

## A SUPPLY CHAIN ANALYZED UNDER THE GAME THEORY

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**RÉSUMÉ :** *This paper proposes a tool for the selection of the most appropriate transports (air, sea, railway and trucks) to provide a wine company. Decisions in the supply chain management of this transport will be based on the game theory, especially on the cooperative games. A British drinks retailer is planning to introduce a new product of its white label. The product, in this case wine, departs from two Spanish denominations of origin. The work considers a set of modalities for the international transport of the wine bottles from Spain to the main warehouse of the company in Great Britain. The problem is planned as the resolution of a cooperative game on shared costs, in which the global cost due to the several ways of transport is minimized. A model is developed considering the Shapley's values. Not only the minimum cost for the transport can be determined, but also the result can help the manager to make strategic decisions to design a robust and reliable transport. The simulation shows the best results of profit and how the cost can be reduced thanks to the use of simultaneous transports, i.e. cooperation.*

**MOTS-CLÉS :** *supply chain management, transport, game theory, cooperative game.*

### 1. INTRODUCTION

The objective of the study is to define, through the game theory, the participation of the different transport agents in the supply chain of a British specialist drinks retailer dedicated to the distribution and sales of wines and liquors. Thanks to the information from the developed system, the different transport frameworks can be dimensioned, as well as the good flows can be adapted to maximize the profits.

The study is focussed on a product which is considered specially elaborated for the company and with origin in Spain. We will follow the first part of the product flow, which goes from the warehouses in the origin to the sales in the stores of the company in the United Kingdom. Although the data in this study are not strictly real to preserve the privacy for the company, the magnitude order will be appropriate and very near to the reality.

The step in the supply chain objected of the work consists in the transport from Spain to the main distribution warehouse in United Kingdom. This service is outsourced, and therefore it is studied as a game in which the different ways of transport are competing for the transport, but the company searches the minimum global cost for this transport.

This service is outsourced, and it is studied as a cooperative game in which the different ways of transport are competing the services offered. The company searches the minimum global cost for the transport and therefore

selects the most advantageous coalitions for them (Bowersox et al, 2002).

The structure of the paper is as follows. In Section 2, the main characteristics of the company are presented. Section 3 describes the supply chain of the company, with special emphasis on the part to be improved. Once the different means of transport have been presented, Section 4 develops the components of the cost function. In Section 5, the model based on linear programming is detailed under the game theory point of view. For the simulation of the process, from which the conclusions will be taken, a spreadsheet is used. Through the study, basic theoretical aspects help to understand the results (Section 6) and the conclusions (Section 7).

### 2. DESCRIPTION OF THE COMPANY

The company is the leading retailer specialized in wines and liquors for the United Kingdom. Its business model is based on the franchising with more than 2,000 stores all over the country.

Although a great amount of wine is sold in supermarkets, these specific stores only have approximately the 30% in the sales of wine products. This percentage of sales is subdivided in: a 14% for the sector chains of sales retailers (in which the company is included and has about 30%), a 10% for independent groceries and the rest (5%) for independent shops specialized in the product. This supposes that the company sells a 3.5%-4.2% of the total sold wine in the United Kingdom.

The most sold Spanish wines are, without considering Jerez and cava, those from La Rioja and Ribera de Duero among others (Torrecillas, 2005). La Rioja supposes a 26.4% of the total sales of Spanish wine (with 1,464,415 boxes per year) and Ribera del Duero, 10.4% (575,667 boxes per year). On the other side, the United Kingdom is the most important international market for denomination of origin La Rioja.

The own white label of the company was created by the company to offer an own product, becoming competence of the great world marks and taking advantage of a particular structure of distribution for a market of more than 2,000 sale points. Nowadays, Spain is not one of the 7 provider countries of this wine. Therefore, the study considers the possibility to introduce the Spanish wine through this distribution channel, what can lead to increase the percentage of sales for Spanish wine in Great Britain. The volume, in thousands of liters, and the value, in thousands of pounds, for the total wine sales in United Kingdom (UK) and only for Spanish wine sold there are presented in Table 1.

