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COST STRUCTURE IN A SHORT SEA SHIPPING LINE

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ABSTRACT

Several years ago the Public Administration, especially the European Union, has been promoting the implementation of the Short Sea Shipping (SSS), basically due to both the necessity to reduce the road goods transport (the congestion of the road could be an important problem in the near future) and the positive environmental effects of using the maritime transport instead of road ways. A combination of road and maritime transport in a logistic chain is the main issue. The aim of this article is to analyze the power of the SSS studying two main aspects related to it: cost of port operations and the ship's economies of scale. For this, an expression of generalized cost of transport considering maritime transport is developed, which is compared to the cost of a logistic chain without utilizing the ship. Port operations and shipping cost are included in the model. The expressions are applied to a numerical case. The works permit analyzing the influence of the variables which have a relevant role in the election of the transport supply chain. In this way the main aspects to improve the maritime transport can be identified.

Key words: Short Sea Shipping, Maritime Economy, Supply Chain

INTRODUCTION

At this moment one of the most important problems in the European Policy transport is the high level of traffic roads and the directly associated problems, which

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are basically congestion and pollution. In Spain, additionally, the strong road congestion in the Pyrenees increases the problem, which could be a bottleneck of the freight transport in the near future.

In this context, the maritime traffic is seen as a valid solution to the problem, especially the Short Sea Shipping (SSS). This type of maritime transport can be defined as the freight and passenger maritime transportation taking place in the European ports or between European ports and ports situated in the vicinity of Europe.

When the possibilities of the SSS are analyzed, several factors are usually pointed out. One of which is the economies of scale in ship, as a way to reduce transportation unitary cost; otherwise, port productivity and port costs are usually argued as problems in developing SSS.

According to this, the aim of this article is to quantify the influence these factors have in the total logistic cost in a particular type of a supply chain.

This article is structured in four parts. In the following section, the basic model is explained, using the second part to develop a mathematical model to calculate logistic costs. In the third part, this model is applied in a particular case, achieving some numerical results. The final section describes the conclusions.

THE BASIC MODEL

According to the aim described above, the study of the influence of the economies of scale in ships and port productivity is reduced to a particular case in order to achieve results as accurately as possible. Particularly, a supply basic chain of a company consists on distributing a homogeneous product to several consumers from its factory, distributed uniformly in a region. It is also considered that the product value is not high.

The company has basically two distribution strategies of the product, as showed in figure 1:

a) One-to-many. Each customer receives directly the product from the factory. It is not necessary that each truck service one customer. When particular schedule is not imposed and the value of the product is not high it is possible that all truck are filled and serve several customers in one trip, in order to reduce the total logistic cost. This is case A of figure 1.

b) One-to-many with transshipment. There is a terminal that receives the trucks from the factory and sent other truck to the customers. Few truck of great capacity can supply the terminal every day and from it several vans, which capacity could be a half of first one for instance, can supply the customers, implying a reduction of the transport cost. The final customers receives the same quality services as the first strategy, with a fewer transport cost but the holding and the handling costs of the terminal increase.

This strategy could be cheaper than the first depending on several factors, such as the length between origin and destination or the demand. Each case should be studied separately.

As the same as the first strategy, this basic structure can be optimized: in case the vans can be full, it's possible that in the same trip several customers are served, reducing the transportation cost.

Our problem is focused on companies for which the second strategy to distribute its product is the optimal. Also, it's assumed that there isn't any problem to consider that each van departs full from the terminal and serves several customers, as it is showed in the case B of the figure 1. This consideration is valid particularly if a long distance is supposed from the terminal to the final customer.

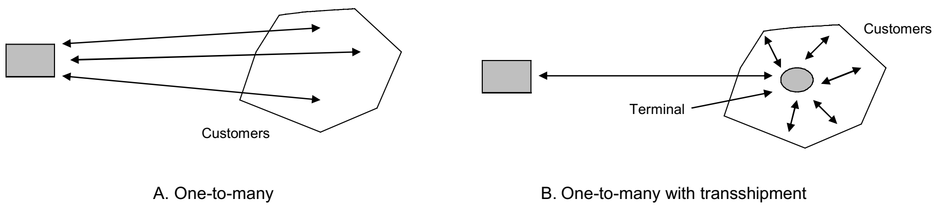

Figure 1. Strategies to distribute a product.

