VOL.I N.o3 DECEMBER 2004

JMR
JOURNAL OF MARITIME RESEARCH

Spanish Society of Maritime Research

JMR JOURNAL OF MARITIME RESEARCH

VOL.I N.o3
DECEMBER 2004

CONTENTS

Articles

Journal of Maritime Research, Vol. I. No. 3, pp. 5-22, 2004

ISSN: 1697-4840

PRODUCTION OF ENVIRONMENTALLY INNOCUOUS COATINGS

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ABSTRACT

It is known the biofouling phenomenon, as well as the negative consequences that it means for the artificial structures in contact with seawater in form of structural defects and of additional expenses for the companies which develop their work in the marine scope due to the processes of cleaning and prevention, the evolution in the world of the technology of antifouling paintings, once we analysed the serious environmental problems caused by an indiscriminate use of byocides of high toxicity in its composition as they are the organic derivatives of tin compounds made up and of the uncontrolled emission of volatile organic compounds (VOC) to the atmosphere, according to the present environmental norm, has as only aim to develop environmentally innocuous coverings based on water in which extracts of the very same marine world are used as byocides compounds.

Key words: Biofouling, antifouling coatings, organic by-products of tin compounds, volatile organic compounds (VOC), environmental norm

1. INTRODUCTION

Any artificial structure in contact with seawater is rapidly coated by a microbiological biofilm, which serves as a base for macro-organisms to grow on. This phenomenon, known as biofouling, causes structural problems and its mitigation involves a severe economic outlay for the industries, which operate in the marine environment.

Biofouling can be defined as *«the undesirable phenomenon of adherence and accumulation of biotic deposits on a submerged artificial surface or in contact with seawater»*. This accumulation or incrustation consists of a film composed by microorganisms affixed to a polymeric matrix created by themselves (biofilm), where inorganic particles (salts and/or corrosion products) may arrive and be retained, as a consequence or other types of fouling developed in the course of the process. This biofilm composed of microorganisms (microbial biofouling or *microfouling*) can originate the accumulation of macro-organisms (macrobial biofouling or *macrofouling*) (Eguía, 1996).

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Biofouling is made up of hundred of species such as tubícolas bacteria, protozoas, seaweed, molluscs, briozoas, cirripeds, polychaetes, ascidias, hidrozoas, etc. These organisms adhere themselves to the substrate developing a fast growth and great reproductive potential, being demonstrated the strategy of the different families in order to obtain the resources that the ecosystem offers, avoiding the competition among them by means of the differentiation of the periods of colonisation, in such a way, that the incrustation begins with the settling of the fitobentónicos organisms during the springtime, to continue with the adhesion of the zoobentónicos organisms next (García P, 1996).

Therefore, biofouling accelerates the processes of corrosion of the materials and causes losses in the operative effectiveness of the structures. These damages take place on movable and stationary structures affecting boats, petroliferous or gas platforms, oceanographic investigation implements, thermal energy conversion plants and subaqueous sounding equipment. It also damages maritime cultivation facilities (aquariums, cages, conduits, and pumps) as well as the same cultivated organisms.

In ships the friction between the hull and the water increase, which means an increase in fuel consumption (up to a 40-50% with little dense biofouling) and there is a decrease in speed and manoeuvrability. The hull of a ship unprotected by antifoulings systems, can accumulate up to 150 kg of biological incrustation by square meter during six months in the sea, which in a long tanker with 40,000 m^2 of underwater hull supposes an increase in weight of 6.000 metric tons of biological incrustations (OMI, 1999), which means enormous economic losses.

In order to avoid economic losses, as well as an accelerated deterioration of the artificial structures in contact with seawater, different types of protections have been used for long. Among them we must point out the copper coatings that began to be used by the Phoenicians and which continued being successfully used on wood ships until the 18th century. When iron ships were first built, paintings widely known as “patents” in which the copper sulphate acted as byocide principle began to be manufactured. From 1960 the use of paintings in whose composition we could find copper, mercury, arsenic, organic derivatives of tin (organic compounds of tin like tributyltin (TBT) and the trifeniltina (TPT)) spread widely, eventually, it has been proven that they were a real risk for the marine ecosystem.

In the seventies the use of antifoulings paints based on the byocide performance of the organic derivatives of tin extended, specially tributyltin (TBT), that is why most of the navigation ships covered their hulls with this type of paintings, which turned out to be effective and economic.

During the eighties we became aware of the consequences that the use of the TBT in antifoulings paintings was having on the marine ecosystems, specially in areas of low water interchange by tidal influence, such as bays or estuaries, where it is specially detrimental on the populations of some invertebrates, molluscs, crustaceans and fish, where very important malformations in some species were detected. As a result of the worries these facts arose, several countries introduced controls to limit the use of TBT in antifoulings paints in small ships. Thus, in 1982, France prohibited the use of TBT in ships with an inferior length to 25 m, Japan, United Kingdom, the United States, Norway, Australia, New Zealand and other countries followed.

At the beginning of the nineties, an OMI resolution recommended governments to ban the use of tributyltin in ships within inferior length to 25 m and restrictions in the leaching process prevail of tributyltin are imposed, having to be inferior to 4 micrograms/ cm^2 /day. In countries such as Japan, New Zealand and Australia the use of antifoulings that contain TBT (OMI, 1999) is forbidden.

Since 1997, Japan forbade to manufacture antifoulings paints that contain TBT, being January 1, 2003 the propose date for the prohibition of the organic derivatives of tin compound use like byocides in the antifoulings systems, being left for the year 2008 its total prohibition.

