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AN OPTIMAL HUB SELECTION ALGORITHM IN MARITIME TRANSPORT SYSTEMS BASED ON THE HUB AND SPOKE MODEL

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This report presents a heuristic algorithm for the optimal hub selection in a maritime transport system which is based on the hub and spoke model. This model has been successfully tested in other maritime systems such as the USA aviation. Its implementation in the maritime transport and particularly in areas such as the Aegean Sea gave very good results with respect to resource savings, improvement of services and drastic reduction of the total time needed for traveling in favour of tourism and shipping companies.

Keywords: *optimization, algorithm, tourism, transport, hub and spoke*

JEL Classification: *L83, M1, O1*

INTRODUCTION

The Hub and Spoke model has numerous applications in many sectors of the economic activity. Networks of combined transports, Logistics and distributions' systems, transportation models and many other systems have at their core the Hub and Spoke model. One of the basic problems that the designers of systems based on the Hub and Spoke model face is the hub selection. In this report we will explore exactly this issue. The search of the optimal location for the transhipment hub. The algorithm presented in this section, investigates the parameters based on which we can choose the optimal location of the transhipment hub. The optimal hub location search algorithm was implemented for the selection of the optimal hubs in maritime transport and particularly in the area of Cyclades of Aegean Sea. Furthermore using the "NAYTILOS" algorithm (Chainas, 2012) we created new optimal itineraries based on the Hub and Spoke model. These models were compared to other bibliography itineraries (Aifantopoulou, 2004) in respect of the total distance traveled as well as to the real itineraries carried out during summer 2009. The result of these comparisons is that the transportation cost for a shipping company that would utilize the hub and spoke system for the Cyclades area, is much lower compared to the cost nowadays to cover the same area with the classic linear itineraries. In essence, this report suggests a new network of Aegean maritime lines which will be based on the Hub and Spoke model and therefore we will be able to go beyond the default until today, indicative network as it is mentioned, which in fact is the same linear network which operates all these years with only a few changes (Chlomoudis et al, 2007).

FOR THE HUB AND SPOKE NETWORKS IN ECONOMY

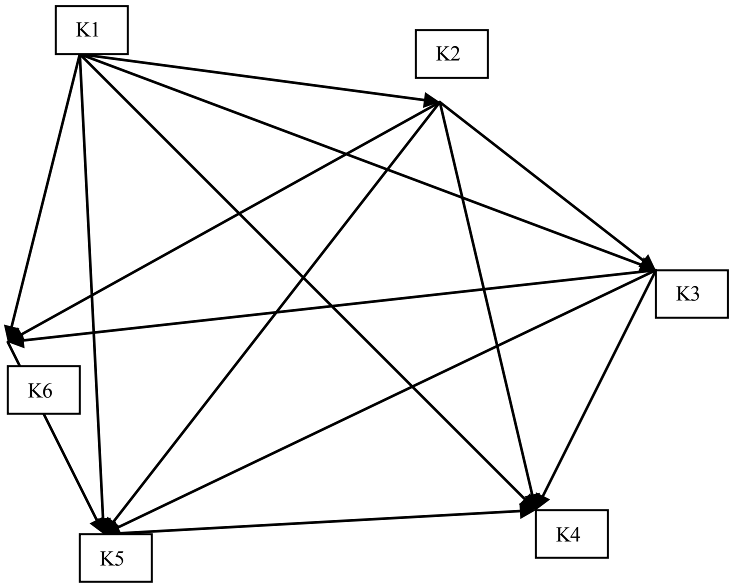
In a network of n nodes, the number of all possible connections between all nodes is, $\frac{n(n-1)}{n}$ (Figure 1). However if we define one of the nodes as a hub then we may connects all other nodes with the hub and the number of connections is reduced to n-1 (Figure 2).

Therefore, the application of a hub and Spoke system in a connection network of n nodes, may create the conditions, in order to have significant cost reductions in the necessary resources. And we say that this may create the conditions since in a hub and spoke system we have to take into consideration all factors affecting the system and which may be connected to the various restrictions which may exist, such as the existence of the necessary infrastructure so as the Hub and Spoke system can operate effectively.

