



# Ship scheduling and routing optimization. An application to Western Mediterranean area\*

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## Abstract

The objective of the paper, knowing the number of ports and ship fleet, is to optimises maritime transport routing of a containership, based on demand scheduling to each port of call ,using the expert system approach with owner utility function (McFadden D. 2000). All that need the operative cost of ships employed and their technical characteristics. The problem solution will be given, for each ship of the fleet, by routing of the ships , container movement for each port of call and transport cost. This paper proposes the use of a methodology based on an expert system computation program with a random utility function of a shipowner operating in a maritime network mapped by geographical information system GIS (Catalani M. 2001).

*Keywords:* Maritime; Networking; Route; Feeder; Optimisation.

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## 1. Introduction

The current trend for giant ships, as can be seen from the constant growth in size of ocean-going container ships, has led the shipping companies which own these ships, known as deep-sea craft, to select a limited number of stop-over ports where they can concentrate large amounts of merchandise. All this involves significant investment on the part of big deep-sea shipping companies in ever larger ships, which, by stopping at few ports, make it possible to cover a wide-ranging market, making use of local feeder services (Frankel E. 2005). In this way, it is possible to serve port terminals where one direct stop-over would not be economically advantageous or even practicable for geographical, technical, or commercial reasons, (distance from the main trade routes, shortage of infrastructures, shallow waters, modest quantities of containerisable cargo, etc.). The feeder service therefore, in the maritime container transport scenario, is a logistic activity where the main merchandise carrier is substituted, for a certain portion

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of the run, by one or more secondary transporters (Ronen D. 1983). With the progressive growth of the feeder service, increasing importance has been given to efficient planning of logistic activities and the resources used, as in this sector too, competition will be increasingly based on the quality of the services offered, especially punctual and frequent delivery. At the moment, container ships are being designed as container carriers of over 11,000 teus called Malacca-max, named after the eponymous Maltese straight (Frankel E. 2004). This would lead to a fall in freight if old ships are not “scrapped” at the same time. The main aim of this paper is to put together an optimisation model for maritime routing, able to automatically manage a sea route optimizing the relative routine over short sea services (Catalani M. 2001). A secondary, but no less important aim is to calculate the parameters of the function to be used in the optimisation process, based on an investigation carried out at a number of shipping companies working in the area of feeder redistribution in the Mediterranean. A random parameters model or mixed logit model (Mcfadden D. and Train K. 2000) based on agent Bayesian approach has been elaborated. The final objective is also to map the feeder service by GIS (geographic information system) with the technical, logistic and operative data of a line (Catalani M. 1998).

## 2. The line operators in the Mediterranean

The main large shipping lines working in the Mediterranean, with their subsidiaries, are mainly Maersk, Hanjin, CP Ships, Neptune Orient Line and P&O NEDLLOYD (the latter two merged into a single society). There are also the Global Alliances (Grand Alliance, The New World Alliance, United Alliance, and CHKY Alliance). At the moment the hold capacity on the charter market is slightly higher than what the various ship owner groups offer (Sturmey, S.G.1967 and Frankel E. 2005).

It is interesting to note how the main line operator, i.e. the Danish group Maersk - Sealand, can call upon a capacity almost double that of the second largest shipping company, the Italy-Swiss colossus MSC – Mediterranean Shipping Company. Going on the available data Alphaliner 2003 it is possible to group the characteristics of the feeder services into two macro sectors: *Deep sea services and short sea services*:

- *Deep Sea services*. For this service there are 106 operators, with 664 ships amounting to 2,337,505 teus. Same with 62 direct services with 277 ships amounting to 507,689 teus and others with 34 handling services with 301 ships to a total of 1,378,816 Teus. Lastly 10 services which do not call at Mediterranean ports with 86 ships to a total of 451,000 teus.
- *Short Sea services*. For this service there are 105 operators to a total of 233 ships, of which 60 are feeder services (common + dedicated) to a total of 122 ships, equal to 88,034 teus of total capacity; 45 “Short Sea” line services with a total 111 ships at 61,933 teus.