2. TECHNOLOGY OF ANTIFOULING PAINTS

The antifoulings paints are specially formulated to be applied on structures in contact with seawater in order to prevent the settlement of the marine organisms that compose biofouling (Arias, 1994).

They are widely known by the name of "patents" and as all the other paints come from a fixed vehicle, a volatile vehicle, pigments and additives. Once applied they make a film dry, uniform and well adhered to the substratum in order to protect it and when in contact with the seawater, they begin to release biologically active products that surround the surface treated within byocide dock that prevents the settlement of the organisms. The capacity of control of the level of liberation of the byocides substances will allow us to differentiate several types of antifouling paints, being the toxin concentration in the laminate waterproof cloak (painting surface in contact with the seawater) the one which determines the antifouling power of the painting. Factors like the speed of the ship, the temperature, salinity and pH of the seawater, light, levels of pollution, etc., are going to remarkably influence on whether the above toxin concentration is higher or lower.

We can classify the antifouling paints as *"no-smoothing "* of soluble or insoluble matrix and *"self-smoothing"*.

2.1. No-smoothing antifouling paints with a soluble matrix

The toxin used is cupreous oxide and is dispersed in a water soluble vehicle, normally *colophony*. The colophony, being a smooth acid, will dissolve slowly when reacting with the seawater, which is a little alkaline. The dissolution of the vehicle will, as a consequence bring about, the dissolution of cupreous oxide, giving rise to the layer of *"laminate impact"*, the toxins becoming on micro-organisms contact. The reactions will, as a consequence bring about, the cupreous carbonate formation, which has the necessary toxic properties. In addition to the cupreous oxide, it is also necessary to use organic derivatives of tin compounds, at present no longer used on accost of their negative effects on the environment. These antifouling systems last between 9 and 12 months.

From a practical point of view, the advantages and limitations of this paints can be summarised as follows: (Guijarrubia, 1989)

· They can be applied on "soft" primers, on wooden or steel hulls
· They cannot be exposed to atmospheric oxygen for long periods of time, which is why the treated surface must be submerged only a few hours after the paint being applied
· The dissolution of the fixed vehicle progresses in an uncontrolled manner, which limits the predictability of the useful life of the film as an antifouling agent, depending on such factors as the speed of the ship, salinity, pH or on the action of bacteria on the vehicle
· The mechanical properties of the dry film and especially of the set of layers formed on the surface after successive paint applications can increase the average roughness of the hull in the case of a ship, when chipping and flaking, etc, occur. This makes it necessary to take off the old layer before applying the new one, with two new coats of paint being applied at a 48 hours interval, to a thickness of 40 microns of dry film per coat layer.

In figure I the state of the recently applied dry film is contrasted with the film after a period of time has passed, in which the fixed vehicle has been diluted and therefore part of bioactive compounds present in the film have been freed.

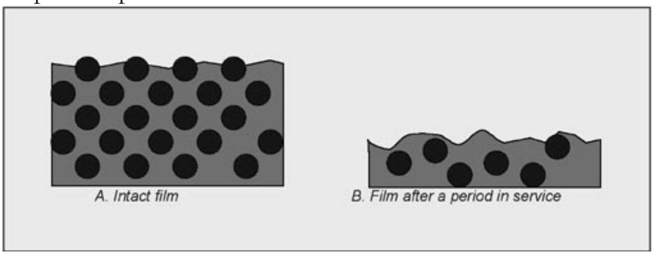

Figure 1. Mechanism of operation (soluble matrix)

2.2. No-smoothing antifouling paints with an insoluble matrix

They are constituted mainly by insoluble water resins, which dry physically (chlorinated rubber, acrylics, vinyls, etc.) mixed with small amounts of soluble resins (colophony and by-products) which, like the byocide compounds, are dispersed in the insoluble matrix. These paints absorb water and the soluble part of the resin gradually disintegrates, leaving a insoluble structure similar to a rigid sponge, full of water, through which the byocide products are dissolved, by diffusion (Arias, 1994).

The antifouling function is obtained by means of the diffusion of byocide compounds towards the external surface of the film in a process known as leaching. Figure II shows the evolution of the speed of leaching during the time the paint is in service: (Quirós, 1995)

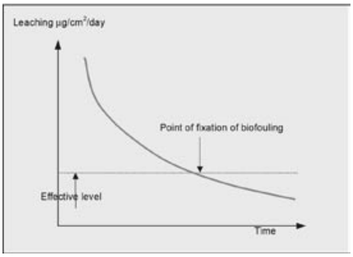

Figure 2. Typical leaching curve (insoluble matrix)

The advantages and limitations of this type of paints can be summarised in the following way:

· The leaching process is controlled.
· Due to their hard resin content, they can remain outdoors for up to two months without loss of their properties. They must be applied in two layers, to a thickness of 80 microns of dry film per layer and it will last from 12 to 24 months depending on the type of waters
· Once the paint has worn away, there is remains an insoluble resin porous structure that should be sealed with a suitable sealing paint before applying the new antifouling layers, since otherwise they would partially absorbed by the old paint.
· The content of byocide elements in the dry film is higher than in the case of those with a soluble matrix
· Their mechanical properties are high quality fixed vehicles bindings are used
· They cannot be applied on "soft" primers, since they contain strong dissolvents.

In figure III the state of the recently applied dry film applied is contrasted with the film after a period of time has passed, in which we can observe the effect of the leaching process of the paint.