Studying the transportation and distribution systems the central position is possessed by the central storage area which is the beginning for the customer service routes of a company or even a group of companies. Nowadays, many companies outsource the distribution process of their products towards the final customers to intermediate distributors. These distributors have organized storage facilities (Logistics) and means of distribution in order to serve their clients fast and at the lowest possible cost. The most important issue for such a company is the selection of the storage hub in order to assure optimal distribution (demand coverage by delivery with the minimum possible delay and at the minimum possible cost). The selection of the main distribution hubs is of uttermost importance for its competitiveness, especially today with the rapid use of new technologies, where combined distribution systems are employed in making the most of all the possible means and ways of transportation (road and railway, marine and aviation network). In most European countries, a transhipment system with central hubs is used for the collection and the final transportation of urban waste to the processing and final screening centres.

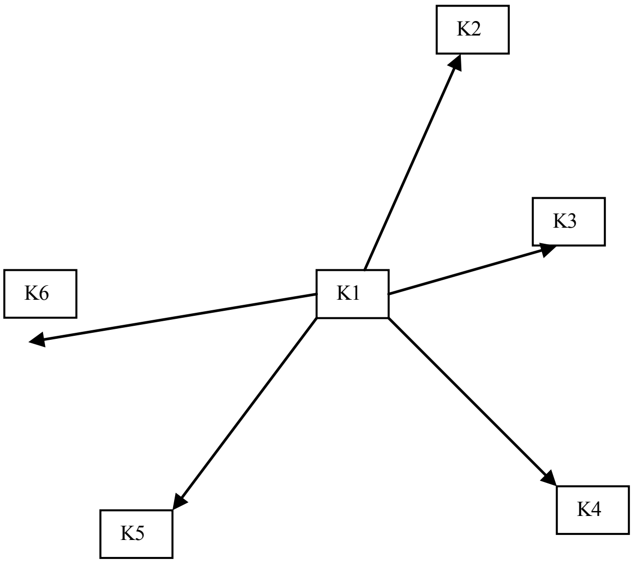
Figure 1 Number of possible connections in a set of n nodes

$$\frac{n(n-1)}{n}$$



The selection of the transhipment stations is again of strategic significance for resource saving and optimal system performance. The hub-and-spoke system is used in numerous transportation and distribution applications and also in other cases, such as network design of any kind. It also finds application in aviation transportation systems (Dobson and Lederer, 1993). In the shipping market, for the past forty years, we observe a tremendous increase in the growth of the maritime transportation. The extent and quality of the provided services are highly correlated with this growth. (Papanastasiou et al., 2006). This report attempts to search for a general optimal selection method of the central transhipment station in a complete maritime transportation system in Aegean Sea, which might however find a more general use and applicability. In this way, a heuristic algorithm was designed and implemented for searching the optimal transhipping hub from a set of n hubs. The contribution of the report is the search of the optimal location of the transhipping station in any transportation problems we would like to use the hub-and-spoke model.

Figure 2 Number of possible connections in a set of n nodes with the hub and spoke network, n-1



The parameters used by the algorithm are the relative position of each node with respect to the rest, within the search region of the optimal transhipment node selection, and the demand of each node at the specific transportation services of each problem. If we consider the region containing all the nodes, for which we are interested in selecting the optimal transhipment node, as a single system, we can rename the problem as the search of the “centre of gravity” of the system, if we consider the demand of each node for transportation services to be its respective “weight”. The optimization achieved is with respect to delivery time saving and resource utilization. It has been used and tested in the maritime transportation system of the Aegean Sea and compared against the already deployed system. The results of this comparison encourage the use of network application policies, which are based on the hub and spoke model, on the maritime transportation systems as well. Of course, the survey shows that the hub and spoke model is not appropriate for all transportation problems. Therefore, there are areas in shipping industry where the hub and spoke system misbehaves, especially in the cases of nodes where there is transportation not only of products and passengers but also of vehicles. Such issues might cause some additional delays, but they must be examined within the framework of the general advantages that a hub and spoke system might have. However, in any case, this system can assure improved timing, prices and services and under this perspective it can coexist with other routing systems. A typical example is the application of the hub and spoke method in the American aviation system by large aviation corporations, where the method competes successfully the aviation transportation systems that other companies have deployed. (Dobson and Lederer, 1993). A significant advantage of the transportation systems using the hub and spoke model is the fact that the itinerary creation process is much faster compared to other systems, as long as the transhipment nodes are selected through an optimized selection process. The liberalization of the maritime transportation has shaped a new competitive environment in the shipping market. An issue of strategic importance for any shipping company is the selection of the area to offer their shipping services, in order to achieve the best possible results. The heuristic algorithm that we propose in this report, for the selection of the optimal transhipping node in combination with the design of an itinerary schedule, based on the hub and spoke system, will allow any shipping company that wants to use this system to investigate and compare the resulting itineraries against those of other companies or against those currently in use, in order to make the appropriate decisions.

