European Research Studies,
Volume XVIII, Issue (2), 2015 *pp. 29-44*

The Coastal Shipping Network in Greek Insular Space: Reorganising it Towards a "Hub and Spoke" System Using Matrices of Flows and Connectivity Matrices

Athanasios Papadaskalopoulos[1] Manolis Christofakis[2], Peter Nijkamp[3]

Abstract:

This paper is based on the analysis of interinsular relations that have been shaped according to the existing coastal shipping network in the Greek insular space. It tries to contribute to the effort that was overwhelmed in the past few years for a more systematic investigation of the differentiation of the existing linear model of the coastal shipping network, with its modification into a "hub and spoke" model. The methods of analysis are based on the use of matrices of flows (coastal shipping origin-destination) and connectivity matrices, in which the direct connections are initially taken into consideration followed by the indirect ones between the islands. The insular area of the Kyklades prefecture in the Aegean Sea is the case study. The possible cohesive territorial units in the insular space of Kyklades, as well as the attainable nodal ports that may function in these units, are defined.

Key Words: *Coastal Shipping, "Hub and Spoke", Connectivity Matrices, Matrices of Flows, Greek Insular Space, Kyklades*

JEL Classification : *R15, R42, R58*

[1] Professor, Department of Economic and Regional Development, Panteion University of Athens. Address: Regional Development Institute of Panteion University, 130 Sygrou Avenue (1st floor), 17671, Athens, Greece. E-mail: pdask@panteion.gr. Tel. 0030 210 9248680. Fax. 0030 210 9232979.

[2] Associate Professor, Department of Economic and Regional Development, Panteion University of Athens. Address: Regional Development Institute of Panteion University, 130 Sygrou Avenue (1st floor), 17671, Athens, Greece. E-mail: mchri@panteion.gr. Tel. 0030 210 9234448.

[3] Professor, Department of Spatial Economics, VU University of Amsterdam. Address: De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands. E-mail: p.nijkamp@vu.nl. Tel. 0031 20 5986090.

1. Introduction

A strong relationship exists between spatial mobility, social exclusion, and developmental perspectives in general (Preston, 2009). Immobility can act as a major disadvantage for those who are either unwilling or unable to move (Rau and Vega, 2012). Many evidences show that unmet shipping needs constitute a key source of socioeconomic isolation, especially in areas with geographical disadvantages, such as mountainous, rural, and insular areas (ESPON and Nordregio, 2010). However, in these latter areas, the permanent geographic discontinuity adds to the other geographical disadvantages, differentiating insular areas from the other types of areas. Of course, discontinuity exists to a greater or lesser degree in all areas. In the mainland, however, geomorphology and distance, as well as communication issues, can be permanently addressed with the proper infrastructure facilities (Christofakis et al., 2009), as in case of the construction of a tunnel that connects a remote mountainous area in the mainland. Discontinuity causes problems not only in the cohesion of the insular space but also in the spatial and socioeconomic cohesion of a country as a whole due to the existing special relationship between the islands and the mainland, which has, as a result, limited access to the islands only made possible during specific time periods and from determined spots (ports and airports).

It is understood that in countries with extensive and dispersed insular areas, such as Greece, the issues concerning the formulation of air and sea shipping policies are of great importance to the developmental process. Coastal shipping has especially been of major importance to the development of Greece, and the issues surrounding it have been followed closely by both governments and the citizenry. With a total area of 131,957 sq. km and a coastline of 14,854 km, Greece has the most extensive coastline of all the Mediterranean countries. The coastal zone is divided almost equally between the mainland and the islands, with 7,700 km of coastline corresponding to a large number of islands. More specifically, the Greek insular space includes a variety of islands (major and minor islands, islets, and deserted islands). The 9,837 islands cover 18.8% of the country's surface (24,739.4 sq. km), ranking Greece at the top of the insular countries of the world. These particularities have determined the historical course of coastal shipping, fully diversifying it at the same time from the evolution of Greek oceangoing shipping (Lekakou et al., 2002; Christofakis et al., 2009).