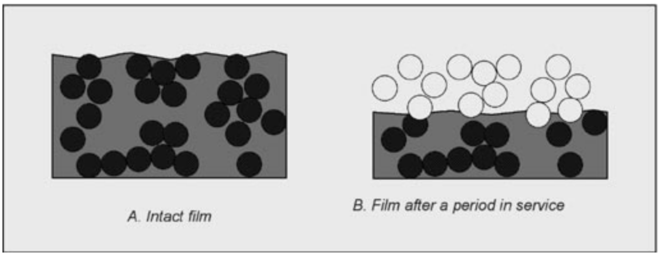

Figure 3. Mechanism of operation (insoluble matrix)

2.3. Self-smoothing antifouling paints

These are products based on byocide polymers whose speed of dissolution can be controlled by affecting the physical-chemical process regulating. In this type of paint the toxic substance incorporated in the resin dissolves gradually, in a self-programmed way, by means of a hydrolysis reaction of the polymer when it comes into contact with seawater.

In addition to this, the byocide pigments that contained there also dissolve in a controlled fashion.

Figure IV shows the rate of toxic liberation during the time is in service the paint. (Quirós, 1995)

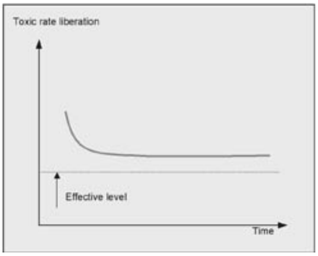

Figure IV. Typical leaching curve (self-smoothing)

The following characteristics of these paints should be emphasized:
· Although not a hard product, it permanently retains a certain plasticity that is accentuated when submerged it in water, and can remain outdoors for up to 3 months without losing any of its properties
· They are applied in several layers to a thickness of a 100-150 microns per layer. It has durability directly proportional to its thickness: 100 microns/year (maximum of 5 years). Its surface once submerged and in good condition, is extraordinarily smooth, with excellent hydrodynamics properties, which helps towards the attainment of high speeds
· The average speed of byocide element liberation remains constant over time, which makes its antifouling function highly reliable
· In the case of a ship, layers through successive entrances to dock are not accumulated, which eliminates that factor of increasing roughness average of the hull
· When one layer of paint is put on top of another, all that is required is a pressure jet water wash down, without an intermediate sealing coat being necessary
· Self-smoothing antifouling paints, besides providing the hull with antifouling protection, offer the added benefit smoothing of their own external surface.

In figure V the state of recently applied the dry film is compared against the film after a period of time has passed, in which we can observe the effect of the leaching process of the paint.

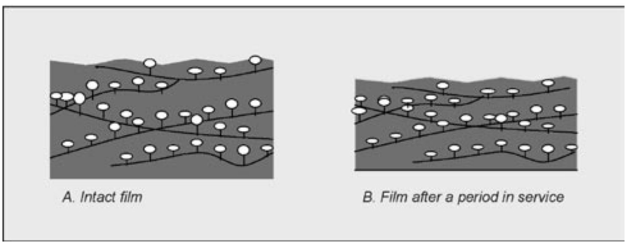

Figure V. Mechanism of operation (Self-smoothing)

3. CONSEQUENCES OF THE USE OF ORGANIC DERIVATIVES OF TIN COMPOUNDS SUCH AS BYOCIDES IN ANTIFOULING PAINTS

Generally speaking, all the organic compounds of tin, and especially tributyltin (TBT), are extremely toxic compounds, even at concentrations of only a few nanograms per litre. The organisms of the marine environment (from bacteria to fish) are affected by a wide range of harmful effects from sub-lethal to lethal. Their presence can be seen in alterations in growth, production of anatomical and reproductive anomalies, changes in behaviour patterns, etc. The macroinvertebrates that are the most affected are the molluscs due to their high rate of bioaccumulation and to their low rate of purification. Within these, the most sensitive groups are the gastropods and the bivalves. In other taxonomic categories they follow to them in sensitivity, crustaceans, algae and fish. Nevertheless, no organism has so far shown the sensitivity that characterises neogastropods.

The magnitude of the effects of TBT and the repercussion of the legislation of their use were particularly remarkable in oysters and neogastropods. Specifically, the most devastating effects of TBT in the marine environment were observed on the curly or Japanese oyster, *Crassostrea gigas* and the coastal gastropod *Nucella lapillus* (snail multicoloured). The harmful effects of TBT on *Crassostrea gigas* were what set in motion the beginning of the legislation to control the use of this compound in the formulation of antifouling paints, a fact that is now a milestone in the recent history of environmental protection (Quintela, 2002).

The Bay of Arcachon (Atlantic coast of France) is one of the most important areas for the oyster breeding in the world and its economy depends on the sale both of oyster seeds and of the adults themselves. It produces from 10,000 to 15,000 metric tonnes of Japanese oyster, 10% of the French total production. During the summer season there is a great deal of maritime movement a dense marine occupation, with the number of pleasure ships sometimes reaching 15,000. At the end of the Sixties there began to be observed, occasionally, a thickening of the oyster shells and from 1974 on this was to be seen in all the oyster beds of the bay, affecting between 80 to 100% of the oysters. Between 1971-1986 a series of phenomena took place that severely damaged the oyster breeding in the area, such the appearance of physical anomalies (malformations in the shell characterised by the thickening of valves), reduction in individual oyster growth and drastic fall of the putting. Different studies consistently related these anomalies to contamination by TBT coming from antifouling paints.