The objectives of a transportation system in a Hub and Spoke network

A transportation system based on the Hub and Spoke model consists of two subsystems:

α) The first subsystem corresponds to the itineraries from the central distribution point towards the transhipment nodes.

β) The second subsystem corresponds to the itineraries from the transhipment nodes towards the final destinations.

The intended objectives of the application of the Hub and Spoke model:

1. To minimize the total covered distance by all vehicles while serving the demand. In the first phase towards the transhipment nodes, the distance is a function of the itineraries necessary to cover the demand towards the transhipment nodes. Hence, during this phase the optimal selection of the transhipment node and the selection of the optimal vehicle type to cover the demand are of importance. In the second phase from the transhipment nodes towards the final destination points, the selection of the optimal itineraries to minimize the travelled distance to cover all the required nodes and the selection of the appropriate vehicle type to cover the demand of these nodes are of importance.
2. To minimize the total distribution time towards all the destinations. This is a function of the first objective regarding the total distance minimization, and the selection of the appropriate type of vehicles that can cover adequately well the demand in optimal and safe timing.
3. To minimize the number of vehicles for covering the demand while maximizing the vehicle occupancy.
4. To minimize the total cost of each route.

A GENERAL DESCRIPTION OF THE OPTIMAL HUB POSITION SELECTION ALGORITHM

The mathematic model

Let's consider a space of n_i $i=1,2,3,\ldots,k$ nodes for the optimal transhipment node position search.

We assume that each node has a demand for transportation services m_i, $i=1,2,3,\ldots k$

Each node is depicted in the figure as a circle whose diameter is proportional to the node's demand in transportation services.

In addition each node has Cartesian coordinates x_i,y_i , $i=1,2,3,\ldots k$

Figure 3 A k node space. The size of each node (diameter of the circular disk) represents the amount of its demand in transportation services.

So, if we assume that each node i has “weight” equal to the demand in transportation services (m_i), then the “centre of gravity” or “centre of mass” of the system has coordinates (assuming two dimensions):

$$x_k = \frac{\sum_{i=1}^{n} x_i m_i}{\sum_{i=1}^{n} m_i}, \quad (1)$$

$$y_k = \frac{\sum_{i=1}^{n} y_i m_i}{\sum_{i=1}^{n} m_i} \quad (2)$$

The demand of each node i (i=1,2,,…,n) in transportation services (m_i) is calculated as the mean of the demand from each other node in the search region towards this node. In other words:

$$m_i = \frac{\sum_{j=1}^{n} m_{ij}}{n} \quad (3)$$

Based on the coordinates of the position and the values of demand for transportation services, of each node, we calculate the coordinates of the required “centre of gravity” or else the optimal position of the transhipment node in a space consisted of n nodes.

One more main characteristic of the “centre of gravity” is its orbital radius, which is given by equations:

$$r_k = x_{ki} + y_{kj} \quad (4)$$

$$r_k = \frac{\sum_{i=1}^{n} x_i m_i}{\sum_{i=1}^{n} m_i} + \frac{\sum_{i=1}^{n} y_i m_i}{\sum_{i=1}^{n} m_i} \tag{5}$$

$$r_k = \frac{\sum_{i=1}^{n} r_i m_i}{M_k} \tag{6}$$

If the number of nodes grows to a very large number (infinity) then equation (5) becomes:

$$r_k = \lim_{\Delta m_i \to 0} \frac{\sum_{i=1}^{n} r_i \Delta m_i}{M} = \frac{1}{M} \int r dm \tag{7}$$

With this approach we can determine the optimal position of the transhipment node in an n node space and, in addition, the optimal "action region" of this transhipment node, which is the cyclic region created with the selected node at the hub in its centre and radius r_k.