	<b>Volume (*1000 l)</b>	<b>Value (*1000 £)</b>
Total wine sales in UK	761,712	3,848,337
Black	346,189	1,814,772
Rosé	37,957	196,921
White	370,522	1,800,768
Spanish wine sales in UK	50,982	248.357
Quote of Spanish wine	6,70%	6,50%
Black Spanish wine	10,30%	9,90%
Rosé Spanish wine	4,10%	3,80%
White Spanish wine	3,40%	3,00%

Table 1. Total and Spanish wine sales in United Kingdom.

The white label of Spanish origin has a potential 4% on the total number of bottles for the United Kingdom if sales are similar to the French and Italian origins. At short term, the potential number of Spanish white label bottles is at least twice than the current, what implies 11 million bottles per year.

### 3. The supply chain of the company

The company has a complex collecting network from the main areas of wine production to its country. Great Britain is the second importer of wines in the world. The logistics for wine is widely extended and studied, as there are logistic companies only devoted to this kind of transport.

The dealt supply chain starts at the Spanish denominations of origin with high recognised prestige in the United Kingdom. In this geographic area, wine is elaborated (produced and also bottled for a white label) following a process which lasts at least two years. The producer and the company agree the sales price in the warehouse of the producer and the transport is assumed by the customer, the company, with a contract *Exworks*. Therefore, the customer assumes all the risk during the transport and can decide how it can be taken to place, the main decision for the company. It must decide which way of transport is used for the transport to the main warehouse of the company in the United Kingdom.

There are four possibilities of transport in order to have the wine at the destination. The main and unquestionable objective is to maintain the merchandise flow in order to provide the British market without stockouts. Another priority for the company is to sell its own label before any other one, arguing strategic and financial reasons (Perona et al, 2001).

Different logistic companies offer four ways of transport:

- First, there is the maritime transport. This way requires an additional transport to arrive by motorway up to the Bilbao port, from where the wine will depart to Great Britain. Once in Dover, the wine arrives with little effort to the main warehouse of the company as it is placed into the port complex.
- Another way to reach Dover is on the railway. This mean is characterized by the night travel because the railway is devoted to the passengers during the day. The main loading station is Logroño and the route is via Biarritz–Bordeaux–Paris–Calais. The train station in Dover is not far away from the port complex and the transport to the warehouse is not expensive.
- A third mean is by planes, the fastest ones, but also the most expensive. For the transport by air of wines, the airport in Vitoria is the most indicated. The destination is one of the three airports in London. This transport has the inconvenient of requiring trucks to move the goods from the airport to the warehouse.
- Last but not least important, the fourth mean of transport is the most traditional, the trucks of high tonnage used by the greatest European logistic companies. The route to Dover is close to the railway and has the advantage to be point to point.

From the main warehouse, the goods are distributed to the regional warehouses spread over the United Kingdom. The relation of these buffers respect to the number of shops attended by each one is 1 to 100,

approximately. From the regional warehouses to the sale points, transport is done by trucks of medium tonnage.

Table 2 includes the data used in the cost function for the different transports: the direct cost, the frequency in days between orders, the monthly capacity for each transport, the scrap percentage and the traffic cost for each transport.

	Air	Railway	Road	Sea
Direct cost (€/bottle)	0.778	0.020	0.010	0.005
Frequency (days)	6	10	15	2
Capacity in bot./month	847,800	777,600	324,000	3,240,000
Scrap (%)	1.20%	0.60%	0.30%	1.00%
Traffic cost (€)	0.016	0.066	0.066	0.164

Table 2. Basic data for each transport to be considered.

Several factors strictly related to cost must be taken into account in order to define the transport system and determine the best kind of transport adapted to the particular supply chain for the company (Ghiani et al, 2004). The required time, as instance, can be a key factor in strategic terms. The days to transport the bottles from the denominations of origin up to the main warehouses of the company in Dover,  $x_j$ , are provided in Table 3.

j	Mean of transport	$x_j$ (days)
1	By air (plane)	1
2	By railway (train)	4
3	By road (truck)	4
4	By sea (ship)	10

Table 3. Time for the transport by each mean of transport, where  $x_j$  is the time required by transport  $j$ .

