, 2017, 2021; Tsiotas et al., 2011, 2022) and are presented, by category, in Table 1.

Fig.2. Map of the GBTN Regional Entities' connecting components



Source: Own editing

Table 1 Variables participating in the GBTN empirical analysis

Symbol	Description
Topological and spatial variables	
n	The number of GBTN nodes
m	The number of GBTN connections
$\langle K \rangle$	The average degree of GBTN nodes
$\langle k_{w(km)} \rangle$	The weighted average (kilometric proximity) degree of the GBTN nodes
$\langle k_{w(min)} \rangle$	The weighted average (time proximity) degree of the GBTN nodes
CC	The average centrality proximity of GBTN
CB	The average intermediate centrality of GBTN
C	The average concentration factor (probability of finding connected neighbours) of GBTN
$\langle d_{km} \rangle$	The average mileage of GBTN
$\langle d_{min} \rangle$	The average GBTN time distance
R_{km}	The GBTN mileage range
Network infrastructure variables	
RODENS	Road density, defined as the fraction of the total length of the country's roads to the total area of the country
RADENS	Railway network density, defined as the ratio of the total length of railways to the total area of the country
PRT	The number of ports
AIR	The number of airports
CENTR	Centrality, the average distance of the capital regional unit from all others in the network
FLT	The GBTN fleet, the sum of the fleets of the 25 subnets
DATH	The distance of each service point/background to Athens
DTHS	The distance of each service point/back-up point to Thessaloniki
Socio-economic variables	
POP	The permanent population
URBAN	The degree of urbanisation - ratio of the population of the capital of a regional unit to the total of the regional unit
EDU	The level of education
HUM	Human capital-qualitative characteristics of the population
FRC	The number of employees
A_SEC	The contribution to the national primary sector GDP of the regional study units
B_SEC	The contribution to the national secondary sector GDP of the regional study units
C_SEC	The contribution to the national tertiary sector GDP of the regional study units
TOUR	The contribution to the tourism sector of the study regions
FRM	The number of enterprises registered with the E.E.E.
PRVHC	Private motor vehicles in circulation
MTR	The motorcycles in circulation
PVHC	Public motor vehicles in circulation
BUS	The buses in circulation
TCKATH	The ticket price for Athens
TCKTHS	The ticket price for Thessaloniki
COST	The travel cost/kilometre
GDP	The Gross Domestic Product (GDP)

Source: Own elaboration

The correlation analysis is performed by calculating Pearson's correlation coefficient, which is a measure of linear involvement of two random variables. This coefficient is denoted by rxy (Norusis, 2011) and takes values in the interval [-1,1]. The extreme values -1 and 1 correspond to the case when all points lie on a straight line with a negative or positive slope, respectively. The coefficient rxy is a pure number thus allowing comparisons.

4. RESULTS AND DISCUSSION

4.1. Topological Analysis

The topological analysis of GBTN was performed using basic theoretical topological measures (e.g., degree, concentration factor, centrality proximity), global measures (e.g., degree distribution, average path length) network and community detection. The results of computing the network measures compared to the corresponding measures of the inter-regional road network in Greece (GRN) calculated by Tsiotas (2021) are presented in the comparative Table 2.

Table 2 Comparative table of GBTN and GRN measures[(a)]

Metric/Measure	Symbol	Unit	GBTN	GRN[(a)]
Type of graph	#	#	Non-directed	Non-directed
network nodes	n	#[(b)]	1486	4993
Network edges	m	#	1663	6487
Connected components	a	#	2	156
Maximum degree	k_{max}	#	251	8
Minimum degree	k_{min}	#	1	1
Average degree	k	#	2.238	2.598
Average distance - weighted degree	$\langle k_{w(km)} \rangle$	km	140.657	14.108
Average time - distance weighted degree	$\langle kw_{(min)} \rangle$	min	122.203	N/A[(d)]
Average path length (weighted)	l	#	3.371	46.794
Network diameter (weighted)	D	km	4	993
graph density	P	net[(c)]	0.002	0.001
Average clustering coefficient	$\langle C \rangle$	net	0.686	0.07
Modularity - weighted	Q_w	net	0.774	0.946
No of communities	No_w	#	13	N/A
Modularity - distance weighted	$Q_{w(km)}$	net	0.621	N/A
No of communities - distance weighted	$No_{w(km)}$	#	10	N/A
Modularity - time - distance weighted	$Q_{w(min)}$	net	0.673	N/A
No of communities - time - distance weighted	$No_{w(min)}$	#	11	N/A

[(a)] Source: Tsiotas (2021); [(b)] Number of settlements; [(c)] Dimensionless number; [(d)] N/A: Not available

The GBTN study areas (Eastern Macedonia and Thrace, Central Macedonia, Western Macedonia, Thessaly and Epirus) cover almost half of the geographical area of the GRN since GBTN serves almost half of the regional units. The GBTN consists of 1486 nodes of which 24 are hubs and the rest are spokes. The GBTN is a network with 2 connecting components, no isolated nodes (kGBTNmin≠0) and no self-connections. The maximum value of the GBTN node degree is kmax(GBTN) =251. In the case of GRN, it is kmax(GRN) =8 and is almost half compared to the cases of urban systems (Buhl et al., 2006; Barthelemy, 2011), where kmax(GRN) 20. The average value of the degree ⟨k⟩GPRN =2.238 is of the order of the lattice network structure size and represents the connections attributable to the 1462 regional destinations. Despite the specialization of GBTN in public long-distance road transport, the average value of the degree seems to be in line with the GRN case ⟨k⟩=2.598, outlining that the bus operators have a rudimentary business profile.

The average distance-weighted degree of nodes is equal to ⟨kw(km)⟩=140.657km and expresses the total length of connections that a random node in the network has. The average time-distance-weighted degree of nodes (average time-distance-weighted degree) ⟨kw(km)⟩=122.203min shows a similar magnitude value. From the two weighted degrees, it can be seen that the average access speed of intercity buses is 69km/h. The maximum permissible speed limit of motor vehicles, inside residential areas, is set at 50km/h. Outside residential areas, for highways, expressways and other network, the maximum permissible speed limit is set at 100km/h for buses, 80km/h for double-decker buses and 80km/h for school buses (amendment to Article 20, Government Gazette 57A/1999). As the bus services operate only long-distance routes, it can be concluded that more services are operated in inaccessible areas. The starting points of the bus services are on average 52 km from the furthest geographical boundaries of the regional districts to which they belong. Therefore, according to the weighted (in terms of distance in km), the routes of each bus service extend on average over three regional units. The measure of the weighted average degree and the average degree provide us with the information that, although the bus routes are outward-looking, they cover long distances in terms of kilometers and time, as almost two routes (connections) lead to the destinations, whenever the network cannot serve all the destinations.