Restrictions

In order that a node can operate as a transhipping node, it is necessary:

1. To have the necessary infrastructure depending on the subject of the transporting process for a smooth transhipping process.
2. To be able to accommodate the minimum number of vehicles necessary by the transhipping process in all situations foreseen by the timetable of the itineraries, without any delays or other problems.

Based on the aforementioned a transhipping port for maritime transportations must have the necessary infrastructure to accommodate all types of ships, for the transhipping of vehicles and passengers from one ship to the other and in general to be able to serve the itineraries from and to the port-transhipping hub, within the defined timeframes according to the schedule of ship itineraries to cover a specific region.

Algorithm presentation

Step 1: Selection of the hub search region. Insertion of the demand for transportation services of each node n_i , i=1,2,3,…n and the coordinates of the nodes. Definition of the assumptions (infrastructure, access etc.) that must hold, so that the required node can operate seamlessly as an actual transhipping node (restrictions).

Step 2 : Calculation of the coordinates of the "centre of gravity" of all nodes in the search region based on equations (1) and (2) and the orbital radius or in other words the calculation of the coordinates of the ideal hub for that specific region.

Step 3 : Selection of the nearest node to the ideal hub of the node system based on the coordinates and the positive subtractions of abscissas and ordinates from the coordinates of the ideal hub.

Step 4 : Printing of the coordinates of the node that can operate as an optimal transhipping hub and the actual node that resides closest to the specific coordinates that we calculated based on the algorithm and satisfies the necessary preconditions (infrastructure etc.) that we set as restrictions.

Application of the algorithm in the area of Cyclades and the search for the optimal hub position

The weekly demand of each connection between ports in the area of the Aegean Sea is known (SETHAM,2001). Based on this information we calculate the average demand for each port node i of a specific region based on equation:

$$m_i = \frac{\sum_{i=1, j=1}^{n} m_{ij}}{n}, i,j=1,2,\dots n \quad (8)$$

where $\sum_{i=1,\, j=1}^{n} m_{ij}$ is the summation of the demand of all connections between the n nodes of the search region. The coordinates of all the nodes in this region are also known (SETHAM,2001).

We applied the optimal hub selection algorithm in the Cyclades area for 22 main ports. Having the coordinates of each port and the weekly demand in maritime passengers as inputs, the algorithm returned that the coordinates of the hub for the Cyclades area are :

Gis_x = 602960.71
Gis_y = 4109463,60

Table 1 Results of the optimal hub search algorithm for the Cyclades area

code	**Port**	**GISX**	**GISY**	**Demand**	Subtraction X	Subtraction Y
98	PAROS	602319,15	4104193,27	588,14	641,56	5270,33
101	TINOS	603858,68	4154866,71	331,96	897,97	45403,11
103	KYTHNOS	535208,06	4138839,36	41,42	67752,65	29375,76
104	ANDROS	564838,77	4193356,38	4 3,16	38121,94	83892,78
107	KIMOLOS	551738,82	4070839,64	5,14	51221,89	38623,96
108	MILOS	540069,11	4064348,72	80,82	62891,60	45114,88
109	SERIFOS	545998,32	4109378,39	50,00	56962,39	85,21
110	SIFNOS	559953,71	4093772,03	89,20	43007,00	15691,57
111	AMORGOS KATAPOLA	666435,17	4077544,05	42,34	63474,46	31919,55
112	AMORGOS AIGIALI	676386,32	4085886,49	10,85	73425,61	23577,11
113	DONOUSA	659209,26	4106819,22	3,72	56248,55	2644,38
114	IRAKLEIA	631014,29	4080798,99	2,98	28053,58	28664,61
115	KOUFONISI	641870,00	4088603,50	16,36	38909,29	20860,10
116	NAXOS	623022,18	4107010,29	263,00	20061,47	2453,31
117	SCHINOUSA	635994,57	4083160,53	1,84	33033,86	26303,07
118	ANAFI	658097,04	4023772,56	5,90	55136,33	85691,04
121	IOS	612782,15	4064512,12	147,20	9821,44	44951,48
122	SIKINOS	600408,59	4062045,84	6,08	2552,12	47417,76