The anomalies registered affected the calcification process and comprised the thickening of the shell because of the formation of chambers that contained gelatinous proteins in their interior so that the shell acquired a spherical and unpleasant aspect. The space destined for the body was reduced, which led to the oysters having less flesh on them. Both factors prevented the commercialisation of these bivalves, causing the collapse of oyster breeding from 1977 to 1981. In these circumstances, with a concentration of

TBT in water superior to 100 ng/l, the number of oyster breeders was reduced to half and the economic losses ascended to about 150 million dollars. The resulting profound socio-economic crisis caused French authorities to regulate the use of paints with a TBT base in January of 1982, which made is possible to gather a satisfactory number of oysters in summer, after five years of total loss of life of larvae.

The second paradigmatic case of the negative effects of TBT on organisms that, at the outset, were not the object of their action, is that of marine gastropods, and specifically the neogastropods. What has occurred here is the superimposition of masculine sexual characters on the females and which has received the name of *imposex*. In some species, this phenomenon negatively affects the reproductive ability so that, under certain conditions of contamination, the populations of the most sensitive species are doomed to disappearance.

One of the first impacts of exposure to TBT that was described was the masculinization of the females of neogastropods. This phenomenon was detected almost simultaneously in *Nucella lapillus* around 1970 in Plymouth Sound (England), *Nassarius obsoletus* in Long Island (the United States) and in Erinacea Ocenebra in Arcachon (France).

The term *imposex* was coined to denote that superimposition of masculine sexual characters on females. The first evidence of the bond between this phenomenon and the contamination by TBT did not appear until some ten years later. And it was not until the methods of analysis of organic derivatives of tin compounds were perfected that the sensitivity of TBT response became obvious. Multiple later studies have demonstrated that it is a widely extended event and at the present time it has been stated that some 150 species pertaining to approximately 78 geniuses, including the mesogastropods, show imposex.

When the females of *N. Lapillus* are exposed to TBT, their takes place a masculinization proportional to the dose of polluting agent. A penis and a vas deferens begin to form. The vas deferens extends towards the oviduct and can even actually block it, making it impossible for the egg capsules to come out so that the females functionally become sterile. In extreme cases the bursa copulatrix can even be substituted by a prostate. Finally, the accumulation of the aborted egg capsules causes a trauma that leads to the death of the animal, which is why in highly affected populations there is a low proportion of females.

Both this lessening of the number of females in the populations and, mainly, the sterility of the females affected by advanced stages of imposex entail a decline in the populations of this gastropod. As it is a species of direct development, the lack of a planktonic phase negatively conditions the recovery of the populations, leading them to extinction in some cases.

Minimum amounts of TBT have been found in whales, dolphins and members of the seal family in the United States, Southeast Asia, the Adriatic Sea and the Black Sea, absorbed through the nutritional chain. In addition, tributyltin reduces the resistance to infections in fish like plaice and other flat fish that live at the bottom of the sea and which are exposed to relatively high levels of TBT, especially in those areas with muddy sediments as is the case of ports and estuaries.

4. CONSEQUENCES OF VOLATILE ORGANIC COMPOUND (VOC) USE IN ANTIFOULING COATINGS

The only required function of the constituent volatile vehicle of a liquid paint is to allow it to be elaborated and applied. Both the resins or oils, and the solvent free products, form in general solid or semisolid materials that could not be applied by any of the procedures normally used, such as brushes, rollers or pistol.

Generally, the composition of the volatile vehicle in paints responds to a mixture or combination of different solvents. Real resin or fixed vehicles solvents do exist, as do other organic products which, although not fixed vehicle solvent, are used together with the former as paint extenders. The purpose of including these extenders in the formulation of paints, is to improve the application properties and to be able to properly control the evaporation rate of the volatile vehicle during the drying. Their being volatile, the action of solvents is based on their power to dissolve non-volatile organic substances, without either of them experiencing any chemical modification, with the latter being extended in film form after the evaporation has taken place (González, 1994).

The organic chemical agents normally used, like solvents or extenders, belong fundamentally to one of the following types: (Velo, 1996)

· *Petroleum by-products:* aliphatic solvents. Benzine and gasoline are of this type, their being characterised by being insoluble in water, liquid, colourless and with a characteristic smell
· *Soft coal-tar by-products:* aromatic solvents. Benzol and solvent gasoline are of this type, their physical appearance being very similar to that of the petroleum by-products. Chemically, benzol is the aromatic hydrocarbon benzene C_6H_6, while solvent gasoline contains xylene and superior benzene homologs
· *Organic compounds*. Within this group, obtained by means of deferential chemical processes such as the fermentation, distillation, presence of catalysts, alkaline means, etc., are the *Alcohols*, the *Esters*, the *Ethers* and the *Ketones*.

The need to watch the concentrations of VOC fundamentally derives from their own toxicity, since the use of solvents gives rise to emissions of organic compounds in to the atmosphere that can be harmful to health and produce important damage to natural resources. Most volatile organic compounds (VOC) are harmful to ozone and some of them are known cancerigenic agents, which is why it is necessary to reduce their emissions in to the atmosphere. Therefore, the paints being a source of VOC because of solvent evaporation, it has become necessary to consider these compounds as polluting elements when it comes to formulating and manufacturing the paints, no matter what kind they are.