The average size of deep sea ships in direct service from the Mediterranean amounts to around 1,800 teus, while the ships that work in transshipment (one port of call) have an average capacity which is higher by 4,500 teus. The remaining ships which currently run in the Mediterranean, operating mainly on the Northern Europe-Far East routes and

which do not call at any port in the Mediterranean have an average capacity of 5,500 teus. The 3/4 of the world fleet operating “pendulum” services along the East-West and North-East routes serve the Mediterranean market including one or more ports of call of the Mediterranean Hub in their “port rotation” (Meersman H., van de Voorde E., Vanelslander T. 2005). In the current scenario, with regard to the Mediterranean line services, previously referred to as “Short Sea” services, they tend to combine traditional volumes with pure feeder transshipment cargo, including one or more intermediate stopovers in the transshipment hub in the schedule. In this case the average capacity varies from 500 to 900 teus (Frankel E. 1995).

### 3. Med port rotation

The main cost elements of a voyage is *daily charter rate* of the feeder ship (depending on the size, speed and type of the ship being chartered and the length of the voyage), *expenditure* at the various ports of call (variable from port to port and depending on the number of ports visited, as well as the size of the ship), *bunker costs* (depending on the speed of the ship and the length of the voyage) and *insurance costs* (depending on the size, age and the place where the ship was registered) (Evans JJ., Marlow PP. 1990 and McConville J. 1999). Profits, however, depend on the number of teus carried during the journey and the tariff negotiated with the Shipping Line for the transport based on the FIO (free in–free out) for each stretch. This tariff is normally determined from an analysis of running costs for the service and the operating margin fixed by the operator himself. At the moment, the feeder charters in the Mediterranean are very much influenced by the excess of supply, and the profit margins per unit transported are minimum (Jansson, J.O. and Shneerson B. 1987). The ideal structure of a feeder service will include in their “port rotation” a limited number of ports in the same geographical area, whose combined import and export volumes are able to maximise the use of available capacity. Such a system depends on feeder services that connect a Hub port with a maximum of 4 regional ports. A more complex structure is one that has 3 ships doing “*butterfly*” services, with trips of 21 days, operating on a double loop centring on the Hub port. The three ships do two stop-overs per week at the port of transshipment with one stop-over per week in each regional port included in the port rotation. This structure keeps up the weekly frequency, and with it the connections required, serving two different geographical areas at the same time, requiring 21 days' rotation. A typical example is the Adriatic–Middle Eastern services with the hub at Gioia Tauro or Taranto. In this case, the Adriatic loop is completed in around 9.5 days, while the Eastern loop takes around 11.5 days (Frankel E. 2002).

The incidence of the transport cost on the final price of the merchandise transported varies significantly depending on the commodity categories transported; the degree of this incidence depends on the total value of the load transported. More detailed figures show the existence of cost variability for the various countries of origin of the products. In fact the merchandise has different prices even if the unit value of the cargo constitutes an important variable for an operator. Its oscillation can alter the potential market, especially for merchandise with a low unit value and very wide supply (Engelen S., Meersman H., van de Voorde E. 2006). However, purely as an example, the IMF estimates that for the single stretches, the average cost is equal to around 6 % of the

value of the world total. It appears greater for the developing countries (around 10 %) than for industrialised nations (5 %). On the contrary while the cost of door-to-door transport can be estimated at around 20%, even allowing for the possibility of very anomalous situations. Knowing the incidence of transport on the unit cost of the cargo contributes to identifying the centres of highest cost. Furthermore, in all phases of the cycle, the transport intermediaries (shipping agents and forwarding agencies) need to be considered with their costs; their incidence on the total door-to-door cost is around 8-10 %.