123	FOLEGANDROS	584896,49	4052209,75	12,88	18064,22	57253,85
124	MYKONOS	617571,11	4145437,14	291,04	14610,40	35973,54
125	SYROS	583581,18	4143910,93	165,48	19379,53	34447,33
171	THERA	627406,71	4032877,94	329,50	24446,00	76585,66

The port that resides very close to these coordinates is the port of Paros as shown by the absolute value of the subtractions from the coordinates of the ideal hub.

The resulting itineraries for the Cyclades area based on the hub and spoke system

We implemented the heuristic algorithm that we developed in this report for the search of the optimal hub location in Cyclades area and the algorithm returned the port of Paros. Then we implemented "NAUTILOS" algorithm (Chainas, 2012) for the search of the optimal routes for Cyclades area, where port of PAROS was the departure port (hub) and the target was to cover the demands of all the ports of the area. Table 2 shows all these itineraries and the total travelled distance. Image 1 shows the graphical display of all these routes. We compared these routes with the real ones for Cyclades area as well as with Aifantopoulou routes (Aifantopoulou, 2004) where PIRAEUS port was the departure port and the total distances and the corresponding time needed are drastically reduced. The total distance of Aifantopoulou routes based on the hub-and-spoke system for the same destinations was improved by 18.17% compared to Aifantopoulou itineraries and 14.67% compared to the real itineraries of a typical Sunday in August 2009 for the Cyclades area (Table 2).

Table 2 Optimal itineraries for Cyclades area produced by "NAUTILOS" algorithm with PARO as a hub

	Cyclades itineraries with PAROS as a hub		Miles
1	PAROS-NAXOS-DONOUSA		38.43
2	PAROS-IRAKLEIA-SCHINOUSA-KOUFONISI		33.75
3	PAROS-NAXOS-AMORGOS		51.10

4	PAROS-IOS-THERA-ANAFI		69.22
5	PAROS-IOS-SIKINOS-FOLEGANDROS-MILOS		75.10
6	PAROS-SIFNOS-KIMOLOS-MILOS		53.89
7	PAROS-SIFNOS-SERIFOS-KITHNOS-SIROS		96.73
8	PAROS-SIROS-TINOS-MYKONOS		45.11
9	PAROS-SIFNOS-SERIFOS-KYTHNOS-KEA-ANDROS-TINOS-MYKONOS		135.80
	Total		**599.14**
	PIRAEUS-PAROS (9 Itineraries HUB)		**821.81**
	Grand Total		**1,420.95**
	Aifantopoulou itineraries	**Total**	**Cyclades**
1	PIRAEUS-DONOUSA-AGIOS KIRIKOS-SAMOS VATHI-SAMOS KARLOVASI	207.00	118.76
2	PIRAEUS-MYKONOS-KIMOLOS-FOLEGANDROS-SIFNOS	195.00	195.00
3	PIRAEUS-KOUFONISI-IRAKLEIA-KATAPOLA-ASTIPALAIA-LEROS-FOURNOI	269.00	144.86
4	PIRAEUS-THERA-IOS-ANAFI	178.00	178.00
5	PIRAEUS-PAROS-NAXOS-SCHINOUSA-AIGIALI	147.00	147.00
6	PIRAEUS-TINOS-SIROS-KYTHNOS-GAURIO-LIMNOS MIRINA	287.00	169.64
7	PIRAEUS-MYKONOS-PAROS-KARPATHOS-AGIOS NIKOLAOS	353.00	117.05
8	PIRAEUS-TINOS-SIROS-SERIFOS-SIFNOS-SAMOS BATHY-SAMOS KARLOVASI	277.00	138.59
9	PIRAEUS-IOS-NAXOS-MILOS-THERA	249.00	248.44
10	PIRAEUS-THERA-KATAPOLA-PATMOS-LIPSI-KALIMNOS	252.00	163.39
11	PIRAEUS-PAROS-MYKONOS-LIMNOS MIRINA-THESSALONIKI	398.00	115.76