5. REGULATIONS ON THE MANUFACTURE AND USE OF ANTIFOULING COATINGS

The problems of pollution caused by the TBT present in antifouling paints was dealt with for the first time in the OMI Committee for the Protection of the Marine Environment (CPMM) in 1988, when the Paris 8 Commission asked the OMI to study the need to elaborate measures within the framework of the pertinent legal instruments in order to limit the use of TBT compounds in the seafaring ships. By then there was unequivocal proof on a world-wide scale that tributyltin and other organic by-products of tin compounds were detrimental for aquatic organisms and several countries had already adopted measures either individually or within the framework of regional agreements in order to try to reduce the detrimental effects of antifouling paints containing tributyltin. However, it was clear that it would be necessary to establish international measures to regulate the use of antifouling paints, and in April of 1990, in the Third international symposium on organic by-products of tin compounds, held in Monaco, it was recognised that the OMI was the appropriate organ to carry out that task.

In 1990, in its 30th Sessions, the CPMM adopted the resolution MEPC.46(30) on *"measures to resist the possible adverse effects of the use of tributyltin compounds in antifouling paints"*. In this resolution governments were recommended to adopt measures to eliminate the use of antifouling paints containing compounds of tributyltin in ships of under 25 m in length and whose hull is not of aluminium, and to eliminate the use of antifouling paints whose average rate of leaching is higher than 4 micrograms of tributyltin per cm^2/day.

In 1990, the CPMM of the OMI received the results of a control study of tributyltin, which confirmed the toxicity of tributyltin compounds in marine organisms. The Committee also received information on other existing antifouling systems, which included data on their effectiveness and the risk that they are for the aquatic environment.

In the 38th session, held in 1996, the CPMM established a work group by correspondence so that it could study the pertinent issues. The main conclusions based up on the observations of the 12 countries and four nongovernmental organisations taking part, were presented to the Committee in its 41st session, held in April of 1998.

In the 42nd session, held in November of 1998, the CPMM approved a draft resolution of the Assembly that includes the year 2008 as a deadline for the total prohibition of compounds of organic tin by-products used as byocide in the antifouling systems for ships.

The draft resolution, elaborated by the Work Group that met during the 42nd session of the CPMM, was presented at the 21st Assembly of the OMI, which was held in November of 1999. In this draft resolution the OMI *"urges the Committee for the Protection of the Marine Environment to adopt whatever measures may be necessary to elaborate as quickly as possible a legally binding world-wide scale instrument with the purpose of solving the question of the detrimental effects of the antifouling systems used on ships"*.

In addition, the OMI *"decided that the instrument of world-wide character that the Committee for the Marine Environment elaborates would have to guarantee, on a world-wide scale, the prohibition of the application on ships of organic by-products of tin compounds used as byocide in the antifouling systems on ships, by January 1st 2003 at the latest, and the complete prohibition of the presence on ships of organic by-products of tin compounds used as byocide in the antifouling systems, by January 1st 2008 at the latest"*.

As regards VOC, we can make reference to the Royal Decree 117/2003, of January 31st, on the limitation of volatile organic compound emissions due to the use of solvents in certain activities.

The use of solvents in certain activities causes emissions of organic compounds to be released into the atmosphere and which can be injurious to health and produce considerable damage to the natural resources. Bearing in mind the above, the Council of Ministers of the European Union approved, on March 11th 1999, the Directive 1999/13/CE, the aim of which is to prevent or to reduce the harmful effects for people and the environment stemming from those activities that use large quantities of organic solvents in their manufacturing processes or work.

This Directive lays down certain specific regulations for those plants wishing to carry out the above activities, and among which there appear: (i) that of not exceeding the different maximum emission raking for volatile aromatic hydrocarbon emission (hydrocarbons that, under normal conditions of pressure, have a boiling point equal or inferior to 250 °C and which at least have an aromatic ring in its devised structural formula), which will be equal or inferior to 0.5 % of the product; (ii) the one to reduce their emissions by other means, such as using products with a low solvent content or solvent-free. Likewise, the maximum volatile organic compound content (VOC) will be equal or lower to 200 g/l minus the water. The unit used for the VOC content is "mass in grams of COV per litre of product (g/l minus the water).

6. FUTURE PROPOSALS

6.1. From solvents to water

Theoretically it is possible to replace all the solvent-based products that are traditionally on the market whit water-based ones.

Solvent-based paints have: (i) high tolerance in their application and drying under adverse conditions, like, for example, low temperature, discharge humidity; (ii) good behaviour on difficult substrates, such as very deteriorated surfaces; (iii) good application properties; (iv) good mechanical or chemical resistance; (v) good aesthetic appearance. Nevertheless, the technology for water-based is constantly improving.

Its also possible to produce solvent-based products with a lower solvent content by using the modern technology for high solid contents that can be used to formulate products that offer many of the properties attributed to the traditional solvent-based products, but which significantly reduce the solvent content. Although they are more expensive and normally they dry more slowly, they can play an important role in the reduction of emissions. The use of VOC in water-based paint is normally vital for the behaviour of the product and this is particularly true of water-based products that have been formulated to replace the solvent-based ones. Given the present low levels of VOC in water-based products, any reduction that might occur would not be significant to the total amount of the reduction of VOC emissions.

Water-based products are being researched and, together with the high solid content products, are replacing the traditional solvent-based products. It is still possible to achieve even greater reductions in VOC emission by reducing the volatile organic compounds in water-based and solvent-based products and by increasing the use of water-based or high solid content paints. Nevertheless, this will take time. The industry will need to reformulate an important and wide part of its existing product range, and this can only be achieved over a period of several years. What is more, a greater reduction will mean greater changes in products, in application techniques and in the characteristics of its uses. The changes will also have economic consequences originating from the increase in R+D costs and raw materials and will require new investment in equipment.