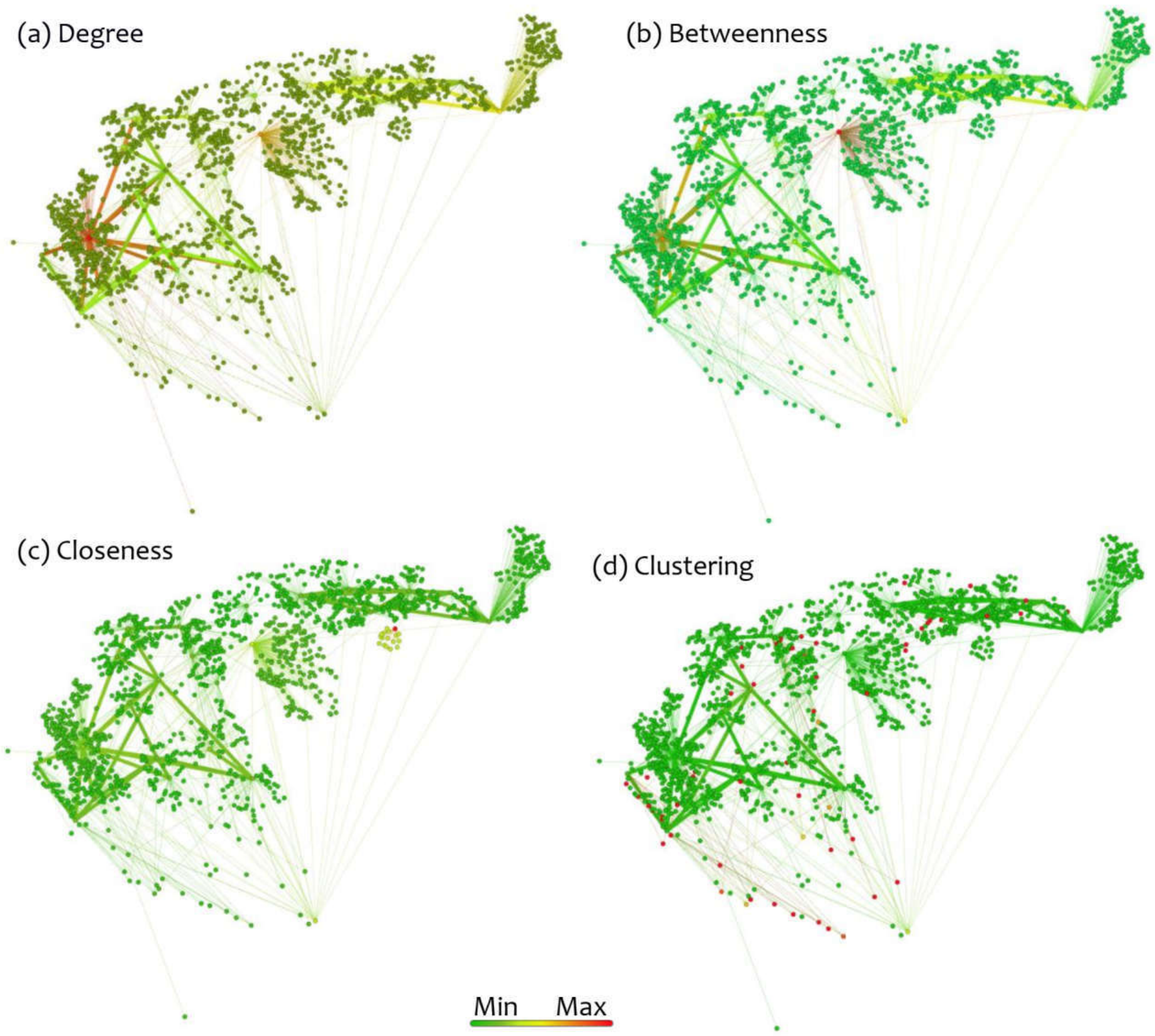
The value of the average path length of the network expresses that the number of steps separating the most distant vertices of the network consists of 3,371 edges (connections). The low value of the GBTN average path length expresses a satisfactory level of directness and accessibility. The GRN consists of $\langle l \rangle$=46,794 edges. The values of $\langle l \rangle$ express the generalized cost of the movements occurring within the networks (Tsiotas and Polyzos, 2015a), which are affected by flatness constraints. Then, the diameter is the largest of all shortest paths and is an upper bound on the average path length. The spatial (kilometric) diameter of GBTN and GRN is equal to 4km and 993km, respectively, and expresses the kilometric distance between the two most distant nodes in the network. The density of the non-planar GBTN is equal to p=0,002, a value which is infinitesimally small and does not seem to be amenable to further interpretation given the planar nature of the network. Next, the average GBTN concentration factor quantifies the neighborhood relationship between nodes in a network. GBTN clustering is of the order of 69%, expressing high efficiency of regional relationships and good regional policy. The high value of the concentration (clustering) coefficient combined with the low value of the average path length demonstrates the efficiency and accessibility of GBTN. The corresponding value for the GRN network is equal to 0.07. Both values of $\langle C \rangle$ are much larger than the corresponding value of a random ER network, which is approximated by (C)ER ~ 1/n=2·10-4 (Barthelemy, 2011), which suggests that GBTN and GRN are far from being described by the random pattern typology. Finally, the value of the modularity of GRN is equal to QGBTN =0.774 and expresses the ability to partition the network into communities. The communities obtained from the analysis are 13, a number that indicates a general competitive behavior but also a complementary behavior between neighboring (in geographical location) GRNs. The value of the modularity was also calculated with the edge weights, kilometer and time distance. The weighted modularity with kilometric proximity is 0.621, with ten communities and with temporal proximity is 0.673 with eleven communities.