In this context, it is logical that the company analyses another way to transport its product, using the SSS. As a first approximation, when the most economical supply chain of a company is using a consolidation terminal, in the terms exposed in figure 2, the part of the maritime transport, particularly port B, could be viewed in the supply chain the same role as the terminal had when all transport is done only by road transport, as it is showed schematically in figure 2.

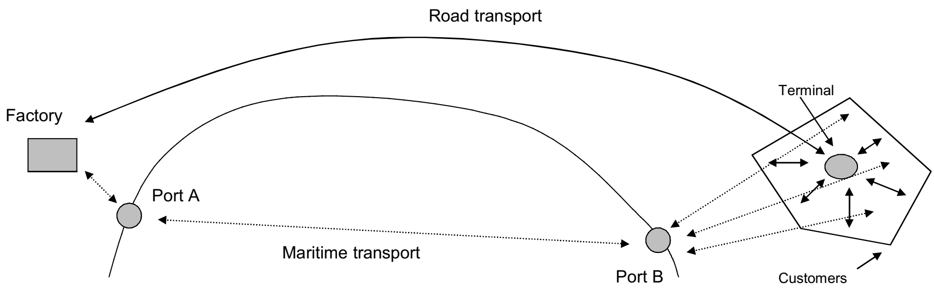

Figure 2. The implementation of SSS compared with road transport.

This alternative way of product distribution, whit maritime transport, in the exposed terms is the base of our study to analyze the SSS.

Focusing on costs, the SSS alternative could be better than only road transport depending basically on maritime cost and port costs, both of which are essentially due to economies of scale in ships and maritime time and operational cost and port productivity respectively. Maritime time and port operational cost are highly difficult to be competitive in respect to the road, because at these moments the usual speeds achieved on roads are higher than the ships and the port labor, port taxes, port congestion, etc make likely port operational cost to be most important than all cost associated to the consolidation terminal. Consequently, the competitiveness of SSS is based essentially on the economies of scale in ship and port productivity, which is analyzed.

It is considered the case that the distance between port B and final customer is not so large that the positive influence of these two factors in cost will be minimal. The weight of ship's economies of scale and port productivity in reducing cost is inversely proportional to the ratio road trip per maritime trip.

THE MATHEMATICAL MODEL

The model of the supply chain showed in figure 2 can be divided into three basic parts (factory to access port A, port A and B and maritime transport and access of port B to final customers), all of which is studied separately.

To calculate the total logistic cost per item a curve between numbers of items versus time is considered (figure 3). This permits analyzing the queue systems generated in the supply chain and then quantifying the holding and inventory cost associated with them.

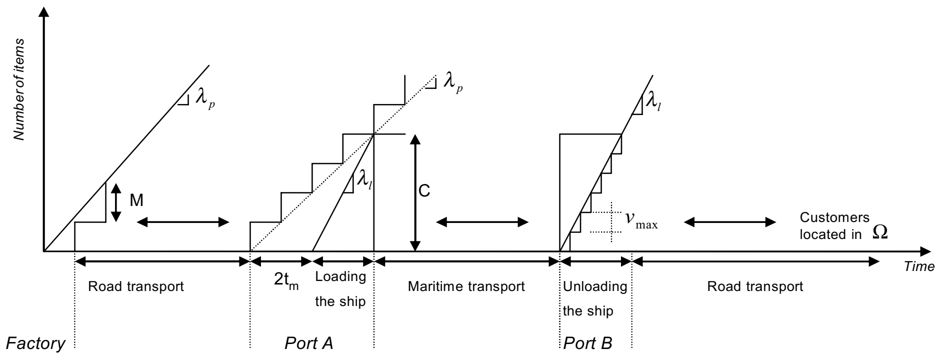

Figure 3. Basic phases of the supply chain considered, including the queue systems generated in factory, port A and port B.

The basic hypotheses are:

— The final customers are located in a region Ω in which the demand is uniformly distributed with rate δ customers per area.