#### 4 Transport costs and performance indicators

The running cost of a voyage assessed from the point of view of the affreighter (charter or feeder-operator) chartering the ship from a ship-owner is made up of the following variables with chartering, insurance, main and auxiliary fuel, berthing, port dues and general expenditure (Russo F. 2001):

$$\left. \begin{aligned}
 Rc = & C_{chart} * T_v + C_{ins} * T_v + C_{IFO} * \\
 & * IFO * T_s + C_{MDO} * MDO * T_v + \\
 & + \sum C_{bi} * T_{pi} + \sum C_{pi} + C_{ge}
 \end{aligned} \right\} \quad (1)$$

where:

$Rc$  = running cost of transport

$T_v$  = total voyage time as steaming, manoeuvring, operation and idle times (days)

$C_{chart}$  = chartering price of ship (\$/day)

$C_{ins}$  = voyage insurance price (\$/day)

$T_s$  = route timing (days)

$C_{IFO}$  = main fuel pricing (\$/mtons)

$IFO$  = main fuel consumption (mtons/day)

$C_{MDO}$  = auxiliary fuel pricing (\$/mtons)

$MDO$  = auxiliary fuel consumption (mtons/day)

$T_{pi}$  = timing at ports (days)

$C_{bi}$  = berth dues (\$/day)

$C_{pi}$  = port fees (variables from port to another)

$C_{ge}$  = general expenditure (maintenance etc.)

When the running cost of a voyage is known, a particularly significant element is the relationship between this cost and the teus actually carried by the ship. Described as  $C_u$ , the unit cost will be:

$$C_u = \frac{Rc}{teus} [$/Teu] \quad (2)$$

This is the most common economic indicator in the seagoing container transportation sector and also the most significant from the point of view of an operator carrying out a feeder service, as it provides an average value for the cost sustained in transporting a single *teu*.

The daily unit cost  $C_{ud}$  is obtained by dividing the  $C_u$  for total days:

$$C_{ud} = \frac{C_u}{days} \left[ \frac{\$}{Teu * days} \right] \quad (3)$$

A transport productivity index  $\Phi$  is calculated from the relationship between time sailing and the duration of the voyage as a whole (sailing time plus time in port):

$$\Phi = \frac{T_s}{T_v} \quad (4)$$

At last an other important indicator is the coefficient of ship utilisation defined by the ratio between the number of transported container and ship's capacity.

## 5. Expert system and mixed logit integration

The aim of this paper is to analyse a model able to minimise the running costs in an open multi-port system served by a fleet of vessels. The model used is based on the expert system code (Catalani M. 2001) interacting with a utility function approach. In particular, it will be possible to optimise the routing knowing the handling of containers in any port of call for each ship. The input data used to calibrate the utility function consists of many variables: distance, ship size, fuel cost, coefficient of ship utilisation. The model includes only a few components of the running costs. The expert system code will allow the calculation of the optimal loading plan of the ships involved on this route. The sum of the running cost of all ships will lead to the definition of the "Routing Plan". The output of the code will provide the route which optimise parameters of utility function. This takes on particular importance in the case of small and medium-sized ships running short routes as a feeder service in the Mediterranean area (Buxton 1971). This case leads us to consider the behaviour of an owner who must allocate ships operating in a multi-port system and minimise the running cost. All that needs to be considered in terms of the operative cost of ships employed and their technical characteristics (Frankel E. 1997). Generally speaking, this approach is partially defined in the literature (Jansson JO., Shneerson B. 1987), but it can be very complex if we consider the large number of variables involved. In our case, we have a port system (nodes) interconnected by routes (links) constituting the maritime network served by a fleet of vessels. We must consider the possibility for each ship to transport containers to each port along the route, minimising overall running costs (Zerby, J.A. and Conlon, R.M. 1982). The solution to the problem is calculated for each ship of the fleet from: the timing and routing of the ships, container movement for each port of call and running

cost. The software that was created to analyse maritime networking route returns optimal routing optimisation according to previous variables declared in the utility function. The aim is to optimise the utility function according also to the distances matrix (distances values between several ports) and containers O-D matrix (matrix origin - destination of containers flow between several ports). The distance matrix and containers O-D matrix and all parameters of function utility ,as said, are used by software to plot and design optimal routing.