6.2. Alternatives to organic by-products of tin compounds

The antifouling systems that do not contain TBT can be made up of soluble marine water matrices that contain biologically active tin free ingredients. The byocides disperse and remain contained within the matrix, although they are not necessarily bound to it via a chemical link. In the sea-water/paint interface, the byocide leaches at a controlled rate. The matrix dissolves and releases new byocide, which allows a predictable yield to be obtained.

The main options available at the present time are the following ones:

· *Antifouling copper-based paints*. The copper is a thousand times less detrimental than TBT, which is why, even if other options were not considered, the change over to copper-based products would immediately benefit the marine environment. Their drawback is that they are only effective against the marine fauna, it being necessary to fight the growth of algae whit pesticide, which can create new threats to the environment.

· *Tin-free antifouling paints*. They are indicated for those ships that enter dry-dock every three and a half years or more frequently since they tolerate a certain amount of biological incrustations. They give a good result on specialised ships such as tugboats, pilot boats, dinghies and research ships of investigation, if these are used at least 100 days a year and enter dry-dock at least every three years. When their use is not so frequent, there is a greater risk of biological incrustation and the ship would have to enter dry-dock every year.

· *Antiadherent coatings.* They do not contain byocides but their surface is very slippery, which prevents biological incrustations and makes washing them down easy when it has to be done. They are preferably for ships with a minimum speed of 30 knots. Once damaged, the coating is difficult to repair. Small incrustations form, which are easy to clean with compressed air hoses in the annual overhaul in dry-dock.

· *Cleaning.* The periodic cleaning of the hull is a very appropriate solution for those ships that sail both on the sea and in fresh water, and in zones where few organisms adhere to the hull. For the cleaning of the merchant ships there ear divers who use revolving brushes or compressed air hoses.

· *Electricity.* On creating a difference in the electrical charge between the hull and the seawater a chemical process that prevents biological incrustations is activated. This technology has proved itself to be more effective than tin free paint to prevent biological incrustations, but the system is expensive and is easily damaged. It also creates a greater risk of corrosion and requires a greater consumption of energy.

· *Coatings with prongs.* It includes coatings with microscopic prongs. Its effectiveness depends on the length and distribution of the prongs, although it has been demonstrated that these do stop certain crustaceans and algae adhering to the hull without causing any damage at all to the environment. However, the prongs could increase the resistance of the ship to the water. The use of surfaces with prongs on static objects such as on buoys and cooling water inlets could well be a realistic option for the future.

· *Natural resistance, natural byocides.* This is the substance produced by nature and which prevents biological incrustations or makes the incrustation process difficult. It is based on the ability of certain marine organisms, such as corals and sponges, to remain free of incrustations. Research relative to the use of natural compounds is still in an initial phase, although some active metabolites have already been identified and new byocides synthesised. The enzymes can stop bacteria from adhering to the hull (the first stage of incrustation growth), whereas the hydrophilic coatings have been based on the preference shown by biological incrustations for hydrophobic surfaces, such as rocks and the ships.

At the present time, we are testing different natural compounds extracted from the marine environment it self to see how effective they can be as byocides in antifouling paints, in a research project by the Ministry of Science and Technology of Spain through Project REN-0519/TECNO entitled "*Application of marine biotechnology in the production of environmentally innocuous antifouling coatings",* in which the Department of Sciences and Techniques of Navigation and Shipbuilding of the University of Cantabria is taking part, Harbour Authority of Santander, the Cantabrian paint company Ferroluz S.A., the Scottish laboratory Ecosearch (International) Ltd. and the Department of Biological Sciences of the University of Heriot-Watt are also collaborators in the project.

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SISTEMAS ANTIINCRUSTANTES: HACIA LA PRODUCCIÓN DE RECUBRIMIENTOS MEDIOAMBIENTALMENTE INOCUOS

RESUMEN

Conocido el fenómeno del biofouling, así como las negativas consecuencias que supone para las estructuras artificiales en contacto con agua de mar en forma de defectos estructurales y de gastos adicionales para las empresas que desarrollan su labor en el ámbito marítimo debidos a los procesos de limpieza y prevención, la evolución en el mundo de la tecnología de las pinturas antiincrustantes, analizados los problemas medioambientales graves provocados por el uso indiscriminado de biocidas de alta toxicidad en su composición como son los compuestos organoestánnicos y por la emisión incontrolada de compuestos orgánicos volátiles (COVs) a la atmósfera, atendiendo a la normativa medioambiental actual, tiene como única alternativa el desarrollar recubrimientos medioambientalmente inocuos en base agua en los que se utilicen como compuestos biocidas extractos del propio medio marino.

Palabras Clave: Biofouling, pinturas antiincrustantes, compuestos organoestánnicos, compuestos orgánicos volátiles (COVs), normativa medioambiental

INTRODUCCIÓN

Toda estructura artificial en contacto con agua de mar es rápidamente cubierta por una biopelícula microbiológica que sirve como base de asentamiento de macroorganismos. Este fenómeno, conocido como biofouling, causa problemas estructurales graves y su mitigación acarrea un severo gravamen económico para las industrias que operan en el medio marino.

Son cientos las especies que pueden formar parte del biofouling, fijándose al sustrato desarrollando un rápido crecimiento y gran potencial reproductor. Como consecuencia, el biofouling acelera los procesos de corrosión de los materiales y provoca pérdidas en la eficacia operativa de las estructuras en contacto con agua de mar. En las embarcaciones se incrementa la fricción entre el casco y el agua lo que comporta un aumento del consumo de combustible y la pérdida de velocidad y capacidad de maniobra.