— The company produces with a constant rate λ_p, items per time.
— The loading and unloading port operations rate is λ_l, in terms of items per time.
— There are several trucks with the maximum capacity (M) as possible and completely filled that are constantly carrying on from the factory to the port A, including the time that the ship is not in the port.
— Some vans depart from port B to final customer, each of which serves a particular subregion of demand (Ω_i , where $\sum_i \Omega_i = \Omega$). All vans are full and with a capacity (v_{max}) enough to serve all customer located in Ω_i.
— The ship only serve the same company and its capacity (C) is one that all the items accumulated when the ship is outside of port A and when it is loading can be transported. For this it is also necessary supposing that $\lambda_l \succ \lambda_p$. The ship departs from port A, arrives at port B and return to port A to carry on new products.
— In order to make calculations easier, it is supposed that $C/M \approx \delta$ and $C/v_{max} \approx \eta$, where δ and η are enter numbers. Thus, the relationcan $\eta \approx \dfrac{\delta M}{v_{max}}$ be automatically obtained.

In these conditions, the total logistic cost per item due to the transport from the origin to the port A access (z_{OA}) is the sum of the fixed inventory time and transport cost per dispatch, that is:

$$z_{OA} = \alpha_o + \frac{\alpha_1}{M} = c_i \left(\frac{r_{OA}}{s} + \frac{M}{2\lambda_p} \right) + \frac{2 r_{OA} c_d}{M}$$

where:
α_0: fixed inventory cost, due to transport and queue in the factory.
α_1 : transport cost per dispatch.
c_i: inventory cost per item-day.
r_{OA}: road distance from the factory to the port A access.
c_d: transport cost per vehicle-mile.

Additionally, the total logistic cost per item generated from the port A access to the port B exit (z_{AB}) is basically due to unloading and loading port operations (other type of port costs like taxes are included in this concept), inventory cost and maritime transport cost. In mathematical terms it means:

$$z_{AB} = \alpha_3 + 2\alpha_4 C + \alpha_5 + \alpha_6 C = \left(2t_m + \frac{C}{\lambda_l} \right) - \frac{M(\delta - 1)}{2\lambda_p} + \frac{\eta v_{max}}{\lambda_l} - \frac{v_{max}^2 \eta (\eta - 1)}{2C\lambda_l} + 2c_o C + c_{sf} + c_{sv} t_m$$

where:
α_3 : inventory cost when the freight is in ports in €/day-item.
α_4 : unloading / loading port cost in €/item.
α_5 : shipping fixed cost per item, in €/item.
α_6 : variable shipping cost per item, in terms of €/item-day.
c_o : port operational cost, in €/item.
c_{sf}: fixed shipping cost, in €.
c_{sv} : variable shipping cost, in terms of €/item-navigation day.
t_m : time in ship.
v_{max} : delivery lot size to a customer, that is equivalent to the vehicle capacity (in terms of numbers of items).

The inventory cost due to the port time in both ports is calculated considering the queue systems created in ports (figure 3) and estimating the average time of a item in the system dividing the total area defined by the queue system and the total items in this system (C in both cases).

Finally, to obtain the total logistic cost per item, the supply chain's cost (z_{BF}) from the port B to the final costumers should be characterized. At this part of the trip there is only one origin (port B) and several consumer that are uniformly distributed in a region Ω. We have several vans each of them serves a particular subregion (Ω_i) in this way: it departs from port B and goes full to its region stopping in each customer. The total demand of the customers of each subregion is equivalent to the van capacity, as it is described in figure 4.

In Daganzo (1996) a logistic cost per item for this particular case is studied, using the continuous approximation method. The cost function per item of each van which serves a subregion Ω_i is:

$$z_{BF} = \alpha_7 + \frac{\alpha_8}{n_s v_{\max}} + \frac{\alpha_9}{v_{\max}} + \alpha_{10} n_s = \frac{c_i r_{AF}}{s_{BF}} + \frac{2 r_{BF} c_d}{n_s v_{\max}} + \frac{c_d k \delta^{-0,5}}{v_{\max}} + \frac{c_i k \delta^{-0,5}}{2 s_{BF}} n_s$$

where:
α_7 : fixed pipeline inventory cost generated by the trip between port B and the customers.
α_8 : transport cost per dispatch.
α_9 : transport cost added by a customer detour.
α_{10} : pipeline inventory cost added per item caused by a customer detour.
n_s : number of stops per tour.
r_{BF} :average distance from port B to the points in a delivery region Ω_i.
s_{BF} : representative vehicle speed from B to a region Ω_i.
k : dimensionless factor for VRP local distance.
δ : customers/area.