This exhaustive methodology entails a computer search of a large number of possibilities to find the optimal solution, which becomes difficult if the number of ports, variables and ships increases considerably. In contrast, this paper proposes the use of a methodology based on an “expert system”. This method allows us to find solutions in a limited domain with the same results as those obtained by human experts. The advantage of this choice, with computerised calculations, allows us to “grasp” the know-how of maritime logistic experts. The program, which will solve the problem of routing for a liner with many ports of call, requires the following operative phases:

- identification of the route and ports
- knowledge acquisition in terms of container traffic
- formulation of logical rules for cost structure
- code of optimum problem solution

As regard the employed methodology for utility function solving it uses a mixed logit model such as McFadden D. and Train K. 2000. This is one of the most complete models developed by McFadden D. (1996), Train K.(1998), Ben Akiva M. - Wolker J. (2002).

The utility function uses only a few cost variables due to the limit of computer program with a large extension of variables. The econometric model application reflects the choice of freighters who operate in the Mediterranean area. In reality there fifty-nine chartered feeder ships which main running costs are: time charter, insurance, bunker and port fees. The charterer operates time by time with different feeder ship sizes. The Bayesian procedure in mixed logit model considers charterer choices (repeated) among j sizes of feeder ships in each T time periods (Allembly G. 1997) and (Train K. 1998). The perceived utility from alternative j in period t becomes (Train K. - Sonnier G. 2003)<sup>1</sup>:

$$U_{njt} = \beta'_n x_{njt} + \varepsilon_{njt} \quad (5)$$

Where  $\varepsilon_{njt} \cong$  iid extreme value and  $\beta_n \cong N(b, \Omega)$ . The vectors of variables  $x_{njt}$  and parameters  $\beta_n$  extended to K. Conditional on  $\beta_n$  the probability sequence of choices being the product of standard logit formulas (Train K, 2003):

$$L \langle y_n | \beta_n \rangle = \prod_t \frac{e^{\beta'_n x_{ny_t t}}}{\sum_j e^{\beta'_n x_{ny_t t}}} \quad (6)$$

<sup>1</sup> Train K. and Sonnier G. 2003“ *Mixed logit with bounded distribution of partworths*”. The methodology, the papers and the manual to implement the procedure described in this paper are available on Train’s website at <http://elsa.berkeley.edu/~train>.

Successively the parameters are defined by  $c_n = T(\beta_n)$ , where T is a transformation that depends only on  $\beta_n$  and is weakly monotonic.

The distribution of  $c_n$ , is determined by the transformation. Utility is specified as:

$$U_{njt} = T(\beta_n)' x_{njt} + \varepsilon_{njt} \quad (7)$$

The chartered probability choice sequence given  $\beta_n$ , as Train K. and Sonnier G, 2003 is:

$$L(y_n | \beta_n) = \prod_t \frac{e^{T(\beta_n)' x_{nynt}}}{\sum_j e^{T(\beta_n)' x_{njt}}} \quad (8)$$

The overall explication of the formulas (5,6,7,8), the code and the papers, as said, are available on Train website.

## 6. Routing networking analysis

The paragraph 6.1 shows an example relating to the times and the costs of a typical voyage of a feeder ship, operating on a routing service in the eastern Mediterranean area (Sturmeijer, S.G.1967 and Buxton, I.L. 1971). The charts show the standard composition of data supplied by a feeder operator (charterer) on behalf of the line. The capacity of the ships examined varies from a minimum of 400 teus (1 teu as a standard capacity of 14 tons) to a maximum of 1000 teus. The average capacity is equal to 650 teus per ship. The database used includes the following division:

- scheduling of the journey, rotation, activity for stop-over, arrival and departure times from each port in the rotation;
- ship profile and container details of unloading /loading per port;
- round trip costs;
- port dues.