In the next step, the key measures of topology and centrality (degree, interest, proximity, concentration) are presented in the topological maps in Figure 3. First, in the spatial distribution of degree (Figure 3a), the highest value appears in Ioannina, at the starting point of the Ioannina Bus Station (Ioannina Bus Station), making this hub. Ioannina, is the largest city in Epirus and the capital of the regional unit of Ioannina with a population of about 70,000 inhabitants (Polyzos, 2019). The regional unit is one of the largest regional units in Greece and occupies about half of the geographical region of Epirus, with an area of 4990 km2, is mainly mountainous and access is mainly by road with the Ioannina bus service. Of the 251 connections, only 32 are outside the boundaries of the regional unit, covering and ensuring access mainly to the villages of the regional unit. The direction of the Ioannina bus service is characterised by introversion and has a specific economic function and geographical limitation. The analysis also revealed the hub of Thessaloniki as the second most centralised (177 connections). In contrast to the case of Ioannina, the connectivity of Thessaloniki is mainly due to the operators of the other regional units in addition to the regional unit itself. First of all, in the regional unit of Thessaloniki, the planning of the interurban road passenger transport network concerns only the interurban lines within its geographical limits, as well as the Athens - Thessaloniki interurban line, a total of 50 connections. For the other regional units, however, Thessaloniki is a key road link and an economic pole as it concentrates the largest part of the country’s population and economic activity after Athens (Polyzos, 2023). Approximately 33% of the national population lives in metropolitan Athens (with 3562538 people), 10% in metropolitan Thessaloniki (with 1054673 people), 6% in 6 medium-sized urban areas (250000 to 0.5 million inhabitants) and 8% in 6 small urban areas (50000 to

250000 inhabitants). The rest of the population (about 43%) inhabit in small municipalities with a population of about 50000 inhabitants or less (Polyzos, 2019, 2023). Finally, Thessaloniki is also the headquarters of the Halkidiki bus station with 102 connections.

Figure 3b and 3c depict the centrality distributions (intermittency and proximity centrality) of GBTN. The highest value on the map for proximity occurs on the island of Thassos, due to the insufficient connectivity of this island component, verifying the empirical research of Tsiotas (2021). Then, the highest value of intermediate centrality belongs to Thessaloniki. An interesting observation concerns the fact that the taxonomic hierarchy of nodes is maintained between the results of degree centrality and intermediacy centrality.

Fig.3. Spatial distribution of GBTN measures: (a) degree (b) intermediate centrality (c) centrality proximity (d) concentration factor



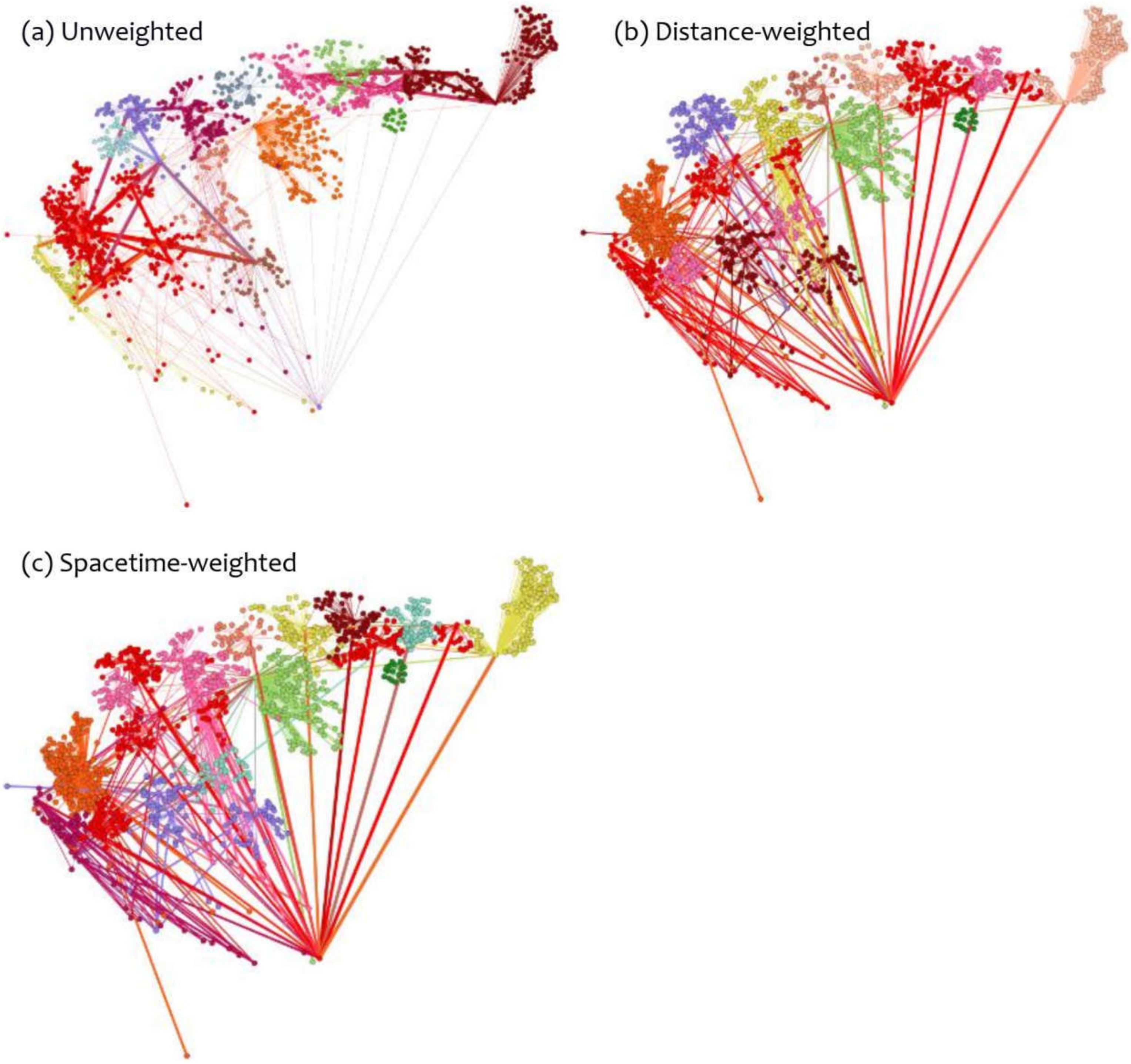
Source: Own ed.