Hence, coastal shipping in Greece has become a complex network of both mainland-to-island and island-to-island connections based on a large number of port infrastructures and facilities, mainly in the insular space. Mainly because of the specific geomorphological characteristics of the country, the precise specification of the number of harbour facilities of all categories is not easy. According to the available data of the Ministry of Development, Competitiveness, and Shipping, the Greek port system includes, in total, 1,250 port facilities, while according to a relevant study of the National Technical University of Athens (2001), the total number of the port facilities exceeds 700, of which only about 450 can be characterised as ports, while 150 serve ships for coastal shipping. Also, 110 of the ports have "measurable" merchandising activity, and 91 have passenger activity, while about 70 serve both shipping categories at the same time (Kyriazopoulos, 2006).

The model that characterises the existing system of costal shipping of the country is linear, following a "polar line form" (Greek Ministry of Environment, Physical Planning and Public Works, 2000). In this network, the major nodes of origin and destination are the port of Piraeus and, second, the neighbouring ports of Rafina and Lavrio (Figure 1). It is stressed that these three ports are located in the greater region of the Greek capital (Athens). For the most part, the coastal lines start from Piraeus, and after passing along various ports, they end up in their final destination (and the opposite).

This model is characterised by major malfunctions and communication problems, enhancing, in many cases, the isolation and depopulation of, mainly, the smaller and most remote islands. At the same time, it enhances and expands the influence of the metropolitan region of Athens through its function as a node of the coastal shipping in the Aegean insular space. Hence, by installing it at the greater Athens area—with the majority of the coastal enterprises, travel agencies, shipping agencies, crew companies, fuel supply companies, ship repair companies, etc.—the metropolitan region of Athens grows into the main pole of the Aegean space. However, in this way, the creation of certain powerful growth centres in the Aegean space is impeded, as well as the enhancement of dynamic sectors, but also the general self-reliant growth.

This situation has created the need for a more systematic investigation, the possibility of differentiating this system, with its progressive modification to a multimodal system of radial form through the creation of a "hub and spoke" coastal shipping model in combination, of course, with the air transport system (Greek Ministry of Environment, Physical Planning and Public Works, 2000; Greek Ministry of Shipping and Communications, 2006).

Towards this direction, the creation of new and the upgrade of the existing infrastructure and services of some ports, which will transform them into main hubs that will serve a number of small and medium islands daily, according to this model, constitute a basic area of intervention. The "hub and spoke" model has constituted, for several years now, an issue of intensive research activity at the international level, among others, in the fields of transport geography, policy, and networks, both on theoretical and practical levels (Brown, 1991; Aykin, 1995; O'Kelly, 1998; Grubesic et al., 2003; Murray et al., 2008).

In this framework, the calculation of the intensity of interinsular flows and dependencies and the modality of the insular ports of coastal shipping constitute a basic research framework for the systematic investigation of the possibility of differentiation of the existing model of coastal shipping in Greece. This paper tries to contribute to this research effort through the use of maximum flow and connectivity matrices and their implementation in the territorial unit of the Kyklades prefecture. With these methodological instruments, investigating the geography of coastal shipping at the insular space, the paper tries to answer some important questions: Are there any nodal places in the insular space that can, inter alia, support the differentiation of the existing network, which in turn could strengthen the self-reliant development of the insular space? Which groups of territorial units are shaped in the context of the creation of such a model?
The general structure of the paper is as follows: Section 2 presents the methodology of the analysis. Then section 3 includes the applications of the methods and the emerged results. Finally, section 4 concludes the paper.

2. Methodology and Material

As mentioned previously, the method of analysis of this paper is based on the use of matrices of maximum flows (origin-destination) as well as connectivity matrices.
The matrices of flows (or polarisation) have been used, inter alia, in spatial analysis (Boudeville, 1972; Guigou et al., 1979; Sidiropoulos et al., 1988; Isard, 1998; Griffith, 2007; LeSage and Fischer, 2010) for the geographical hierarchy of a polar region, a microregion or a territorial unit (e.g., marketplace), or even for the location of functions via calculating the orientation and size of the existing flows. The approach of polarisation is achieved with the help of adapted square tables of flows (inflows-outflows). These tables incorporate either the surges or the flows of territorial units in relation to the rest of a unit. The analysis of the matrix of flows for every function is oriented towards a search for local efficiency in an area. On the basis of this methodological approach, by using data of coastal connections, tables of flows can be created for the insular space, and then spatial insular units can be determined by shaping the existing relations between the islands.