The analysis of the data shown in the following figures must be understood as purely descriptive of the model for costs which was used by the application below, and should not therefore be identified with the true situation. It needs to be pointed out, in any case, that “stevedoring” costs are not normally included, i.e. the shifting of containers in port, but only the costs of transport based on the FIO agreement (Free In – Free Out) between the feeder operator and the main line owner of the container.

Table 1 shows the schedule of a feeder ship. In it, we show the schedule number, the port of call with relative dates of arrival, the start of operations, and departure with container movement such as unloading and loading.

Table 1: Ship's scheduling Med area.

MED / SERVICE Current Schedule					
Schedule No. 3125				2001	
026				Moves	
Ports	Arrival	Start ops	Departure	Disch	Load
1			15 09 (08:00)		199
2	17 <sup>Mon</sup> 09 (06:00)	17 09 (08:00)	17 09 (16:00)	94	55
3	18 <sup>Tue</sup> 09 (06:00)	18 09 (07:00)	18 09 (16:00)	62	110
4	19 <sup>Wed</sup> 09 (08:00)	19 09 (09:00)	19 09 (19:00)	74	121
1	21 <sup>Fri</sup> 09 (02:00)	21 09 (03:00)	21 09 (21:00)	265	
SHIP DETAILS					
Intake					400 Teus
Vessel capacity					281 Teus
Deadweight					4.100 Tons
Speed					15 Knots

Source: MCT, Shipping companies.

Table 2 shows the ship profile representing the weight condition of the ship at departure from each individual port, defined in metric tonnes and teus, full or empty. Specifically, in Table 2 we show the names of ships, the port rotation list, and the quantity of containers loaded and unloaded.

Table 2: Ship profile determination.

M/v HH				voyage N.26					
TEUS Port Rotation	LOADING			DISCHARGING			SHIP'S PROFILE		
	Full	Empty	WGT	Full	Empty	WGT	Full	Empty	WGT
1	280		3.727				280		3.727
2	70	14	1.091	139		1.796	211	14	3.022
3	110	31	1.663	80	8	945	241	37	3.740
4	132	35	1.791	86	11	1.340	287	61	4.191
1				287	61	4.191			
TOTAL TRIP	592	80		(teus full / empty transported during voyage)					

Legenda: 1,2,3,4 = ports

Note: Ship profile represents condition of cargo in every ports in WGT, Teus Full or Empty - Loading / Discharging

Source: MCT, Shipping companies.

Table 3 shows a summary of the overall subdivision of the main components of total round trip costs with the distance travelled, average speed, fuel consumption, manoeuvring, operational steaming, time charter cost, insurance, bunker and mooring fees, and cost per mile in \$.



Table 3: Summary of round trip costs.

Ship name	Voyage n°		Miles travelled	Average Speed (miles/hour)	Consume (tons)		Total (mt)	Daily Consumption (mt)
					Main (mt)	Aux (mt)		
r	26		1.530	14,71	62,76	4,30	67,06	10,21
			Steaming d h m	Manoeuvring d h m	Operation d h m	Idle Times d h m	Total (days)	
			04/ 8.00	00/ 3.23	01/ 3.45	00/ 22.34	06/ 13.42	
		US \$ TC x day	TC (US \$)	Insurance (US)	Bunker (US \$)	Port dues (US \$)	Mooring dues (US \$)	Total (US)
		5.188	34.091,59	201.40	6.194.,94	11.734,25	321,52	52.543,70
		US \$ / mile	mile / mt	Cost subdivision %				
				Time charter	Insurance	Bunker	Port Charges	
4,05	22,81	64,9%	0,4%	11,8%	22,9%			

Legenda: TC = Time Charter  
 Mt = Metric Tons  
 Main = Fuel main motor (tons)  
 Aux = Fuel auxiliary motors (tons)  
 D h m = Day, hours, minute

Steaming = Navigation time  
 Manoeuvring = Port manoeuvring  
 Operation = Handling time  
 Idle Times = Off port time

Source: Shipping companies.