#### 4. Function of costs for possible coalitions

The problems for the cost assignment are often found in real world (Bilbao and Fernández, 2003), when a set of individuals can work together in a common project. The theory of cooperative games gives tools to analyze and solve these problems (Schalk, 2007). The total cost is going to be distributed here considering the costs held by any possible subcoalition working alone. Therefore, it is necessary to study all the possible subcoalitions which can be created (Puente, 2004). The analysis will start taking elements one by one, then in couples, and so on up to a coalition with all the candidate elements.

##### 4.1. Components of the cost function

The above elements are taken into account to compute the cost (Waller, 2003). First the components of the cost function for the use of a mean of transport  $j$  are listed (1) and later they are developed.

$$C_{tot_j} = C_{int_j} + C_{ext_j} + C_{scrap_j} + C_{tr_j} + C_{st_j} + C_{exc_j} \quad (1)$$

- The first cost in function (1) is the internal cost  $C_{int_j}$ , measured in €/km\*bottle, equivalent to the fix and direct cost to move a bottle by a transport.
- The second term is the external cost  $C_{ext_j}$ , equivalent to the impact of all the diseconomies caused by the use of a singular way of transport. These data have been taken from expert sources of information.

Equation 2 expresses both costs, where  $x_j$  is the distance in km for the transport  $j$ ,  $ci_j$  the internal cost and  $ce_j$  the external cost both in €/km\_bottle,  $D$  the monthly demand and  $A_j$  the number of bottles per container for the transport  $j$ .

$$C_{int_j} + C_{ext_j} = (ci_j + ce_j) \cdot x_j \cdot \left[ \frac{D}{A_j} \right] \cdot A_j \quad (2)$$

The cost of a container is the same whatever the quantity is. For this reason, the two last terms in (2) indicate the exact number of bottles to occupy completely a container. The applied hypothesis is: "for the same cost, it will better the highest amount of bottles".

- The third term is the *scrap* cost,  $C_{scrap}$ . This term is referred to goods which do not arrive to the destination in good conditions and, therefore, they cannot be sold. It generates a variable cost according to the mean of transport, as the reliability depends on the transport used. It is expressed in a percentage respect to the total number of sent bottles by transport  $j$ ,  $p_j$ , and of course is multiplied by the unit purchase price  $UP_j$ , in euros per bottle, for transport  $j$ . The unit price will usually be the same without considering the specific transport.

$$C_{scrap_j} = p_j \cdot \left[ \frac{D}{A_j} \right] \cdot A_j \cdot UP_j \quad (3)$$

- Another component is the traffic cost,  $C_{tr}$ . It represents the stock carrying cost of the bottles during the route. This component is added to penalize the excessively long routes of transport, because the company must keep them in good condition.

$$C_{tr_j} = \left( \frac{x}{30} \right) \cdot i \cdot UP_j \cdot \left[ \frac{D_j}{A_j} \right] \cdot A_j \quad (4)$$

where  $x_j$  is the travel time in days,  $i$  the stock carrying rate (/month) on the unit price  $UP_j$ , referred to transport  $j$ .

- The next component is the stock carrying cost. As usually, this cost is caused by the holding of the goods by the company before they can be sold. The deterioration, but specially the handling due to the fragility of the product, represents an important part of the value.

$$Cst_j = i \cdot UP_j \cdot t_j \cdot \left( \frac{\left\lceil \frac{D}{A_j} \right\rceil \cdot A_j}{2} \right) \quad (5)$$

$t_j$  is the time between two consecutive transports in days, referred to transport  $j$ .