Hubs are by definition natural crossroads, so that the correlation between nodes with high degree centrality and those with high value of intermediate centrality is expected (Barthélemy, 2011). Thessaloniki is a modern city of Central Macedonia, the largest city in the geographical area of Macedonia (Polyzos, 2023) and a pole of attraction for commercial, economic, financial, economic, cultural, educational and social activities in the country and the region. The city's location in the wider Macedonia-Thrace region, the existence of an airport, the existence of its port as a natural gateway of this region to the sea make Thessaloniki an important strategic point on the one hand, and a commercial, transport and cultural crossroads on the other (Tsiotas and Polyzos, 2015b; Polyzos, 2023). Thessaloniki is also the most important railway hub in the country on the PATHEP (Patras - Athens - Thessaloniki - Idomeni/Promahon) axis, as it connects Greece with the rest of Europe and Turkey and is the main transport and freight hub in the wider Balkan region (Tsiotas, 2017). The intercity bus station in the city (hub) of Thessaloniki interferes with a large number of closer routes (paths) of the network as it is the terminal station for intercity buses throughout the country. Therefore, due to the attraction of travel and consequently of organised transfers, Thessaloniki is an important transfer station. Finally, the spatial distribution of the clustering coefficient C (Figure 3d) appears to be very complex. High values of the coefficient indicate interconnected areas (existence of triangles), i.e. areas with many circular connections, where nodes have neighbours that are connected to each other. This situation may be related to the existence of areas with significant economic or related activity, since among the locations with high values there are areas within the study regions such as Asprovalta and Farsala, and outside the study regions such as Thebes, Lefkada and Chalkida.

Next, the spatial distribution of modularity values is captured in Figure 4 and appears consistent with theory (Barthelemy, 2011; Tsiotas, 2021). Relevant empirical research has generally highlighted that the sharing of spatial networks in communities is generally governed by geographical criteria, not providing particularly useful structural information, because the most important flows in the network are located between nodes belonging to the same or similar geographical areas (Guimera et al., 2005; Kaluza et al., 2010; Barthelemy, 2011). For example, in the study by Haznagy et al. (2015), the city centre was found to have few communities while the periphery has many communities. Moreover, a total of 46 communities with a strong modularity value of 0.91 were observed in an urban rail transit system in China (Zhang, et al., 2013). In a similar context, the spatial distribution of GBTN modularity values is also shown, which is partitioned into 13 color bands, highlighting a partial bipolar trend with relative geographical relevance. In contrast, the communities of mileage-weighted (Qkm) and time-weighted (Qmin) proximity-weighted modularity do not appear to be strictly determined by geographical criteria. The composition of communities involving modules located in different geographical areas, for both Qkm and Qmin, also highlight connections between disparate spatial modules.

We further proceed to study the degree distribution, which is insightful in revealing topological patterns in networks (Tsiotas, 2019). Intuitively, although we would expect that a certain number of stops in the network are served by a large number of routes, it is interesting to verify such a property mathematically. Figure 5 shows that both the degree and power (weighted degree) distributions follow a power-law distribution with a hierarchical structure, highlighting scale-free properties in GBTN with hyper-node operation. Compared to the normal distribution, this property expresses that a high percentage of nodes have connectivity less than the average value, while a low percentage of nodes have a degree greater than the average (hubs). The scale-free property in public transport networks expresses that hubs carry 80% of the load, having more connections, and 20% of the load is carried by the remaining nodes. Networks with such a structure are quite widespread in the transport sector mainly due to the fact that a transport operator needs to minimize its operational costs, even if this is not accompanied by minimizing the average travel time of commuters (Tsiotas and Polyzos, 2015b; Tsiotas, 2021). The emergence of the hub-and-spoke topology in public intercity road networks is a consequence of economic expectations, due to the creation of hub-and-spoke bus stations in areas with large urban concentrations (regional capitals), but also due to the efforts of bus operators to increase network efficiency (serving more destinations with the minimum total number of transfers) while reducing operating costs. Therefore, a profitability-oriented strategy emerges (Tsiotas and Polyzos, 2015b), an obvious strategy for any sound business organization operating in a free competition market (Tsiotas, 2022; Polyzos, 2023). Finally, from Figure 5(a), the price dispersion is adjusted to 66%. Although this is a normal but not high adjustment, it does not invalidate the network structure.