Table 4 shows the details of the fees paid at each port. Generally we have different dues for different ports.

Table 4: Port fees.

RECAP - port dues			
Ship Name	Voyage	Port	US\$
1	26	1	1.201,55
2	26	2	1.458,32
3	26	3	3.800,11
4	26	4	1.274,28
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Source: MCT, Shipping companies

Table 5 shows detailed container movements in the loading/unloading ports. As we can see, the details of containers transported on each link of routing are given here with indication of size, WGT, full or empty.

Table 5: Detail of containers transported on routing.

Pol	Pod	LOADING								DISCHARGE								Mvs
		20 F	40 F	TEUS	WGT	20 E	40 E	TEUS	WGT	20 F	40 F	TEUS	WGT	20 E	40 E	TEUS	WGT	
1	2	49	45	139	1.796													199
1	3	33	17	67	784													
1	4	36	19	74	1.147													
1	1																	
<b>Total</b>		<b>118</b>	<b>81</b>	<b>280</b>	<b>3.727</b>													
2	3	3	5	13	145		4	8	16									149
2	4	1	2	5	48	6		6	13									
2	1	36	8	52	869													
<b>Total</b>		<b>40</b>	<b>15</b>	<b>70</b>	<b>1.062</b>	<b>6</b>	<b>4</b>	<b>14</b>	<b>29</b>	<b>49</b>	<b>48</b>	<b>139</b>	<b>1.796</b>					
3	4	7		7	122	1	2	5	10									172
4	1	47	28	103	1.474	24	1	26	57									
<b>Total</b>		<b>54</b>	<b>28</b>	<b>110</b>	<b>1.596</b>	<b>25</b>	<b>3</b>	<b>31</b>	<b>67</b>	<b>36</b>	<b>22</b>	<b>80</b>	<b>929</b>	<b>4</b>	<b>8</b>	<b>16</b>		
3	1	68	32	132	1720	7	14	35	71									195
<b>Total</b>		<b>68</b>	<b>32</b>	<b>132</b>	<b>1720</b>	<b>7</b>	<b>14</b>	<b>35</b>	<b>71</b>	<b>44</b>	<b>21</b>	<b>86</b>	<b>1317</b>	<b>7</b>	<b>2</b>	<b>11</b>	<b>23</b>	
<b>Total</b>										<b>151</b>	<b>68</b>	<b>287</b>	<b>4.063</b>	<b>31</b>	<b>15</b>	<b>61</b>	<b>128</b>	265

Legenda: 20 F = Container 20' feet (full)  
 40 F = Container 40' feet (full)  
 WGT = Weight Cargo tonn  
 POL = Port of loading

20 E = Container 20' feet (empty)  
 40 E = Container 40' feet (empty)  
 Mvs = Moves discharging/loading containers  
 POD = Port of discharge

Source: Shipping companies.

From ships data base elaboration, more generally, from data base the total trip routings number are 140 and the main considerations deriving from the overall aggregated data analysed are:

- the number of voyages carried out by the same ship in the reference month varies from 1 to a maximum of 5.
- the cost of chartering the ship is equal to 64.07 % of the cost of the voyage.
- the bunker cost amounts to 11.27 % of the total cost.
- the port costs are 24.08 % .
- the insurance costs, however, account for the remaining 0.58 %.
- the average daily bunker consumption is around 11.61 tons per day while at sea.
- the average cruising speed is around 15 knots.
- the average navigation cost is US \$ 6.55 per mile.
- the ship does 15.83 miles per bunker tonne

### 6.1. Routing optimisation application.

Based on data base available from feeder operators with different feeder ships size in the Mediterranean area, and after mixed logit calibration by maximum likelihood simulation of the utility cost function parameters, an application of a Train K. code (see note pag. 6) with coefficients transformation of the above data has been attempted. The results of the application, with statistical data analysis, are shown in the Table 6.