The matrix of flows (origin-destination) is a square matrix with dimensions *nxn*, where *n* is the number of examined spatial units (in this particular case, islands and ports) of the area of study. The relationship of interdependence in this matrix appears as follows:

$$O_i = \sum_j Tij \quad (1)$$

where *Tij* represents the number of trips from the origin port, *i* (outflows), to the destination port, *j*. Consequently, the sum of all trips, *Tij*, between the port *i* and all the destinations *j* equals the total number of shipping produced at the port *i* (meaning that they leave the port *i*). Moreover, in the same matrix, the following equation applies:

$$D_j = \sum_i Tij \quad (2)$$

where *Tij* represents the number of return trips from the port *i* to the port *j* (inflows). Hence, here, the sum of trips between the ports *i* and *j* refers to the total number of movements that are attracted to port *j* from all the other ports.

Consequently, the total outflows and inflows (*Oi* and *Dj*) derive as the sum of the horizontal and vertical lines of the matrix of flows, respectively, where the horizontal lines can refer to the outflows of each port, with the vertical ones to the inflows. The sum of all trips, *Tij*, from all ports of origin, *i*, to all ports of destination, *j*, is equal the total number of produced trips, as well as with the total of all attracted trips in the ports of the area of study. So we have the following:

$$\sum_i O_i = \sum_j D_j = \sum_i \sum_j T_{ij} \quad (3)$$

A table like this can be allocated in tables, referring to the aim of travel, the used mean of transportation, the time of trips, etc. (Giannopoulos, 2005), which are issues that are not examined in the present research.

However, as it appears in this research, spatial units can be determined from the maximum flows (outflows and inflows), which imprint the existing relations between the islands, according to the lines of maximum origin or destination among the ports-islands. In this way, ports that are interconnected on the basis of the maximum lines of origin (meaning they share more powerful relations compared with other ports) constitute a spatial unit, while the same can be achieved with the case of the maximum destination lines.

In the connectivity matrices widely used in transport geography (Hammond and McCullagh, 1982; Taaffe et al., 1996; Griffith, 2007; Grubesic et al., 2008; Rodrigue et al., 2009), according to traffic flow, initially, the direct (straightforward) connections (first class) are taken into consideration followed by the secondary connections (second class and so on) between the settlements. In this framework, the accessibility of a place (e.g., a port) can be indicated through the connections with the rest of the network. Consequently, the modality of each place can be measured and compared with others through the amount of lines that converge there (Cliff and Ord, 1981; Anselin, 1988; Papadaskalopoulos et al., 2005).

More specifically, the connectivity matrix (first class) is a square matrix with dimensions *nxn*, where *n* is the number of examined spatial units (islands-ports) in the area of study. In this matrix, the nonzero elements denote the existence of a direct connection (neighbour relationship). The relationship takes the form of a binary variable ($Wij = 1$, when the islands *i* and *j* are neighbours, and $Wij = 0$, when they are not) that describes the interaction intensity between the neighbouring places *i* and *j* (Anselin, 1988). Thus, nonzero elements of the connectivity matrix indicate the network contribution to the modality of the respective port-island. In that way, the sum of the values of each row *j* (which corresponds to each port *j*), $\sum_j Wij$, is the expression of the respective island's nodality (Papadaskalopoulos et al., 2005). This matrix can be extended in constructing the total connectivity matrix, including the rest, indirect connections between its elements. A total connectivity matrix contains the number of all possible connections (direct and indirect) among the examined places (ports) of the network. Therefore, this method constitutes an integrated approach of the system's degree of coherence and, in our case study, of the nodality of ports in the insular space. The calculating methodology of the total connectivity matrix (*T*) is as follows (Rodrigue et al., 2009):

$$T = \sum_{k-1}^{D} Wk \tag{4}$$

$$W_1 = \sum_{j}^{n} Wij \tag{5}$$

$$W_k = \sum_{i}^{n} \sum_{j}^{n} W_{ij}^{1} * W_{ji}^{k-1} \quad (\forall k \neq 1) \tag{6}$$

Where:
n = the number of ports-islands (*i*, *j* = port-island)
k = connections
D = diameter.
More specifically, the construction of the total connectivity matrix follows this procedure (Taaffe et al., 1996):