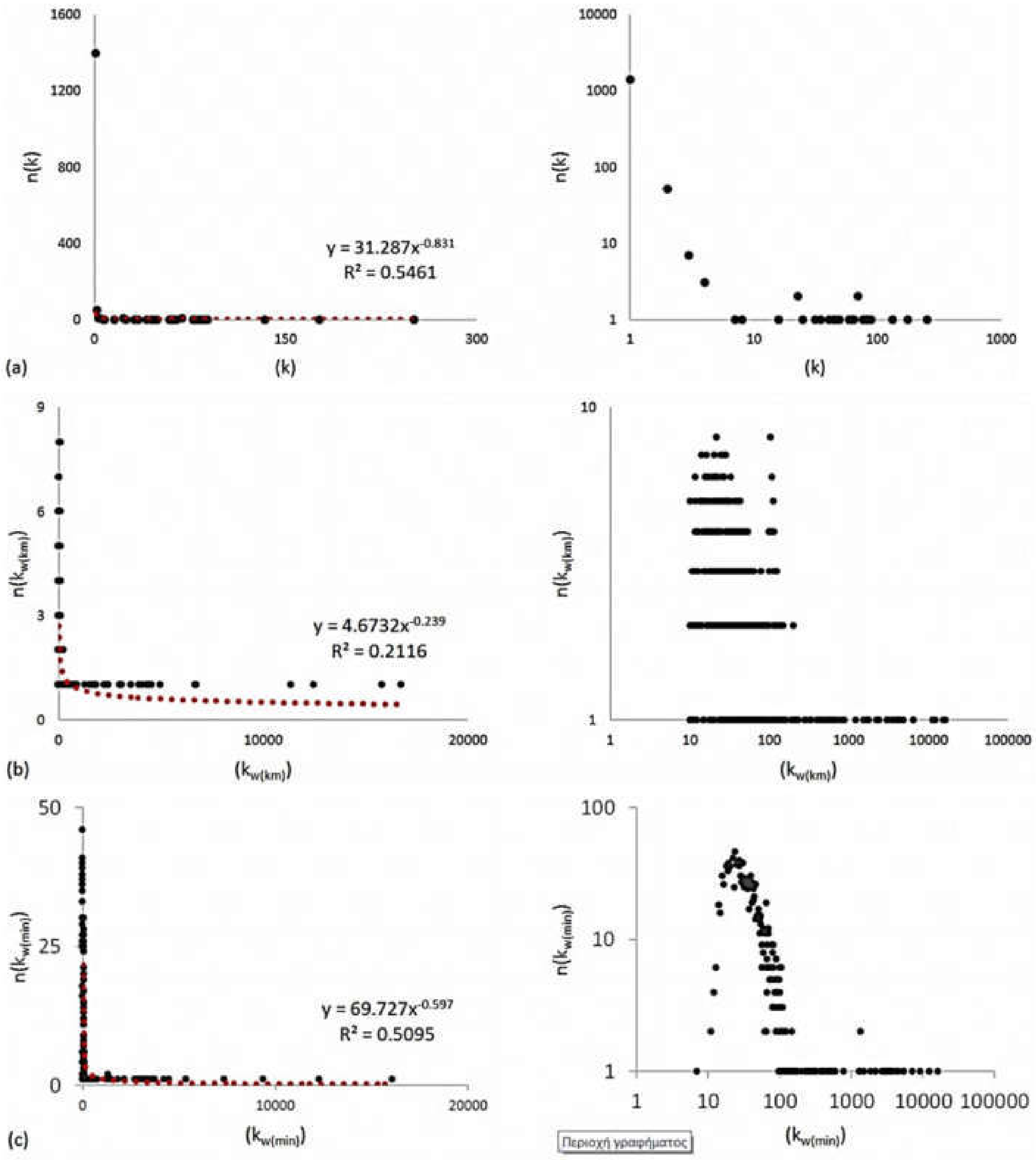
Fig.4. Spatial distribution of (a) weightless modularity, (b) modularity weighted by the information of kilometric proximity and (c) modularity weighted by the information of temporal proximity



Source: Own elaboration

Overall, the topology analysis shows that GBTN is subject to spatial limitations, failing to serve all destinations in a more direct manner. At the same time, however, long-distance routes are characterized by extroversion, as they extend over long distances in terms of kilometers and time. The routes of each bus company cover on average three regional units. In terms of immediacy and accessibility, this finding characterizes the network as satisfactory, as three stops or transfers are interspersed between the most remote destinations on the network. The network serves 69% of the regional locations, further outlining the business profile of the Ioannina network, which is oriented towards local markets. This quite satisfactory percentage reflects relatively high efficiency of regional relations, good regional policy and support and promotion of the economic profile of local markets.

Fig.5. Spatial distribution of (a) weightless modularity, (b) modularity weighted with the information of kilometric proximity and (c) modularity weighted with the information of temporal proximity



Source: Own elaboration

At the same time, a strategy oriented towards profitability is highlighted. The GBTN analysis provides topological information such as the existence of a hierarchical hub-and-spoke structure and the absence of scale in the network. This situation is due to the operation of hubs, which carry 80% of the switching load, having more connections, and 20% of the load is carried by the other nodes. Networks with such a structure are quite widespread in the transport sector mainly due to the fact that a carrier needs to minimize its operational costs, even if this is not accompanied by minimizing the average travel time of the commuters (Barthelemy, 2011; Rodrigue et al., 2013; Tsiotas, 2021). The emergence of this topology in public long-distance road networks is a consequence of economic expectations, due to the creation of hub bus stations in areas with large urban concentrations such as the capitals of regional districts (Polyzos, 2019; Tsiotas, 2022). Similarly, it is an outgrowth of the efforts of bus operators to increase the efficiency of the network (serving more destinations with the minimum total number of transfers) while reducing operating costs. It is an obvious strategy for any sound business organization operating in a free competition market (Tsiotas, 2022; Polyzos, 2023). Also, the results of the analysis express that GBTN shows strong heterogeneity in terms of traffic. The central hub areas from a geographical point of view (first three highest values in Thessaloniki, Ioannina and Athens), having only a few main roads with high traffic, are expected to be the beneficiaries of future transport infrastructure projects (Polyzos and Tsiotas, 2020; Tsiotas et al., 2021, 2022). The analysis also found that bus services operate more in hard-to-reach areas and that they serve more travel within the regional unit or with neighboring regional units, underlining the operational local character of bus services

4.2. Empirical Analysis

In the empirical analysis part, a correlation analysis is performed on the variables in Table 1 to identify relationships between network measures and GBTN socioeconomic variables. The results of the analysis for different levels of significance (5% and 1%) are presented in Table 3.

Table 3 Results of the GBTN correlation analysis

Metric	Stat.	FLT	POP	PRVHC	PVHC	BUS	MTR	GDP	DATH	TCKATH	DTHS	TCKTHS	COST	URBAN
n	r	.466*	.094	.142	.005	.090	.007	-.192	.234	.193	.139	.159	.101	-.183
	Sig.	.022	.596	.423	.978	.611	.969	.276	.282	.377	.538	.479	.654	.301
	N	24	34	34	34	34	34	34	23	23	22	22	22	34
m	r	.431*	-.020	-.015	-.009	-.005	-.048	-.056	.169	.145	.199	.217	.115	-.209
	Sig.	.036	.928	.946	.966	.980	.825	.796	.442	.509	.376	.331	.612	.328
	N	24	24	24	24	24	24	24	23	23	22	22	22	24
⟨k⟩	r	.001	.959**	.975**	.975**	.970**	.973**	.511**	-.216	-.229	.307	.322	.218	-.318
	Sig.	.997	.000	.000	.000	.000	.000	.002	.323	.293	.164	.144	.330	.063
	N	24	35	35	35	35	35	35	23	23	22	22	22	35
⟨CC⟩	r	.421*	.907**	.899**	.903**	.905**	.902**	.615**	-.096	-.118	.175	.182	.204	-.311
	Sig.	.040	.000	.000	.000	.000	.000	.000	.664	.593	.436	.417	.362	.069
	N	24	35	35	35	35	35	35	23	23	22	22	22	35
⟨CB⟩	r	.172	.968**	.989**	.992**	.986**	.985**	.532**	-.094	-.232	.148	.124	-.091	-.271
	Sig.	.421	.000	.000	.000	.000	.000	.001	.671	.287	.511	.584	.689	.116
	N	24	35	35	35	35	35	35	23	23	22	22	22	35
⟨C⟩	r	.026	.095	.083	.112	.090	.112	.262	-.139	-.023	.141	.177	.327	-.117
	Sig.	.905	.586	.636	.523	.606	.523	.128	.526	.916	.531	.432	.137	.502
	N	24	35	35	35	35	35	35	23	23	22	22	22	35
⟨dkm⟩	r	-.063	.003	.011	.015	.018	.015	.278	-.063	.040	.577**	.587**	.422	-.408*
	Sig.	.769	.989	.958	.943	.935	.945	.189	.775	.858	.005	.004	.050	.048
	N	24	24	24	24	24	24	24	23	23	22	22	22	24
⟨dmin⟩	r	-.014	-.008	.000	.007	.016	.018	.245	-.223	-.107	.665**	.668**	.457*	-.417*
	Sig.	.948	.971	.999	.975	.942	.934	.249	.307	.626	.001	.001	.032	.043
	N	24	24	24	24	24	24	24	23	23	22	22	22	24
Rkm	r	-.038	.005	.025	.016	-.021	.022	-.128	.986**	.934**	-.057	-.050	-.113	.221
	Sig.	.862	.982	.906	.940	.923	.919	.551	.000	.000	.800	.825	.616	.299
	N	24	24	24	24	24	24	24	23	23	22	22	22	24