- A final cost, called “cost of excess”, imposed to surpass the constraints for the supply in a specific transport. This cost will be defined as the double of the above internal and external costs. The “abuse” of a single transport will be penalized, as reality shows that the resources are limited to a nominal capacity  $L_j$ .

$$Cexc_j = \max \left\{ 0, (ci_j + ce_j) \cdot \left( \left\lceil \frac{D}{A_j} \right\rceil \cdot A_j - L_j \right) \right\} \quad (6)$$

#### 4.2. Comparison of costs for each coalition

Once the cost has been computed for each single transport with equations (1) to (6), the cost for all the feasible subcoalitions must be computed (Fudenberg and Levine, 2006). For instance, the cost of coalition composed by railway and air transports is computed to reach the minimum cost. The value is obtained solving a linear program based on the following pattern.

In order to oblige the participation of all the means included in a coalition, we use a factor called as the strategic minimum value of the transport. This factor, which we fix in two containers of bottles, is used to determine a minimum of goods quantity in case of cooperation where a certain transport is considered. Basically, in this way the most expensive transports will have a lower weight in case of cooperation with them. Without this factor, the model does not assign participation to the most expensive transports.  $SV_j$  is the strategic minimum value to use for, at least, a minimum number of bottles for a transport  $j$  to be considered in a coalition of means of transport.

$$[MIN]C_{tot} = \left\lceil \frac{D}{A_j} \right\rceil \cdot A_j \cdot \left[ \sum_{j=1}^4 (ci_j + ce_j) \cdot x_j \cdot (1 + z_j) \right] + \left\lceil \frac{D_j}{A_j} \right\rceil \cdot A_j \cdot \left[ \sum_{j=1}^4 \left( \frac{1}{30} + \frac{t}{2} \right) \cdot x_j \cdot i \cdot UP_j + x_j \cdot p_j \cdot UP_j \right] \quad (7)$$

s.t..

$$x_j \geq SV_j \quad j = 1, \dots, 4 \quad (8)$$

$$x_j \leq L_j + z_j \cdot M \quad j = 1, \dots, 4 \quad (9)$$

$$\sum_{j=1}^4 x_j = D \quad (10)$$

$$x_j \geq 0 \quad j = 1, \dots, 4 \quad (11)$$

$$z_j \in [0, 1] \quad j = 1, \dots, 4 \quad (12)$$

The cost function to be minimized is presented in (7). Constraint (8) establishes the accomplishment of the minimum strategic value for each transport  $j$ . Constraint (9) penalizes, as it was presented at the end of Section 4.1, the use of a singular mean of transport. Constraint (10) shows that the addition of all the transported amounts must be equal to the demand. Expressions (11) and (12) are for the variable domain.

Table 3 shows, for instance, the value of the costs due to the different causes and for the different means of transport for the coalition of the four transports. The first column includes the number of units to be moved by the corresponding transport considering a demand of nearly 230,876 bottles. The other columns are for cost of excess, internal and external costs and transport cost in the above part of the table and the scrap and the stock carrying costs and final the total cost  $Ctot_j$ .

j	$x_j$	Cexc <sub>j</sub>	Cint <sub>j</sub> +Cext <sub>j</sub>	Ctr <sub>j</sub>
1	12,846.00	0.00	11,975.51	210.67
2	110,098.87	0.00	4,987.84	7,222.49
3	64,731.05	0.00	5,887.34	4,246.36
4	43,200.00	0.00	1,191.44	7,084.80

j	$x_j$	Cscrap <sub>j</sub>	Cst <sub>j</sub>	Ctot <sub>j</sub>
1	12,846.00	379.21	1,128.61	13,694.01
2	110,098.87	1,625.06	3,482.31	17,317.69
3	64,731.05	477.72	910.06	11,521.47
4	43,200.00	1,062.72	341,58.86	43,497.82

Table 3. Results of the model for the coalition of the 4 means of transport with a demand of 230,876 units.

In this case, the most important part of bottles are transported by railway (110,099 approximately), it is followed by the 64,731 moved by road, 43,200 bottles moved by sea and the rest are sent by plane. These values are repeated in the upper and lower tables.