Firstly, the construction of the first-class connectivity matrix (first order), *W1*, is on the basis of direct/straight links between the islands-ports. Secondly, the construction of the second-class connectivity matrix (second order or two linkage paths) is a result of the *W1*W1* multiplication. This matrix includes every possible second-class connection (i.e., through an intermediary single port) of each port-island. Thirdly, this procedure is repeated depending on the network's diameter size (*D*) and, more specifically, depending on the number of connections between the most faraway islands of the network. For example, a network with a diameter of 3 will demand the construction of three matrices: the first-class matrix, *W1* (direct connections); the second-class matrix, *W2 (W1*W1);* and the third-class matrix, *W3 (W1*W2).* Fourth, construction of the total connectivity matrix (*T*), calculated as the sum of the first-class matrix with the intermediary connection matrices ($k-1$, obtained on the basis of the network's diameter). This sum represents the total number of all possible (direct and indirect / second, third, and so on class) connections of each port-island with the rest.

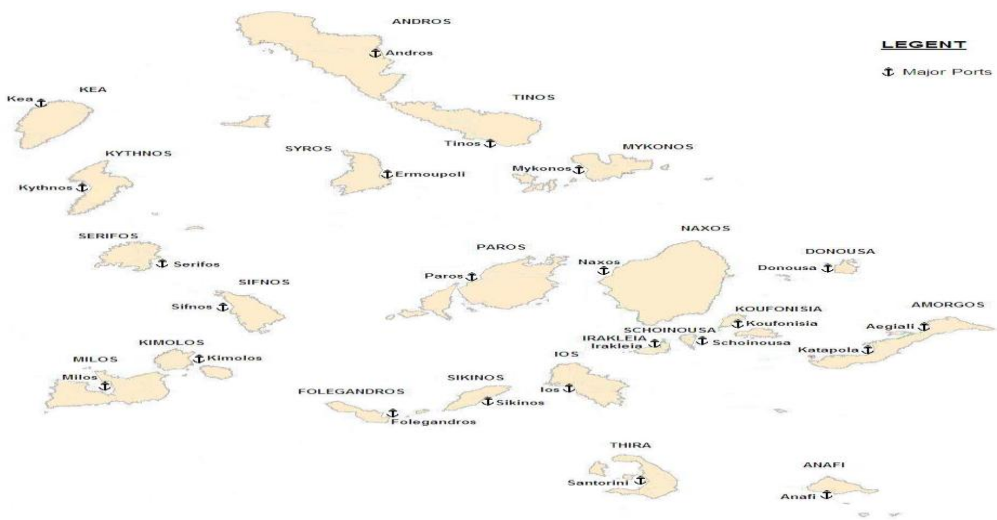
In the context of this research, official figures of coastal shipping lines have been used during 2010 (Regional Development Institute, 2012), associated with the islands in the Kyklades prefecture and originating from the port of Piraeus (which is, as we mentioned above, the main port of the county, located in the capital city of Athens), as well as from the two neighbouring ports, Rafina and Lavrio.

The prefecture of Kyklades (Figure 1), with a total area of only 2,572 sq. km, holds the first place among the nation's prefectures in terms of the number of insular territories (with 2,242 insular territories). According to the last official census of 2011, it has a population of 117,987 residents, which multiplies during the summer due to the large wave of tourists. It consists of 24 inhabited islands in the central and southern Aegean (Regional Development Institute, 2012).

Figure 1. Greek territory and Kyklades Prefecture

In our research, we have taken into consideration 22 islands-ports of the Kyklades prefecture, which are served by the main costal shipping lines (without taking into consideration the local lines**)** and are the following: Naxos, Andros, Paros, Tinos, Milos, Kea, Amorgos, Ios, Kythnos, Mykonos, Syros, Sifnos, Thira, Serifos, Sikinos, Anafi, Kimolos, Folegandros, Irakleia, Donousa, Schoinousa, and Koufonisia (Figure 2).

Figure 2. Major Coastal Shipping Ports in Kyklades Prefecture



It is noted that islands with more than one port (and specifically in the case of Amorgos), which are connected with the main lines for coastal shipping, are considered as one destination or origin, and therefore, the sum of all lines starting or ending there is taken into consideration, regardless of the port of access.

3. Applications and Results

3.1. Grouping of Islands According to Maximum Flows

A prerequisite for the system reformation of coastal shipping in the Kyklades and the Aegean space in general is the analysis of insular spatial groups, which have been formed on the basis of the existing linear system of coastal shipping. These groups form systems of relations and flows, which outline potential developmental programming micro-regions.