Table 3 (continued) Results of the GBTN correlation analysis

Metric	Stat.	EDU	HUM	FRC	A_SEC	B_SEC	C_SEC	TOUR	FRM	RODENS	RADENS	PRT	AIR	CENTR
n	r	.103	.120	.091	.111	-.177	.146	.059	.095	-.212	-.030	-.223	.147	-.236
	Sig.	.561	.500	.609	.533	.318	.409	.739	.594	.229	.868	.204	.408	.179
	N	34	34	34	34	34	34	34	34	34	34	34	34	34
m	r	-.017	-.015	-.015	-.159	-.063	.164	-.032	-.016	.199	-.123	.092	.228	-.124
	Sig.	.939	.943	.944	.459	.770	.443	.881	.942	.352	.566	.669	.284	.563
	N	24	24	24	24	24	24	24	24	24	24	24	24	24
⟨k⟩	r	.963**	.901**	.964**	-.356*	-.056	.239	.945**	.958**	.817**	.863**	.700**	.205	.100
	Sig.	.000	.000	.000	.036	.749	.166	.000	.000	.000	.000	.000	.237	.566
	N	35	35	35	35	35	35	35	35	35	35	35	35	35
⟨CC⟩	r	.907**	.865**	.908**	-.439**	-.025	.246	.909**	.910**	.855**	.703**	.809**	.314	.065
	Sig.	.000	.000	.000	.008	.888	.155	.000	.000	.000	.000	.000	.067	.710
	N	35	35	35	35	35	35	35	35	35	35	35	35	35
⟨CB⟩	r	.975**	.885**	.975**	-.338*	-.045	.218	.954**	.967**	.861**	.879**	.744**	.193	.062
	Sig.	.000	.000	.000	.047	.799	.209	.000	.000	.000	.000	.000	.266	.722
	N	35	35	35	35	35	35	35	35	35	35	35	35	35
⟨C⟩	r	.091	.102	.096	-.371*	.471**	-.336*	.087	.093	.204	.088	.396*	.050	.111
	Sig.	.604	.558	.582	.028	.004	.049	.620	.594	.240	.616	.019	.774	.527
	N	35	35	35	35	35	35	35	35	35	35	35	35	35
⟨dkm⟩	r	.008	-.096	.011	-.112	-.123	.203	.044	.017	.225	-.357	.093	.244	.050
	Sig.	.970	.656	.958	.602	.568	.341	.837	.937	.291	.087	.664	.251	.818
	N	24	24	24	24	24	24	24	24	24	24	24	24	24
⟨dmin⟩	r	-.003	-.099	.001	-.142	-.180	.285	.038	.011	.249	-.491*	.145	.344	.193
	Sig.	.988	.645	.998	.507	.401	.178	.859	.960	.241	.015	.500	.100	.365
	N	24	24	24	24	24	24	24	24	24	24	24	24	24
Rkm	r	.002	.029	.002	-.017	.374	-.407*	-.058	-.030	-.148	.450*	-.351	-.037	-.746**
	Sig.	.993	.893	.993	.937	.072	.048	.787	.890	.491	.027	.093	.862	.000
	N	24	24	24	24	24	24	24	24	24	24	24	24	24

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

(Source: Own elaboration)

Firstly, there are correlations (significant at the 5% level) between the variables of number of nodes n and number of edges m with the variable of the fleet FLT of the public interurban road networks of the regional districts, namely r(n,FLT)=0.466 and r(m,FLT)=0.431. Given that the fleet is a structural and functional characteristic of the public transport operators, the above correlations indicate that the fleet is a determinant and determinant of the network size. Bus operators serving more settlements (nodes) have a larger fleet and undergo economies of scale (Polyzos, 2019, 2023). As the number of service locations increases, the fleet of operators increases. Also, the fleet is significantly correlated at the 5% level with the average GBTN proximity centrality, where r(⟨CC⟩,FLT)=0.421, highlighting that the network with the largest fleet extends farther and distances become shorter.