- There is no cost of excess for any mean of transport.
- The direct cost has a great influence on the ranking of internal plus external costs, as the transport by plane (11,975.51) is twice at least the costs in the other transports (5,887.34; 4,987.84 and 1,191.44).
- Traffic costs are leaded by the train (7,222.49), but the ship is not far away (7,084.80) as this later is the slowest transport.
- The scrap costs follow the same pattern as the traffic costs: the highest quantity is for the train (1,625.06), followed by the ship (1,062.72), the truck and the plane.
- The stock carrying cost is more important for the ship transport (34,158.86), because of the days of the trip. The rest of costs are at least 10 times lower (for example, 3,482.31 for the railway transport).

Finally, an important part of the total cost, approximately the half, is due to the sea transport (43,497.82); the other three means of transport has similar values, headed by the railway with a cost of 17,317.69; plane follows it with 13,694.01 and truck is the last with a cost of 11,521.47. Therefore, as the total cost of transport is 86,031 and the total demand is 230,876, the unitary cost is 0.3726 € per bottle.

Once all the costs for any initially possible coalition have been found, the saving will be computed with:

$$v(S) = \sum_{j \in S} c(j) - c(S) \quad \text{for any } S \subseteq N \quad (13)$$

The coalition with the highest saving will be finally taken.

When the minimum cost is found for the coalition including all the means of transport these would be the percentages to transport, but thanks to the theory of games we can go further.

The value of Shapley (14) takes into account the vector of marginal contributions for each transport and any of the coalitions in which it can be included (Shapley, 1953). I.e., it shows the cost importance of a transport to be included in a coalition.

$$\phi_j(v) = \sum_{S \subseteq N/\{j\}} \frac{|S|!(n-|S|-1)!}{n!} [v(S \cup \{j\}) - v(S)] \quad (14)$$

For economic purposes, this value can be very useful as the weight in the coalition is proportional to the strategic importance. In other words, the most important transport agent can be cared, although the cost were slightly higher than the optimum, maintaining enough guaranties for the distribution of the product.

Therefore, when the cost has been computed for any possible coalition, a cheaper cost than the finally reached can be found to transport the goods, but the savings will be lower. So, one can assure a set of minimum values for the transports in such a way that in case of incidences and the best transport agents cannot be used, there is information to know which is the cost to use a new logistic strategy. And even more important, the agent can be used as it will have been used for a long time at a reduced level without a particular need.

## 5. The problem under the game theory

The selection of the means of transport in order to minimize the total cost of transport is not very frequent in literature. The decision of the assignment of proportions to the different alternatives can be obviously intuitive. We had no notice of a similar point of view to our objectives. For tactical decisions, we could take advantage from methods for the operations management, and study the case as the apportionment problem, for example. But we think the information necessary for strategic decisions would not be complete.

In these last years, literature on supply chain management has been focused on strategic decisions. Muller et al (2003) summarized three criteria used in literature for the supply chain management: supply chain processes to fulfill customer requirements; focus of the supply chain on the management of flow and transformation of goods, the flow of information and that of funds; and supply chain processes as company spanning. This work can be classified in the first group.

Research using real cases has been done to demonstrate how strategic decisions can lead to reduce costs in supply chains with the use of quantitative models (Chivaka, 2005). Most of the quantitative model-driven research conducted in supply chain management has been developed under simulation models, and basically the discrete-event simulation. On the other hand, Thun (2005) shows the applicability of cooperative game theory as a methodology for analyzing supply chains. According to him and Cachon and Netessine (2004), cooperative game theory has great potential in supply chain management applications since rationality may lead to success in strategic decisions.

The problem of costs in the international transport of wines is formally defined as follows:

(a) A set of available means of transport in the market,  $\mathbf{G}=\{1,\dots,m\}$ , controlled by the vendor (the British company). The goods are the number of bottles exported from Spain to Great Britain.

(b) A set of users or offers of the service, who will be known as players and noted by  $\mathbf{N}=\{1,\dots,n\}$ . In our case,  $n=4$ , being 1 for air transport; 2 for railway transport; 3 for road transport and 4 for sea transport.