In each part of the supply chain, there are other types of costs, such as fixed cost of a vehicle stop, but here the basic costs are only considered to make the analysis of the results easier.

Finally, the total logistic cost per item (z_{OF}) when the SSS is used can be modeled by the sum of the three last terms of cost:

$$z_{OF} = z_{OA} + z_{AB} + z_{BF}$$

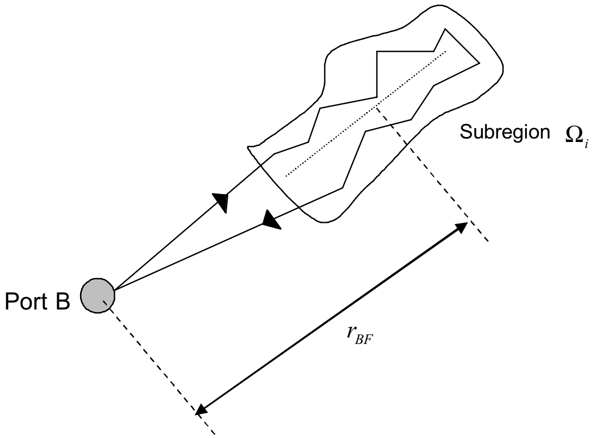

Figure 4. Route from port B to customers situated in subregion Ω_i.

Using this expression is possible to analyze the influence of the economies of scale in ships and unloading and loading port productivity in the total logistic cost per item, which permits evaluating the role of these two factors in competition of SSS in respect to road transport.

A valid way to do so is obtaining the variation of the total logistic cost per item when the port operational productivity (λ_l) and the representative variables of ship's economies of scale (c_{sf} and C) change. Considering a particular trip, the average shipping transport cost, in €/item, is the ratio between the total shipping cost (the sum of fixed, CT_{sf}, and variable costs, CT_{sv}) and the total transported items (the ship capacity in studied case). In case of increasing ship capacity (C), the average cost will reduce basically due to the importance of CT_{sf} in front of CT_{sv}, so that the ship's economies of scale is essentially represented by the variations of the value of fixed shipping cost per item (c_{sf}) and ship capacity (C).

It is important to remark that in a competitive situation a growth of productivity implies a reduction of cost production. However, in case of port industry, due to the present regulation and monopolies, it is difficult that an increasing of port productivity generates directly lower port cost. Consequently, in our analysis the port operational cost (c_o) is considered constant, independent of port productivity increase.

If $z_{OF}(C, c_{sf})$ and $z_{OF}(\lambda_l)$ represent the total logistic cost per item when only the ship's economies of scale and port operational productivity change respectively, the following elasticities are defined to study the influence of two factors in the logistic total cost:

$$\varepsilon_C^Z = \frac{z_{OF}(C, c_{sf}) - z_{OF}^*}{\Delta C} \frac{C^*}{z_{OF}^*} \quad \text{and} \quad \varepsilon_\lambda^Z = \frac{z_{OF}(\lambda_l) - z_{OF}^*}{\Delta \lambda_l} \frac{\lambda_l^*}{z_{OF}^*}$$

Where z^*_{OF} is the logistic total cost per item in the initially considered value of variables.

A NUMERICAL CASE

In this section the total logistic cost per item is obtained in a particular case. It is supposed a factory situated 2 miles far from port A. The freight is loaded in a ship and one day of navigation to arrive at port B is necessary. The distance between port B and a group of customers served by each van is about 5 miles.

The other variables' values are showed in table 1. These values permit obtaining the total logistic cost per item substituting in expression of z_{OF}. This cost is 661€/item.