To determine groups of islands, the travel data of coastal shipping for the Kyklades prefecture were used, which concern a number of coastal connections from Attica to the Kyklades and Dodecanese Islands (through the Kyklades). Based on these data, which are the only available data of interinsular flows, origin-destination tables were prepared for the islands of Kyklades. Without taking into account the ports of Attica, the existing spatial groupings' interinsular relations can be determined using either the data of maximum destination (outflows) or the data of maximum origin (inflows).

In this framework, the grouping of islands according to the destination data of coastal shipping is presented in Figure 3.

According to the results of the maximum outflows figure, two geographically distinct spatial units emerge: (1) Western Kyklades and (2) Eastern Kyklades.
Correspondingly, the grouping of islands on the basis of origin data of coastal shipping (maximum inflows) is presented in Figure 4, according to which two similar, but not identical to the above units, are formed, and they are the following: (1) Western and Northeastern Kyklades and (2) Central and Southeastern Kyklades.

Figure 3. Insular Spatial Groups According to Destination Data (maximum outflows)

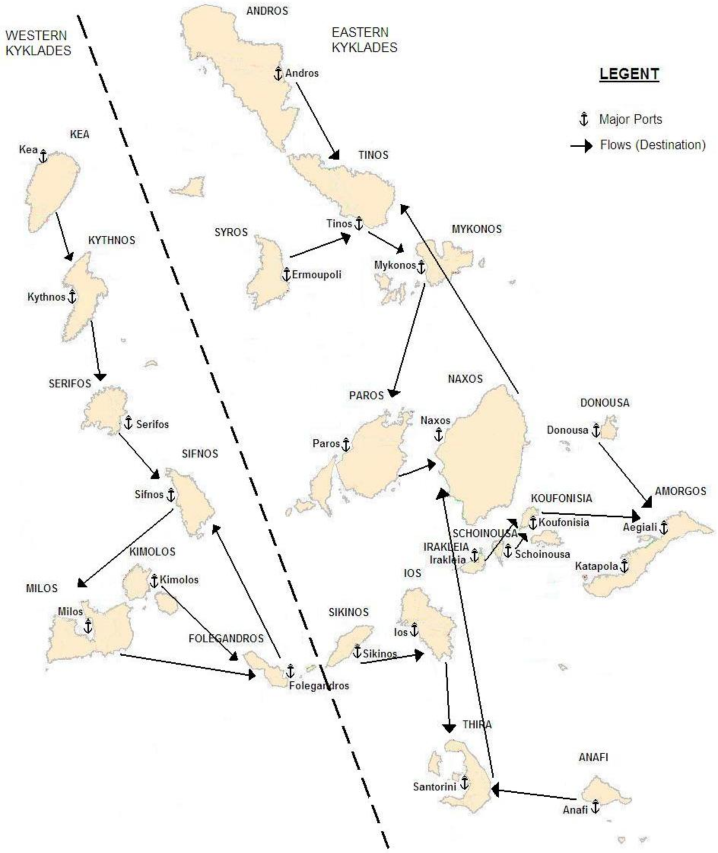
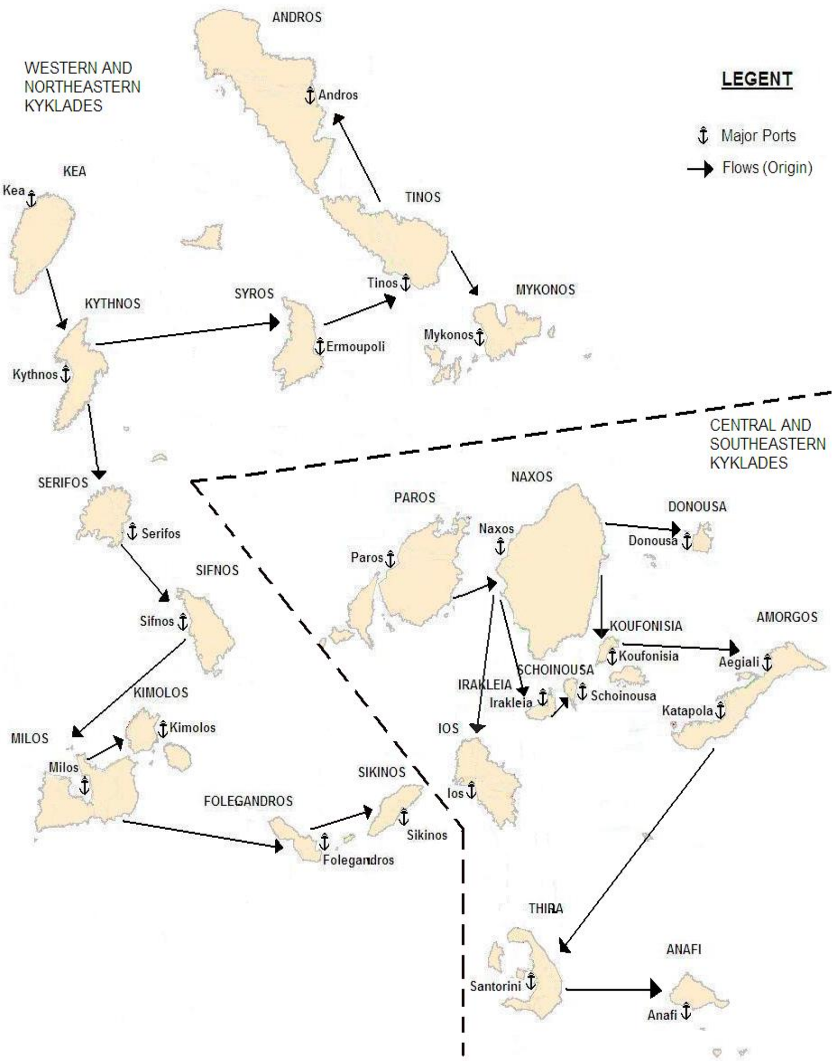