(c) The service offered by each one of the players  $i \in \mathbf{N}$ , noted by  $OP_i$ . It is the capacity, in bottles, for each mean of transport in a period. Beyond this limit the service will be outsourced and the cost will vary.

(d) The functions of costs  $f_j, j \in \{1, \dots, m\}$ , correspond to each one of the offered services. Each function  $f_j$  assigns a cost for a each number of units  $f_j: \mathbf{N} \rightarrow \mathfrak{R}; x \rightarrow f_j(x)$ .

Two additional hypotheses on the data are:

- Each cost function is supposed to be positive,  $f_j(x) \geq 0, \forall x \in \mathbf{N}$ , as it is referred to the prices for the services.
- The cost of zero service for a transport  $j$  can be positive, i.e.  $f_j(0) \geq 0$ . This situation has sense if it is supposed that the transport imposes the use of all the services for the set  $\mathbf{G}$ , independently of the customer demand.

The above information leads to define an offer/demand cooperative problem:  $\Omega=(\mathbf{N},\mathbf{G},\mathbf{OP},f)$ .

where  $\mathbf{N}=\{1,\dots,n\}$  is the set of players,  $\mathbf{G}=\{1,\dots,m\}$  is the set of transports or services,  $\mathbf{OP}=(OP_1,\dots,OP_n)$  is the vector of offer profiles and  $\{f_j(x)\}$  with  $j=1,\dots,n$  is the set of cost functions for each one of the transports.

This means that given the  $n$  players, the  $m$  services or transports and the offer profiles, the offer matrix  $n*m, \mathbf{O}$ , is built. It has the number of units of each good offered per player. Formally,  $\mathbf{O}=(o_{ij})$ , with  $i=1,\dots,n, j=1,\dots,m$ , where  $o_{ij}$  expresses the number of services  $j$  included in the offer profile of player  $i$ .

Alternatively, we consider if it is necessary the offer matrix instead of the profile vector. In this case, the notation of the cooperative problem will be  $\Omega=(\mathbf{N},\mathbf{G},\mathbf{O},f)$ .

## 6. Simulation and results

### 6.1. Economic base of the study

Considering the sales of Spanish wine in Great Britain, the percentage of the denominations of origin Rioja and Ribera del Duero respect to the total Spanish wine and the market shares of the company in Great Britain, the expected sales would be 1.087.000 bottles per year. Nevertheless, if the company promotes the sales of its own label, the sales could tend to increase. It is supposed that a 75% of the Spanish wine sold by the company can be

with the while label. The rest of sales (25%) would correspond to an expert consumer who is looking for a concrete label of Spanish wine.

The white label of Spain has very short sales compared with other wine producers, as France and Italy. Due to this fact and trying to fill this gap in the market, the company can establish different objectives to reach similar sales for the Spanish white label compared with the rest of traditional wine countries. Table 4 shows the demand according to the percentage of covered market gap.

The model was performed in Microsoft Excel with the macros generation with Visual Basic and Solver.

% covered market gap	total demand (bottles per year)	monthly demand (bottles/month)
100	16,664,130	1,388,677
80	13,739,158	1,144,929
60	10,814,185	901,182
40	7,889,213	657,434
30	6,426,726	535,560
20	4,964,240	413,686
10	3,501,754	291,812
5	2,770,511	230,876

Table 2. Different scenarios according to the covered market gap of Spanish wine in Great Britain.

### 6.2. Long-distance transport

In this part of the study, it is carried out an analysis on how the long-distance transport can be split into the considered means of transport. As the company does not know exactly which market gap can be achieved, the equilibrium for cooperative games with different demands, or scenarios, has been computed. The results will reflect the selection of transports according to an increasing demand.

For each possible coalition, the minimum cost is computed with the model of linear programming described in Section 4, starting from the single-component coalitions and finishing with the one composed with all the means of transport. Table 5 shows the values obtained with the hypothesis to fill the 5% of the market gap (230,876 bottles per month).