Variable	Value	Units	Variable	Value	Units
c_{mf}	400	€/item	r_{OA}	2	miles
c_{mv}	50	€/item-day	t_s	0,5	hr
c_i	1	€/item-hr	c_d	15	€/veh-mile
C	500	items	c_s	120	€/vehicle
tm	1	day	k	1,15	
co	70	€/item	δ	0,5	Customers/ miles^2
λ_l	15	items/hr	s_{BF}	80	km/hr
λ_p	10	items/hr	r_{BF}	5	miles
M	50	items	s_{OB}	90	km/hr
η	16,67		v_{max}	30	items
δ	10				

Table 1. Supposed values of the variables.

The next step is evaluating the variation of this total logistic cost, using the concept of elasticity expressed above, when both the ship capacity (C and c_{sf}) and port productivity (λ_l) increase.

- If the value of λ_l goes and to 15 items/hr to 26 items/hr and the rest of the variables' values remain equally, the costs and elasticities showed in table 2 and figure 5 will be obtained. The following conclusions are derived from the results:
- To reduce the logistic cost per item an important way to do it is increasing the port productivity.
- The elasticity's values are lower than one, so the growth of port productivity is higher than the cost reduction.
- The non linear shape of the curve is due to the influence of port productivity in the inventory cost dividing the other factors, as it can be seen in expression of z_{AB}.

— In case of port industry would be completely competitive, a growth in port productivity implies a reduction also of port cost. For instance, if an increase of one unit port productivity, in items per hour, induces a reduction of port operational unitary cost (c_o) in a 5%, the reduction of total logistic cost will be higher as it is showed in figure 5 and in table 2. The elasticity is three and four times better than in case of only port productivity changes.

— Because port productivity affects basically the inventory cost in ports, the growth of port productivity is proportional to unitary inventory cost (c_i).

Increasing only of port productivity			Increasing of port productivity and decreasing port cost			
λ_1	z_{OF}	Elasticity	c_o	λ_1	z_{OF}	Elasticity
15	661		70,0	15	661	
16	658	-0,078	66,5	16	651	-0,250
17	655	-0,073	63,2	17	641	-0,251
18	653	-0,069	60,0	18	633	-0,251
19	650	-0,065	57,0	19	624	-0,251
20	648	-0,062	54,2	20	617	-0,250
21	646	-0,059	51,5	21	609	-0,249
22	645	-0,056	48,9	22	603	-0,248
23	643	-0,054	46,4	23	596	-0,247
24	642	-0,052	44,1	24	590	-0,245
25	641	-0,050	41,9	25	584	-0,243
26	639	-0,048	39,8	26	579	-0,241

Table 2. Total logistic cost per item in case of increasing only port productivity and increasing port productivity and reduction of port cost.

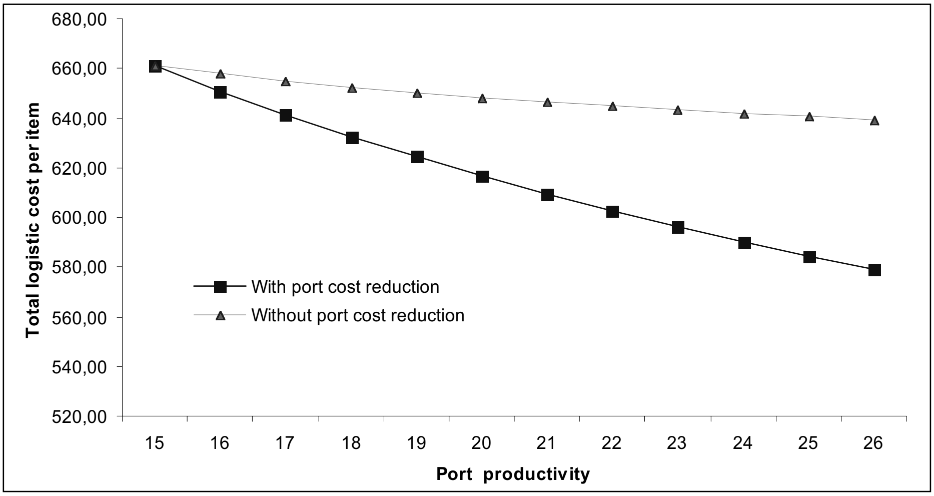

Figure 5. Curve of total logistic cost per item with respect to port productivity.