Figure 4. Insular Spatial Units According to Origin Data (maximum inflows)



We can conclude that the above groupings lead us to identify coherent spatial units within the research area, according to the existing interinsular relations of coastal shipping connections, while they provide some indications for the existence of emerging nodes. However, a more systematic approach of the polarisation degree, namely the nodality, and therefore, the formulation of safer conclusions on this issue, could be done through the use and the results of the connectivity matrices.

3.2. Nodality According to Connectivity Matrices

The investigation of the nodality at the coastal shipping system in the insular complex of Kyklades is based on the geography of the insular space and the existing coastal shipping system as expressed by the interconnections between the islands.
In this framework, in order for the nodality to be determined and the ports/nodes to be identified, starting with the first-class matrix (direct/straight connections), connectivity matrices up to fourth class were constructed based on the existing lines of coastal shipping and the related insular interconnections. According to the followed methodology, from the results of these matrices, the total connectivity matrix for the insular space of Kyklades emerged. Given that, as has already been mentioned, the system is linear (Western and Eastern Kyklades), the selection of fourth-class matrices means that existing travel lines serve insular destinations via three intermediate ports at maximum. Thus, the ports/nodes serve the purpose of accessibility from the western to the eastern transport axis and vice versa.

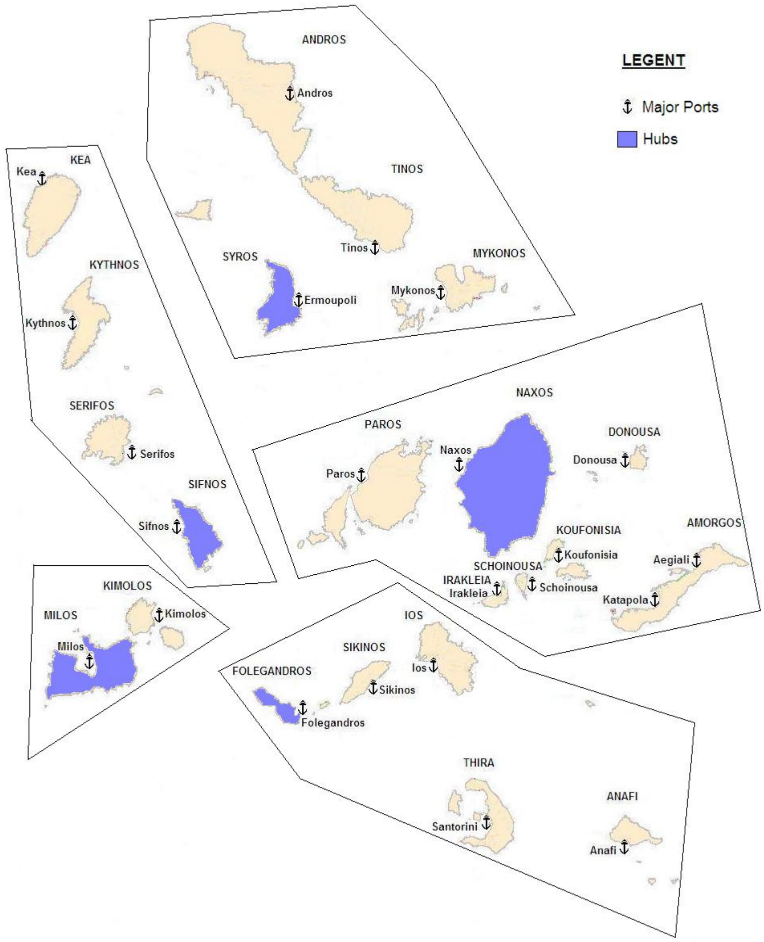
By constructing the first-class matrix and the total connectivity matrix, which refers to not only the direct connections but also every possible way of indirect network connections, for $k-1 = 3$, the nodes of the coastal shipping network in Kyklades' space can be presented hierarchically (Table 1).