Para evitar las pérdidas económicas, así como un deterioro acelerado de las estructuras artificiales en contacto con agua de mar, vienen empleándose distintos tipos de protecciones desde antiguo. Entre ellas destacan los revestimientos de cobre que comenzaron a ser utilizados por los fenicios y que siguieron empleándose con éxito hasta el siglo XVIII sobre embarcaciones de madera. Con la aparición de los buques de hierro comenzaron a elaborarse pinturas en las que el sulfato de cobre actuaba como principio biocida. A partir de 1960 se extendió el uso de pinturas en cuya composición podíamos encontrar cobre, mercurio, arsénico, derivados organoestánnicos (compuestos orgánicos del estaño como el tributilestaño (TBT) y la trifeniltina (TPT)), las cuales con el paso del tiempo, se ha podido comprobar que suponían un riesgo real para el ecosistema marino.

En la década de los setenta se extendió el empleo de recubrimientos antiincrustantes basados en la actuación biocida de los derivados organoestánnicos, en especial del tributilestaño (TBT), por lo que la mayoría de los buques de navegación marítima recubrieron sus cascos con este tipo de pinturas, que resultaron ser eficaces y económicas.

Durante la década de los ochenta se tomó conciencia de las consecuencias que el uso del TBT en las pinturas antiincrustantes estaba teniendo sobre los ecosistemas marinos, especialmente en áreas de bajo intercambio de agua por influencia mareal, como bahías o estuarios, donde resulta especialmente perjudicial sobre las poblaciones de algunos invertebrados, moluscos, crustáceos y peces, detectándose malformaciones muy importantes en algunas especies. Como consecuencia de la preocupación desatada ante estos hechos, varios países introdujeron controles para limitar el uso de TBT en las pinturas antiincrustantes en los buques pequeños. Así, en 1982, Francia prohibió el uso de TBT en los buques con una eslora inferior a 25 m, siguiendo su ejemplo Japón, Reino Unido, Estados Unidos, Noruega, Australia, Nueva Zelanda y otros países.

A principios de los años noventa, una resolución de la OMI recomienda a los gobiernos la prohibición del uso de tributilestaño en los buques de eslora inferior a 25 m y se imponen restricciones en el proceso de lixiviación del tributilestaño, debiendo de ser inferior a 4 microgramos por cm^2 /día. Países como Japón, Nueva Zelandia y Australia prohiben el uso de antiincrustantes que contengan TBT (OMI, 1999).

En 1997, Japón prohibe la fabricación de pinturas antiincrustantes que contengan TBT, siendo el 1 de enero de 2003 la fecha propuesta para la prohibición del uso de compuestos organoestánnicos como biocidas en los sistemas antiincrustantes, quedando para el año 2008 su total prohibición.

TECNOLOGÍA DE LAS PINTURAS ANTIINCRUSTANTES

Las pinturas antiincrustantes están especialmente formuladas para aplicar sobre estructuras en contacto con agua de mar e impedir el asentamiento de los organismos marinos que componen el biofouling.

Popularmente se las conoce con el nombre *"patentes"* y como todas las pinturas están formadas por un vehículo fijo, un vehículo volátil, pigmentos y aditivos. Una vez aplicadas forman una película seca, uniforme y bien adherida al substrato a proteger y al entrar en contacto con el agua de mar, comienzan a liberar productos biológicamente activos que envuelven la superficie tratada en un manto biocida que impide la fijación de los organismos. La capacidad de control del nivel de liberación de las sustancias biocidas nos permitirá diferenciar varios tipos de pinturas antiincrustantes, siendo la concentración de toxinas en la capa de agua laminar (superficie de pintura en contacto con el agua de mar) la que determina el poder antiincrustante de la pintura. Factores como la velocidad del buque, la temperatura, salinidad y pH del agua de mar, iluminación, niveles de contaminación, etc., van a influir de manera notable en que dicha concentración de toxinas sea mayor o menor.

Las pinturas antiincrustantes las podemos clasificar como *no pulimentantes de matriz soluble o insoluble* y *autopulimentantes*.

CONSECUENCIAS DEL USO DE COMPUESTOS ORGANOESTÁNNICOS COMO BIOCIDAS EN LAS PINTURAS ANTIINCRUSTANTES

En general todos los compuestos orgánicos del estaño, y en particular el tributilestaño (TBT), son compuestos extremadamente tóxicos, incluso a concentraciones de pocos nanogramos por litro. La magnitud de los efectos del TBT y la repercusión sobre la legislación de su uso fueron particularmente destacables en las ostras y los neogasterópodos, aunque también se han encontrado cantidades mínimas de TBT en ballenas, delfines y miembros de la familia de las focas en los Estados Unidos, sudeste asiático, Mar Adriático y Mar Negro, absorbido a través de la cadena alimenticia. Además, el tributilestaño reduce la resistencia a las infecciones en peces como la platija y otros peces planos que habitan en el fondo del mar y que están expuestos a niveles relativamente altos de TBT, en particular en las zonas con sedimentos limosos como es el caso de puertos y estuarios.

CONSECUENCIAS DEL USO DE COMPUESTOS ORGÁNICOS VOLÁTILES (COVS) EN LAS PINTURAS ANTIINCRUSTANTES

El vehículo volátil constituyente de una pintura líquida, tiene como única misión permitir su elaboración y aplicación. Tanto las resinas o aceites, como los productos exentos de disolvente, forman en general materiales sólidos o semisólidos que no podrían ser aplicados por cualquiera de los procedimientos normalmente utilizados, tales como brocha, rodillo o pistola.