Then the majority of network variables, the average degree of nodes ⟨k⟩, the average centrality proximity ⟨CC⟩, the average intermediate centrality ⟨CB⟩, the average weighted (kilometric proximity) degree of nodes ⟨kw(km)⟩⟩ and the average weighted (temporal proximity) degree of nodes ⟨kw(min)⟩⟩ include (high or moderate) information about the network infrastructure, as shown by the positive correlations (significant at the 5% level) with RODENS country road network density, RADENS country rail network density and with the number of PRT ports. This observation suggests that network variables are related to structural aspects of the public long-distance road transport network, which highlights the interaction of network topology and geometry in spatial networks (Tsiotas and Polyzos, 2018). Also, regional units of public interurban road networks with high connectivity, accessibility and long distances tend to have ports and railway stations, highlighting the advantage of intermodality. An efficient public long-distance road network acts positively towards the regional unit's coastal (Tsiotas and Polyzos, 2015a) and rail (Tsiotas, 2017) activity. Intermodality is part of sustainable mobility (Polyzos, 2023) and aims to improve the efficiency and attractiveness of a trip made by combining more than one mode of transport avoiding the use of private cars (Rodrigue et al., 2013). Using and combining different modes of transport in a flexible way in a single trip is vital for a more efficient and sustainable intercity transport system. In central cities and towns, intermodal stations have a central role for the proper functioning of an efficient intermodal transport chain (Rodrigue et al., 2013; Polyzos, 2023). In this context, the lack of correlation with the airport number variable highlights that no significant intermodal cooperation occurs between the public long-distance road network and the air network and that the public long-distance road network has developed to serve more other types of transport. On the other hand, the correlation coefficient of the average concentration coefficient with the number of ports shows a low correlation value at the 1% significance level. The negative correlation, recorded between the average time distance and the RADENS country rail network density, suggests that the differences in travel time between modes of transport that is an important factor affecting the competitiveness of modes of transport. Finally, the positive correlation at a low 45% of the RADENS variable with the mileage range of the public intercity road network indicates that the complementarity between public intercity road transport and the rail network takes place to cover long distances.

Also, the network variables, the average degree of nodes ⟨k⟩, the average centrality proximity ⟨CC⟩, the average intermediate centrality ⟨CB⟩, the weighted average (kilometric proximity) degree of nodes ⟨kw(km)⟩⟩ and the weighted average (temporal proximity) are positively correlated (significantly at the 1% level) with the variables of permanent population POP, Gross Domestic Product (GDP) GDP and contribution to the tourism sector TOUR of the regional units. This result suggests that the network variables also include demographic and economic information economic information about the transport system they represent. The case with POP population is exceptionally high and reflects the tendency of cities with high population to also have high public interurban road connectivity, which is probably related to the more intensive land use and clustering effects that occur in such cities (Polyzos, 2023). The correlation with GDP reflects that an efficient intercity public transport network acts as an economic growth factor (to the extent that economic growth is reflected in a region's GBTN). The correlation with the TOUR variable suggests that regional sections of public road transport networks with high connectivity, proximity, centrality tend to carry a higher tourism load and in particular perhaps certain segments of tourism related to short distance (e.g. domestic tourism and "accommodation"), tour preferences (e.g. bus travel). The same network variables are positively correlated (significant at the 1% level) with private motor vehicles in circulation PRVHC, public motor vehicles in circulation PVHC, buses in circulation BUS and motorcycles in circulation (MTR). From this result it can be concluded that the level of service of public interurban road transport has an impact on car and motorcycle ownership. In regional units with high connectivity, proximity, centrality of public interurban road network, which implies the existence of rapid development infrastructure, more private cars and motorcycles are in circulation

Connectivity ⟨k⟩ seems to be related to the education level of the EDU population at 96.3% (significant at the 1% level) describing that regional units with high connectivity of public transport networks tend to be distinguished by a higher education level of their population. Also, connectivity is related by the human capital-qualitative characteristics of the HUM population at 90.1% and by the number of FRC employees at 96.4%. By way of explanation, access to job opportunities is related to the likelihood that an individual will perform well in the labour market (Polyzos, 2019). This is true for developing countries because public transport plays a key role in mobility, especially for poor households. In this sense, public transport is one of the most important policies to enhance accessibility (Tsiotas and Tselios, 2023). The academic literature that has linked unemployment and accessibility refers to the lack of physical link between households and labour markets and its impact on the job search process and access to employment. In other words, spatial accessibility can therefore explain, at least in part, the probability of individual unemployment (Polyzos, 2023). Job seekers with higher or adequate levels of employment accessibility have more job opportunities available to them, which may also shorten the job search duration (Korsu and Wenglenski, 2010). Conversely, job seekers with low employment accessibility may face higher travel and job search costs. Also, the EDU, HUM and FRC variables are highly correlated with accessibility ⟨CC⟩, intermediate route structure ⟨CB⟩, mileage ⟨kw(km)⟩ and time ⟨kw(min) ⟩ proximity by more than 85%.

The contribution to the national primary sector GDP of A_SEC regional units appears to be negatively correlated at less than 45% (significant at the 5% level) with connectivity ⟨k⟩, accessibility ⟨CC⟩, the structure of intermediate routes ⟨CB⟩, the status of neighbors' connectivity ⟨C⟩, the kilometric ⟨kw(km)⟩⟩ and temporal ⟨kw(min)⟩ proximity of public road networks of regional units. Regional units with high rates of topological characteristics of public road networks tend to show low participation of the primary sector in the country's GDP formation and more freely low agricultural production or activity. This result, as far as regional policy is concerned, verifies Polyzos et al. (2014), who have noted that the Greek state adopts disjointed strategies for rural and tourism development, preferring a spatial separation of their activities that potentially loosens competition and complexity and allows local economies that do not rely on tourism to grow. They also highlight that agro-industries prefer locations that ensure easy access to raw materials and efficient supply chains for marketing their products rather than centralized locations of large inland markets (Polyzos et al., 2015; Kokkinou et al., 2018).

Then, a negative correlation is observed in the contribution to national tertiary sector GDP of the study regional units with the status of neighborhood connectivity and with the range of kilometric distances having coefficients r(⟨C⟩,C_SEC)=-0.336 and r(Rkm ,C_SEC)=-0.407 significantly at the 5% level. On the other hand, the contribution to the national secondary sector B_SEC GDP of the study regional units is reflected at 47.1% (significant at the 1% level) in the state of neighbor connectivity. The notion of correlation of the above variables implies that regional modules with networks of high status of neighbor connectivity facilitate the development of the secondary sector and compete with the functionality of the tertiary sector. This interpretation verifies established theoretical approaches on the relationship between accessibility and industrial location (Polyzos, 2023). Moreover, a low correlation (significant at the 5% level) with a negative sign is observed between the degree of URBAN urbanization and the average kilometric ⟨dkm⟩⟩ and temporal ⟨dmin⟩ distance. The result expresses that regional units with public interurban road networks with long average kilometric and temporal distance tend to have low level of urbanization. Public long-distance road networks with long-distance destinations are more likely to be found in less urbanized regions.