In case of variation of ship capacity, fixed unitary shipping cost (c_{sf}) and ship capacity (C) may change. At this point, a correlation between the variations of both variables has to be made. The unitary fixed shipping cost, in € per item, is the ratio between the total fixed cost (CT_{sf}) and the ship capacity, so when the second value changes the variations of c_{sf} will be about:

$$\frac{dc_{sf}}{dC} = \frac{d}{dC}\left(\frac{CT_{sf}}{C}\right) = \frac{-CT_{sf}}{C^2} \Rightarrow \Delta c_{sf} \approx \frac{-CT_{sf}}{C^2}\Delta C$$

In this relations between the variation of both variables it is supposed that the total fixed shipping cost and the variable shipping cost (c_{sv}) are approximately constant. Using this last expression the new values of the total logistic cost per item are calculated whilst ship capacity is increasing, as it is showed in figure 6. Also the elasticity of the logistic cost in respect to shipping cost is obtained. The following remarks can be pointed out:

— Increasing the ship capacity, it is possible achieving important reductions of logistic cost per item.
— These reductions are decreasing constantly when the ship capacity growths.
— The elasticity of logistic cost in respect to ship capacity is lower than unity, so if the ship capacity increases one unit, the reduction of logistic cost will be lower than the unity.
— The values of this elasticity is higher than the elasticity of logistic cost with respect to port productivity, which implies that the logistic total cost per item can be reduced more increasing ship capacity than growths of port productivity. However, both factors are strongly important to achieve the competitiveness of SSS in respect to road transport.

c_{sf}	C	z_{OF}	Elasticity z_{OF} -C
400	500	661	
367	550	630	-0,53
337	605	603	-0,50
309	666	578	-0,47
283	732	556	-0,44
260	805	536	-0,41
238	886	519	-0,37
219	974	503	-0,33
201	1072	490	-0,30

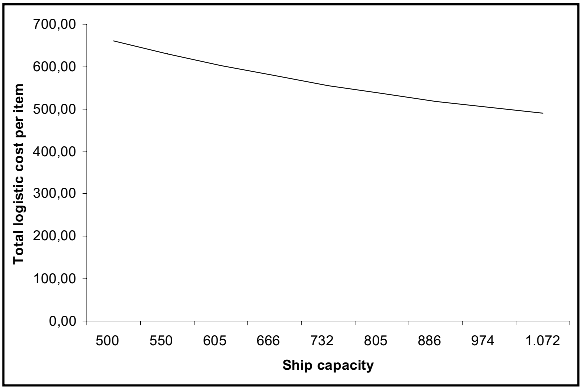

Figure 6. Variation of total logistic cost when ship capacity increases.

CONCLUSIONS

The following conclusions are derived in this article:

— In this article it is considered a supply chain in which a consolidation terminal is optimal in case of only road transport. In this situation, possibility to use maritime transport as an alternative way can be analyzed, considering that ports could have the same role as the consolidation terminal has in the first transport alternative.

— In the implementation of maritime transport in the supply chain there are two factors important: economies of scale in ships and port productivity. The port cost is also essential, but at this moment port industry has strong restrictions to competition so that constant port cost is supposed.

— A mathematical model has been developed to achieve the total logistic cost per item depending on the value of the most significant variables of the considered supply chain.

— In the numerical case, the elasticity of total logistic cost per item in respect to ship capacity is lower than one. Consequently, in case of increasing the ship capacity with one unit, the reduction of logistic cost is lower than one.

— Also, in case of increasing port productivity, a reduction of logistic cost is achieved, with elasticity lower than one, which could be increased if port cost is also reduced.

— The reduction of logistic total cost will be better if the ship capacity increases instead of growth of port productivity.