	Total		**1,736.49**
	Difference		**315.54**
	Improvement		**18.17%**
	Real Itineraries for Cyclades (August 2009)	**Total**	**Cyclades**
1	PIRAEUS-PAROS-NAXOS-LIPSI-LERO-KALYMNO	212.99	169.83
2	PIRAEUS-PAROS-NAXOS	106.38	106.38
3	PIRAEUS-FOLEGANDROS-THERA	127.84	127.84
4	PIRAEUS-IOS-THERA	128.12	128.12
5	PIRAEUS-SIROS-TINOS-MYKONOS	98.90	98.90
6	PIRAEUS-PAROS-MYKONOS-TINOS	137.12	137.12
7	PIRAEUS-KYTHNOS-SERIFOS-SIFNOS-MILOS-KIMOLOS	117.43	117.43
8	PIRAEUS-PAROS-NAXOS-THERA	150.01	150.01
9	PIRAEUS-SERIFOS-SIFNOS-MILOS	101.50	101.50
10	PIRAEUS-PAROS	91.31	91.31
11	PIRAEUS-SIFNOS-FOLEGANDROS-THERA-KATAPOLA	167.00	167.00
12	PIRAEUS-SIROS-MYKONOS-TINOS	104.99	104.99
13	PIRAEUS-SIROS-PAROS-NAXOS-IRAKLEIA-SCHINOUSA-KOUFONISI-KATAPOLA	164.85	164.85
	Total	**1,708.45**	**1,665.29**
	Difference		**244.34**
	Improvement		**14.67%**

CONCLUSIONS

The optimal transit hub search algorithm may be implemented in various problems of vehicle routing, transportation and distribution, where a transhipment hub is needed. A distribution company undertakes the delivery of the orders to the customers of a corporation, on a regular basis, who are within a city, a wider area or even within a country or a set of countries. The selection of the appropriate location of the transhipment storage area or areas is among the most serious logistics problems which a modern distribution company faces, in combination with the search for the optimal routes and the proper vehicle types which are necessary for each route, in order to achieve the best results. In the Aegean shipping we face respectively the following problems. For each marine area we seek for the appropriate port to play the role of the transhipment and transit hub, combined with the optimal itineraries and the appropriate vehicle type (ship), which are necessary for the coverage of demand in the particular area (Chainas, 2012). This report contributes to the search of the optimal transhipment-transit hub-port and was implemented in the Aegean area with very good results. Furthermore it could be implemented in the cruise sector for the search of the optimal homeport (Lekakou et al., 2009). A subject for further investigation is the transportation problem in a region, such as Aegean area, as a problem of holistic view, within the frame of a complete combined transportation system where the road, sea and air transport, will operate within the frame of a healthy competitive market, for complete and high quality transportation services.

REFERENCES

Aifantopoulou, G. (2004). Implementation of experienced technicians and systems optimum design of vehicle fleet distribution routes, Ph.D. dissertation, School of Civil Engineering, *Aristotle University of Thessaloniki*, Greece.

Chainas, K. (2012). The optimization of the Greek Coastal Shipping Transportation Network, *Tourismos,* Vol. 7, pp. 353-367

Chlomoudis, K., Lekakou, M., Panou, K., Papademetriou, E., Syriopoulos, Th. & Jannatos, E. (2007). *Transportations - Life arteries for the islands.* Athens, ITA Publications.

Dobson G. & Lederer P. (1993). Airline Scheduling and Routing in a Hub-and-Spoke System, *Transportation Science,* Vol. 3, pp.281-297

Lekakou, M., Pallis, A. & Vaggelas, G. (2009). Which homeport in Europe: the cruise industry's selection criteria. *Tourismos,* Vol. 4, No.4, pp.15-29.

Papanastasiou, J., Lazaridis I. & Noulas A. (2006). Tourists' preferences for quality of services: empirical investigation of Lesvos, Samos and Chios islands. *Tourismos,* Vol. 1, No.2, pp.95-101.

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