Table 6: Estimâtes coefficients of normals transformations.

Variables $\beta$	coefficients	t-statistics
Ship Dimension (TEU)	1.0	1.8
Movement level	10.0	2.1
Distance	1.0	1.1
Running cost	0.5	1.9
Simulated log likelihoods	-62.8915	

It is clear that the ship utilization coefficient is statistical significant because t-value is greater than +/- 1.96 unlike ship dimensions variable and distance variable. All that needs more investigation. It is essentially an exemplification of a proposed routing based on an expert system (Russel S.J. and Norvig P. 2003). The proposed model makes use of a calibration model of McFadden's utility function as above. Essentially, the cost function calculation method (utility) uses a mixed logit model calibrated using a sample of 59 feeder ships operating in the Mediterranean, and chartered by the operator himself. The routing under examination takes into account the following ports:

- Istanbul
- Izmir
- Marmaris
- Pireus
- Saloniki

In these ports there are some containers for the same routing which must be transported. The variables that come into play in this problem, in addition to the distances between the ports, are also those concerning the cargo to be loaded onto the ship. Theoretically, to identify the best route able to optimise the merchandise distribution costs, it is necessary to assess an important number of combinations of different container flows combined with different pathways (Erichsen S. 1971). The criterion proposed is based on the following assumptions: we assume that we are in port with the ship empty; we have to decide which containers to load and how many (containers with the same destination are considered to be "equal") and we must select the next node to be chosen. We can use one criterion and evaluate the best route. We can then change criterion and redo the calculation procedure. Finally, we will compare the best routes, as many as the number of different criteria and call this solution the relative best one. Here we define the following criterion, which includes:

- the routing with 5 links .With the increase in the number of stretches, there will be a relative excellent closer to the real excellent. With a sufficiently high number of stretches, there will be an absolute excellent, but the calculation of the excellent will be particularly difficult.
- the utility function as explained( Cascetta E. 2001)



Figure 1: GIS mapping of the network.