For a demand of the 5% market gap, the minimum cost corresponds to 35,000 €/month using only the railway (C2). Nevertheless, the option of railway plus road (C2,3) with 37,961 €/month is not far away and the company can study the option of use a second transport to improve the supply reliability.

Coalitions	Cost (€/month)
C1	246,445
C2	35,000
C3	41,682
C4	232,653
C1,2	47,255
C1,3	54,258
C1,4	238,589
C2,3	37,961
C2,4	71,997
C3,4	77,495
C1,2,3	49,033
C1,2,4	84,253
C2,3,4	73,776
C1,3,4	90,071
C1,2,3,4	86,031

Table 5. Cost of transport, in €/month, for the different coalitions of means (covered a 5% of the market gap).

Using (13), Table 6 reflects the maximum savings comparing any subcoalition with the included coalitions, in the hypothesis to fill the 5% of the market gap.

Coalitions	Savings (€/month)
S1,2	234,190
S1,3	233,869
S1,4	240,509
S2,3	38,721
S2,4	195,656
S3,4	196,840
S1,2,3	274,094
S1,2,4	429,845
S2,3,4	235,559
S1,3,4	424,027
S1,2,3,4	469,749

Table 6. Savings obtained from the transport costs for the different coalitions (covered a 5% of the market gap).

If the company wants to evaluate coalitions through the savings obtained with the addition of new means of transport, the highest result corresponds to the coalition with the four ways of transport (S1,2,3,4) with 469,749 €/month.

Table 7 includes the optimal values for the possible coalitions with the four transports considered, respect to the costs and to the savings.

%market gap	Ctot*	Coalition Ctot*	S*	Coalition S*
5	35,000	C2	469,749	C1,2,3,4
20	62,954	C2	883,429	C1,2,3,4
40	99,396	C2	1,448,277	C1,2,3,4
80	184,253	C2,3	2,849,663	C1,2,3,4
100	230,669	C2,3	3,634,404	C1,2,3,4

Table 7. Optimal values of cost and savings for several percentages of the market gap.

The exclusive use of railway leads to the minimum cost with a demand lower than 40%, while the road transport is added for a higher demand. The maximum savings are reached with the coalition of the four transports, what gives idea of the cost magnitude of the other two transports.

The model always determines that air and sea transports reach at least the strategic minimum value in case of cooperation with railway or road transports. Analyzing the data, one can see that their cost is much higher than the rest and it is cheaper to outsource trucks or trains at double price as usual than contract the other means of transport. The Figure 1 shows the potential saving of a transport to be included in a coalition from a covered market gap of 5% up to a 100%.

If someone wants to design a system of distribution for merchandises, he can know the mean cost of including a mean of transport thanks to the study; these are the Shapley's values for each mean of transport.

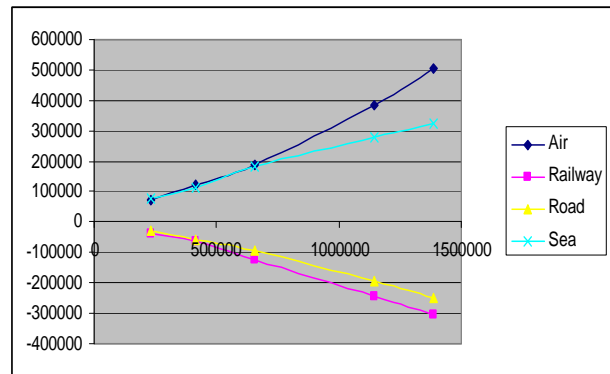


Figure 1. Shapley's values for each transport and different demands, according to the covered market gap.

The model in Section 4 can be applied to different scenarios, related to an increasing demand. We observe the results of the simulation in Figure 1. The abscise axis corresponds to the values of demand, while the ordinate axis is for the cost contribution of each transport, based on the Shapley's values. The air and sea transports contribute with a very high cost in any possible cooperation. If the objective is limited to transport the goods at the minimum cost, the supply network will only include the railway and the road transports.