Expected correlations, significant at the 5% level, are recorded between the network variables of mean kilometric distance ⟨dkm⟩, mean time distance ⟨dmin⟩, the average weighted (kilometric proximity) degree ⟨kw(km)⟩ and the average weighted (time proximity) degree ⟨kw(min)⟩ and the distance of each service point/back-up point for Thessaloniki DTHS and the ticket price for Thessaloniki TCKTHS. On the other hand, the corresponding variables for Athens DATH and TCKATH are highly correlated (at the 1% level) only with the mileage distance range Rkm. Also, the average time distance ⟨dmin⟩ is correlated with the travel cost/kilometer variable COST. In summary, the above correlations express that the public intercity road network with long travel mileage tends to determine higher travel ticket costs. This observation is verified by the legislative framework for determining the fare for public bus passenger transport, according to which kilometre factors are used to determine a uniform way of calculating the intercity bus fare. These coefficients may be uniform for the whole country or different for each region or regional unit or regional units or for categories of lines with similar operating characteristics. Finally, the negative correlation of the variable of the average distance of the capital of a regional unit from all others in the CENTR network with the kilometric distance range Rkm, underlines that the greater the extraversion of a regional unit's public long-distance road transport network, the more distant the capital of the regional unit will be from all others in the network.

Overall, the empirical analysis has shown that bus operators serving more settlements (hubs) have a larger fleet. As the number of service locations increases, the fleet of operators increases. The network with the largest fleet extends further and distances become shorter. It was also highlighted that there is no intermodal relationship between the public long-distance road network and the air network and that the public long-distance road network has developed to serve more other types of transport. On the other hand the differences in travel time between modes of transport that is an important factor affecting the competitiveness of transport modes. Finally, the complementarity between public long-distance road transport with the rail network is carried out to cover long distances. Next, correlation analysis provided evidence that the network variables include demographic and economic information economic information about the transportation system they represent. The network correlation with GDP expresses that an efficient intercity public transport network acts as an economic growth factor (to the extent that economic growth is reflected in a region's GBTN). Also, GBTN service locations emerged as important and popular in receiving passenger flows that provide easy access to tourist destinations. Finally, the empirical analysis showed that the level of service of public intercity road transport has an impact on car and motorcycle ownership.

5. CONCLUSION

Public transport is one of the most important policies for improving accessibility. By studying the public transport bus network of Northern Greece, this article has shown that Regional Units with high topological characteristics of public road networks tend to have low participation of the primary sector in the country's GDP formation and more freely low agricultural production or activity. Regional units with networks of highly connected neighbours facilitate the development of the secondary sector and compete with the functionality of the tertiary sector. In addition, it was observed that public long-distance road networks with distant destinations are more likely to meet in less urbanized areas. Furthermore, the more extroversion a regional unit's public long-distance road network has, the more distant the regional unit's capital city will be from all others in the network. A public long-distance road network with a long distance travelled tends to determine higher travel ticket costs. Our correlation analysis provided evidence that the spatial distribution of public interurban road networks is described by the characteristics of the network infrastructure as well as socio-economic characteristics. Finally, bus networks form a specific category of complex networks that grow and evolve in physically constrained spatial networks.

The current study takes into account a subset of the large-scale network. It would be interesting to carry out a comprehensive study involving all operators of the interurban road networks. Since transport plays an important role in the economic development of a city, the current study can be extended to incorporate other networks, such as rail passenger networks. A holistic approach to these networks will help us understand each level of complexity in society. Overall, this article highlights the effectiveness of using complex network analysis in modeling spatial networks and in particular transport systems.

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Appendix

Internet resources used for GBTN modeling (access date: 31/12/2021)

Long-distance K.T.E.L.	Source :
Rhodope	http://www.ktelrodopis.gr
Drama	http://www.kteldramas.gr
	https://diavgeia.gov.gr/doc/4Α8Ω7ΛΒ-1ΨΡ
	https://diavgeia.gov.gr/doc/45ΠΑ7ΛΒ-ΚΜ8
Evros	http://www.ktelevrou.gr
	https://diavgeia.gov.gr/doc/Ω34Β7ΛΒ-ΗΣ5
Kavala	http://www.ktelkavalas.gr
	https://diavgeia.gov.gr/doc/Ω69Ν7ΛΒ-ΞΞΜ
	https://diavgeia.gov.gr/doc/ΩΞΥΚ7ΛΒ-ΤΒΟ
	https://diavgeia.gov.gr/doc/ΩΠΗΞ7ΛΒ-ΦΧ6
Xanthi	http://www.ktelxanthis.gr
	https://diavgeia.gov.gr/doc/6Ρ2Ψ7ΛΒ-ΑΩΣ
Thessaloniki	http://www.ktelthes.gr
Imathia	http://ktel-imathias.gr/
Kilkis	http://www.ktelkilkis.gr
	https://diavgeia.gov.gr/doc/6ΟΑ17ΛΛ-ΒΝΛ
	https://diavgeia.gov.gr/doc/ΩΘΙ07ΛΛ-ΔΟ0
Pella	http://www.ktelpellas.gr/
Pieria	http://www.ktelpierias.gr
Serres	http://www.ktelserron.gr
Halkidiki	http://www.ktel-chalkidikis.gr
Kozani	http://www.ktelkozanis.gr

Grevena	http://www.ktelgrevenon.gr
Kastoria	http://www.ktel-kastorias.gr
	https://diavgeia.gov.gr/doc/72ΩΦ7ΛΨ-Ο5Ζ
Florina	http://www.ktelflorinas.gr
	https://diavgeia.gov.gr/doc/7ΝΙΖ7ΛΨ-ΕΞ7
Ioannina	http://www.ktelioannina.gr
Artas	http://www.ktelartas.gr
	https://diavgeia.gov.gr/doc/68ΨΗ7Λ9-ΨΦΑ
Thesprotia	http://www.ktel-thesprotias.gr
Preveza	http://www.ktelprevezas.gr
	https://diavgeia.gov.gr/doc/6ΡΧΧ7Λ9-ΓΓΣ
	https://diavgeia.gov.gr/doc/ΨΜΞΜ7Λ9-Ω79
Larissa	http://www.ktellarisas.gr
Karditsa	http://www.ktel-karditsas.gr
Magnesia	http://www.ktelvolou.gr
Trikala	http://www.ktel-trikala.gr