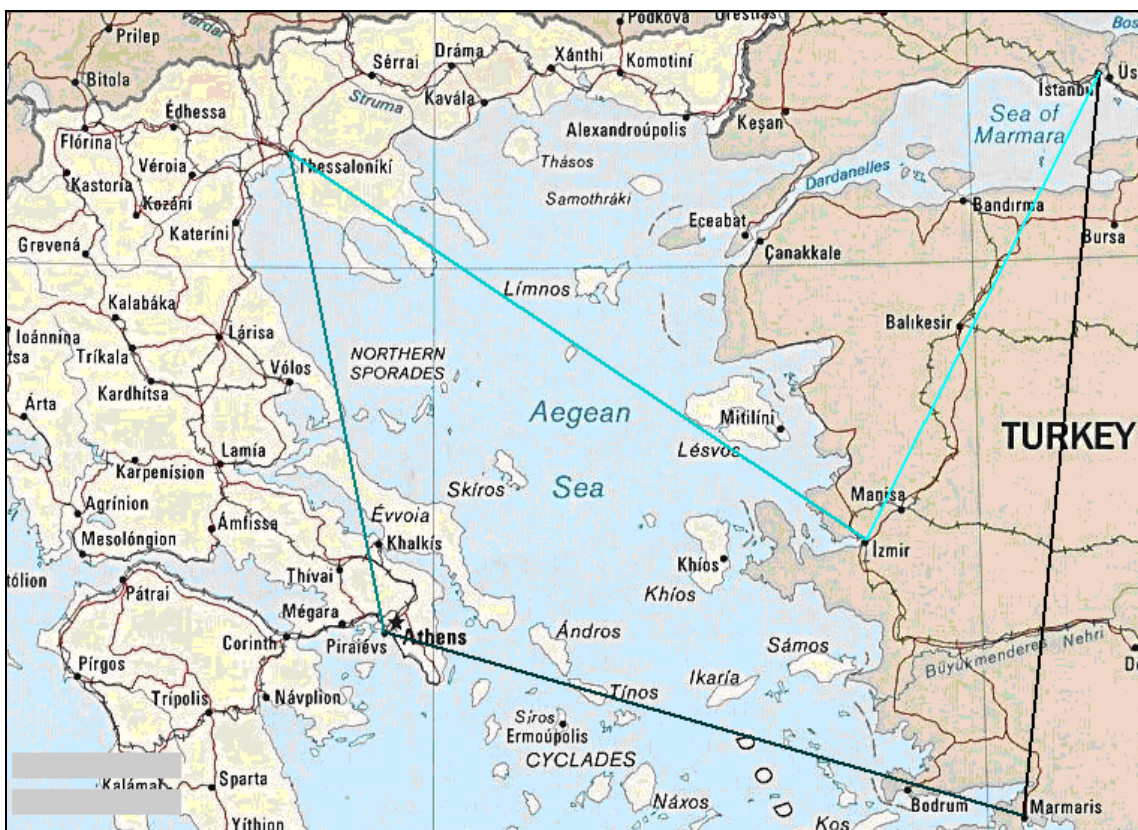


Figure 2: Routing optimisation output.

This graphic representation of the area has been mapped using a geographic information system (GIS) with the Aegean and Marmara seas and the Greek and Turkish coastal areas (Affum K. J., Taylor M.A. 1998). The map in the Figure 1 shows the five ports involved in this study.

Figure 2 shows the best routing based on the previously identified parameters. The map shows the overall routing with different shades of colour to illustrate it better. The routing of the ship is: Istanbul, Marmaris, Pireus, Saloniki, Izmir, Istanbul.

## **7. Conclusion**

The model proposed in this paper is an example of how to implement an application based on an expert system strategy plus a mixed logit calculation of parameters to be used in the routing optimisation code. The model must be considered also as an extension of the paper presented at the 9<sup>th</sup> WCTR from the author (Catalani M. 2001). The high level of data based on the feeder service allows us to implement many real models. Nevertheless the difficulty of code implementation has limited our ability to consider a higher number of variables than mixed logit calibration will allow. For a good calculation response, we will need all the parameters affecting routing cost which need to be taken into account such as ship size, voyage frequency, distance covered, total cost, cost per mile, bunker, chartering pricing etc. Nevertheless, the expert system application must be considered as a prototype to maritime transport.

The model has a high flexibility parameter that allows the updating (when cost factors are added or changed) or the adaptation (when the application has to represent different contexts) of the routing problem. The obtained results reflects the size of data base. So if I modify the surveyed variables it is possible to obtain a better results with a goodness fitting of data with statistical significance.

In the model proposed, the value of the routing link equal to 4 or 5 was fixed (for a simple representation of the routing diagram), but more realistically, to simulate route planner behaviour, an extension to 6 – 7 is needed. As specified, all this significantly increases the complexity of calculation.

Finally, the application of output shows a net differentiation regarding the traditional planner ships' assignment to the port system. It is particularly evident that the main routing link does not start with the nearest link, in terms of distance, from the departure port. The network is emphasised also distance, container movement and handling at ports. The trade-off between vessel size and the number of ports present in the network is evident. This analysis is substantially useful in the interaction of new modes of planner fleet capacity within the network. Despite the limitations that can be found in a symmetric maritime network geographical area of study, the application is interesting for route planning operations because it integrates the traditional optimisation approaches. Lastly, it will be possible in the future to experiment on specific area characterized by the presence of frequent storms, the approach proposed. This can be applied for example in the Tyrrhenian sea, in Med area, where the need to avoid the storm area by high speed ferries, in winter time, is a rule. In this case the advantage for shipping companies and passengers (high sea negative condition) must be quantified with different utility function variables.

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