However, strategically, the use of only two means of transport can be dangerous as the reaction power in case of any problem is importantly reduced. The cost of including a new mean of transport to avoid a break in the distribution can be quantified with this study. If the company knows how much a break costs in service days, the company can determine the convenience of paying a new way of distribution.

If these factors are taken into account, the global cost to transport the goods with the four ways of distribution can be determined. If the four terms (the four Shapley's

values) are added, two terms will be negative, as they contribute with savings, and two will be positive, as they contribute with costs. The addition of the four terms determines the cost of the coalition with four agents.

Figure 2 shows the unitary cost of transport for a bottle depending on the demand, i.e. the covered gap market. We observe that only for the sea transport the cost is constant independently from the demand. The capacity of this mean of transport is so high that the requirements of the problem do not affect at all. For the rest of means of transport the cost remains constant when the demand is low, but when the demand increases the costs become higher. On the one hand, the cost is heavily increased when demand is increased for the air transport. And on the other hand, the cost increases lightly for the other two transports.

An additional comment on the evolution of the unitary cost can be added if the four means of transport are simultaneously taken. If the monthly demand is low, the transport cost of a bottle is substantially higher respect to only considering the railway and road transport.

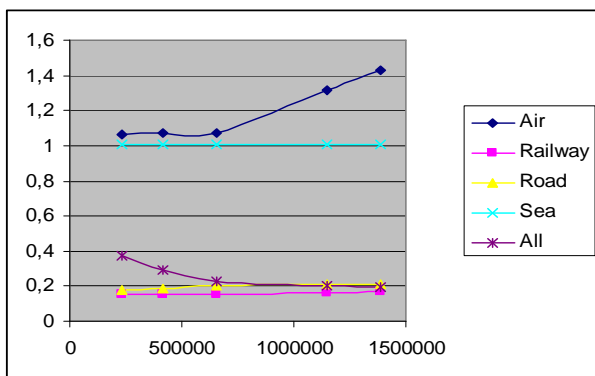


Figure 2. Transport unitary cost per bottle according to different demands, i.e. the covered market gap.

The greater the demand reaches, the closer to the minimum value the unitary cost tends. If the four transports are taken, the sea and air transports will be moved to the strategic minimum. Moreover, if the demand of bottles continues increasing, this cost will be hold and become less and less significant. Therefore, for a high demand, all the means of transport can be used, some of which in his minimum strategic coefficient, as the unitary costs of transport will be not much significant and the objective of a defined service level can be accomplished.

If we take into account the figures 1 and 2, the company can decide with a solid base which means of transport move its goods. Depend on the selected criterion, different strategies can be applied. If the criterion is the minimum cost without worrying about service problems, the selected coalition will include the railway and the road transports. If the demand can be very random and the breaks in the service can be important with a worth emphasizing level of loses, all the ways of transport will be taken. If the tendency of demand cannot be easily pre-

dictable, the company has elements to weight if the use of a particular transport is profitable. The results obtained through the game theory can be the core of a decision support system.

## 7. Conclusions

This work has demonstrated the usefulness of game theory, specially the cooperative games, as a tool to improve the efficiency of the supply chain. Given a set values taken from a real case, it leads to determine the best solutions, with minimum cost, for the supply logistics in a company. Not only this, but it also helps to quantify the strategy cost of including a transport which *a priori* would make more expensive the global system.

The cost function includes a set of different concepts (scrap, traffic,...) which lead to consider the sources of cost. Nowadays, the service levels are essential to assure a constant increase of sales; the often breaks in the service can suppose at medium term a high cost for the company. To reach a robust supply chain not affected by variations in the market transport and use quantitative information it supposes a great advantage to improve logistics efficiency. The results show different strategies depending on the selected criterion. If the cost has to be minimized, the coalition will include the railway and maybe also the road transport. If the demand can be very random and the service cannot be easily guaranteed, all the ways of transport will be taken considering the savings. The results of the different scenarios can be the core of a decision support system.

Finally, the transport of the future for this and similar supply chains seems to be the railway, as the study of costs shows this fact; the results give a quantitative worth, as it is clean, fast and has enough capacity.

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