Table 1. Coastal Shipping Nodes in Kyklades

Island-port (node)	Direct connections (according to the first-class matrix)	Possible connections (according to the total connectivity matrix)
Syros	4	91
Sifnos	3	90
Folegandros	4	85
Milos	3	81
Naxos	6	74

As the last step in our analysis, from the combined results of maximum flows (origin-destination) and accessibility/nodality, we conclude that the insular complex of Kyklades can be divided into five distinctive coherent insular units (Figure 5). Moreover, each one of these units could be potentially served by one major port/transport hub.

Figure 5. Insular Spatial Units and Transport Hubs in Kyklades



These emerged spatial units and especially the defined insular hubs could constitute the basis for further research of the requested diversification of the existing Greek coastal shipping network (linear -"polar in line" form), which would eventually lead to a multinodal model of radial form on the basis of the well-known "hub and spoke" system.

4. Conclusion

In an effort to reform the existing linear shipping network (as in the case of coastal shipping in the Greek insular space) and convert it into one that follows the "hub and spoke" system, the systematic analysis of the potential coastal shipping nodes and their areas of operational influence is an issue of major research interest.

The combined utilisation of the flows (origin-destination) and connectivity matrices allows such a potential as it enables, according to shipping interconnections and flows between different territorial units (as it is a specific case study between ports/islands), the identification of the possible coherent spatial units (that constitute groups of interconnected ports) and nodal points that can function in each spatial unit.

This analysis can be expanded more by incorporating other important variables that are directly related to transport, such as the purpose of the trip, the means of transport, the travel time, etc. Moreover, the matrices' results regarding the nodal intensity and the nodal influence areas can be further exploited if combined with other variables, some of which may not be directly related to the shipping flows yet have an important role in the pursuit for a systematic approach to the coastal shipping system. Such variables could be the population size of the spatial units, their administrative structure, the adequacy of their infrastructures, and the existence of other nodal infrastructures (e.g., airports, customs stations, and freight centres). All these can contribute to a more systematic research of the reformation of the existing coastal shipping system not only within the framework of integrated coastal shipping but also within spatial and development planning.

In this framework, at the level of policy decision making, the systematic improvement of port activities, the investments in modern infrastructure, facilities and systems administration (primarily in the nodal ports) and management of transport project in Greek ports and the development of combined transport (mainly with the air transport system in insular space) are necessary (Christofakis et al., 2013). Moreover, the accessibility/connection of the ports with hinterland areas and the training of employees, adopting best practices and implementing training and know-how transfer from other ports should be policy priorities (Niavis and Tsekeris, 2012), in order to enhance the competitiveness of coastal shipping and the efficiency of insular ports into a new differentiated "hub and spoke" network. Besides, the new technical developments occurred during the last decades in the transport sector are characterized as an important driving force. New infrastructure opportunities that can result in attractive transport properties are realized. Moreover, in transport operation, the use of informatics creates new prospects for decreasing the cost and increasing speed and reliability (Bithas and Nijkamp, 1997). Of course, it is obvious that these developments should be exploited in the coastal shipping sector.

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