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ESTRUCTURA DE COSTES DE UNA LÍNEA DE TRANSPORTE MARÍTIMO DE CORTA DISTANCIA

RESUMEN

Desde hace algunos años la Administración Pública, incluyendo la Comunidad Europea, está promocionando el Transporte Marítimo a Corta Distancia (TMCD), motivada esencialmente por la necesidad de reducir el transporte de mercancías por carretera (los costes asociados a la congestión suponen un importante problema a efectos de bienestar social) y por los efectos positivos en términos de costes sociales y ambientales que implica sustituir los tráficos por carretera por vía marítima. Con el TMCD se trata de combinar transporte por mar y por carretera. El objetivo del presente artículo es analizar el potencial de esta combinación modal centrando los trabajos en dos aspectos: la productividad de las operaciones portuarias y las economías de escala del buque, elementos estos que tradicionalmente se han considerado básicos para el desarrollo del TMCD. Para ello se ha calculado el coste total de una cadena logística formada por transporte por carretera y por mar y se ha comparado con el caso de utilizar sólo la carretera. El modelo se ha aplicado a un caso numérico.

METODOLOGÍA

En consonancia con el objetivo del artículo, los trabajos se han centrado básicamente en la obtención de un modelo del coste total unitario del transporte de mercancías en dos casos: suponiendo una cadena logística formada íntegramente por el transporte por carretera; y otra que combina buque y camión. En ambas situaciones se ha supuesto el caso particular de una fabrica que distribuye sus mercancías (*one-to-many*). Respecto al segundo de estas cadenas, se ha considerado que el volumen de transporte y la distancia entre el origen y los destinos son tales que para la empresa resulta más rentable adoptar una configuración de red con terminal de consolidación (*one-to-many with transshipment*); para lo cual los puertos de origen y destino y el transporte marítimo se han concebido como la terminal de consolidación.

Entre los cálculos de los costes conviene destacar los derivados del tiempo, para los cuales se ha estimado las colas formadas en los puertos, y las distancias de reparto del puerto destino a los destinos finales.

A partir de la construcción del modelo de costes de ambas cadenas logísticas, éste ha sido aplicado a una situación hipotética.

A efectos de cuantificar la influencia de las economías de escala del buque y la productividad de las operaciones portuarias en el potencial del TMCD sobre el transporte único por carretera, se ha valorado la elasticidad coste total unitario respecto a la capacidad del buque y a la productividad de las operaciones portuarias respectivamente.

RESULTADOS

En el caso de los costes portuarios, se han obtenidos unas elasticidades coste total unitario-productividad portuaria menores que uno, pero que en términos absolutos suponen una importante reducción de los costes por TMCD. Este efecto positivo puede verse incrementado en caso de una situación de plena competencia de la industria portuaria, en la que cualquier incremento de productividad, y por ende de los costes operativos, los traslada a la tarifa cobrada al usuario final del puerto.

En el caso de los incrementos de la capacidad del buque, hay que tener presente que, al propio tiempo, por las economías de escala, se produce una reducción del coste unitario del transporte marítimo. A tenor de los resultados obtenidos en el caso supuesto, las reducciones del coste total unitario del TMCD a medida que la capacidad del buque es mayor son significativas, superiores al caso anterior, aunque con elasticidades menores a uno.

CONCLUSIONES

Las principales conclusiones son:

— En este artículo se ha considerado el caso de dos cadenas logísticas de distribución de la mercancía de una fábrica a varios destinos: suponiendo transporte únicamente por carretera y combinando carretera y buque. Se ha supuesto una configuración de red logística de *one-to-many* con terminal de consolidación.

— En el desarrollo del TMCD hay dos aspectos que tiene un papel esencial: la productividad portuaria y las economías de escala de los buques.

— Se ha desarrollado un modelo de costes para ambas cadenas logísticas que permita evaluar la variación del coste total unitario con las variables que caracterizan los dos factores del punto anterior.

— Se ha supuesto un caso particular, de donde se ha obtenido que la elasticidad del coste total unitario respecto a la productividad portuaria es negativa y menor que uno, aunque las reducciones del coste unitario en términos absolutos son significativas.

— En caso de la elasticidad del coste total unitario respecto a la capacidad de la terminal, se obtienen valores negativos y menores que uno, aunque mayores que con la productividad portuaria. Esto es, con incrementos de la capacidad del buque es más competitivo el TMCD respecto a la carretera que con mejores de la productividad portuaria.