La necesidad de vigilar las concentraciones de COVs se deriva fundamentalmente de su propia toxicidad, ya que el uso de disolventes da lugar a emisiones de compuestos orgánicos a la atmósfera que pueden ser nocivas para la salud y producir importantes perjuicios a los recursos naturales. La mayoría de los compuestos orgánicos volátiles (COVs) son precursores del ozono y algunos de ellos son conocidos agentes cancerígenos, por lo que es necesario disminuir sus emisiones a la atmósfera. Por lo tanto, siendo las pinturas una fuente de COVs por evaporación de disolventes, se hace necesario considerar como elemento contaminante estos compuestos a la hora de formular y fabricar las pinturas, sean de la naturaleza que sean.

NORMATIVA RELATIVA A LA FABRICACIÓN Y USO DE PINTURAS ANTIINCRUSTANTES

Los problemas de contaminación causados por el TBT presente en las pinturas antiincrustantes se trató por primera vez en el Comité de Protección del Medio Marino (CPMM) de la OMI en 1988, cuando la Comisión de París 8 solicitó a la OMI que estudiase la necesidad de elaborar medidas en el marco de los instrumentos jurídicos pertinentes para limitar el uso de los compuestos de TBT en los buques de navegación marítima.

En 1990, en su 30° periodo de sesiones, el CPMM adoptó la resolución MEPC.46(30) sobre *"medidas para contrarrestar los posibles efectos adversos del empleo de compuestos de tributilestaño en las pinturas antiincrustantes"*. En dicha resolución se recomienda a los gobiernos que adopten medidas para eliminar el empleo de pinturas antiincrustantes que contengan compuestos de tributilestaño en los buques de eslora inferior a 25 m y cuyo casco no sea de aluminio, y eliminar el empleo de pinturas antiincrustantes cuya tasa media de lixiviación sea superior a 4 microgramos de tributilestaño por cm^2 /día.

El proyecto de resolución, elaborado por el Grupo de trabajo que se reunió durante el 42º periodo de sesiones del CPMM, se presentará a la vigésima primera Asamblea de la OMI, que se celebrará en noviembre de 1999. En dicho proyecto de resolución la OMI "insta al Comité de Protección del Medio Marino a que adopte las medidas necesarias para elaborar de forma rápida un instrumento jurídicamente vinculante a escala mundial con el fin de resolver la cuestión de los efectos perjudiciales de los sistemas antiincrustantes utilizados en los buques". Además la OMI "decide que el instrumento de carácter mundial que elabore el Comité de Protección del Medio Marino debería garantizar la prohibición a escala mundial de la aplicación en los buques de compuestos organoestánnicos utilizados como biocidas en los sistemas antiincrustantes en los buques, el 1 de enero de 2003 a más tardar, y la prohibición completa de la presencia en los buques de compuestos organoestánnicos utilizados como biocidas en los sistemas antiincrustantes, el 1 de enero de 2008 a más tardar".

En cuanto a los COVs podemos hacer referencia al Real Decreto 117/2003, de 31 de enero, sobre limitación de emisiones de compuestos orgánicos volátiles debidas al uso de disolventes en determinadas actividades.

PROPUESTAS DE FUTURO
Del disolvente al agua

Teóricamente es posible sustituir todos los productos que tradicionalmente están en el mercado de base disolvente por versiones en base agua.

También es posible producir productos de base disolvente con un menor contenido de disolvente utilizando la moderna tecnología de altos contenidos en sólidos que puede ser usada para formular productos que ofrecen muchas de las propiedades que se atribuyen a los tradicionales productos en base disolvente, pero que reducen significativamente el contenido de disolvente.

Alternativas a los compuestos organoestánnicos

Los sistemas antiincrustantes que no contienen TBT pueden estar compuestos por matrices solubles de agua marina que contienen ingredientes libres de estaño biológicamente activos. Los biocidas se dispersan y quedan contenidos en la matriz, aunque no estén necesariamente ligados a ella mediante un enlace químico. En la interfaz agua marina/pintura, el biocida se lixivia a un ritmo controlado. La matriz se disuelve y libera nuevo biocida, lo que permite lograr un rendimiento predecible.

Las principales opciones de que se dispone en la actualidad son las siguientes:

· *Pinturas antiincrustantes a base de cobre.*
· *Pinturas antiincrustantes libres de estaño.*
· *Revestimientos antiadherentes.*
· *Limpieza..*
· *Electricidad.*
· *Revestimientos con púas.*
· *Resistencia natural, biocidas naturales.*

En la actualidad, estamos ensayando la eficacia como biocidas en pinturas antiincrustantes de diferentes compuestos naturales extraídos del propio medio marino, en una investigación financiada por el Ministerio de Ciencia y Tecnología de España a través del Proyecto REN-0519/TECNO titulado *«Aplicación de biotecnología marina en la producción de recubrimientos antiincrustantes medioambientalmente inocuos»,* en el que participa el Departamento de Ciencias y Técnicas de la Navegación y de la Construcción Naval de la Universidad de Cantabria y colaboran la Autoridad Portuaria de Santander, la empresa cántabra de pinturas Ferroluz S.A., el laboratorio escocés Ecosearch (International) Ltd. y el Departamento de Ciencias Biológicas de la Universidad de Heriot-Watt.

Journal of Maritime Research, Vol. I. No. 3, pp. 23-36, 2004

ISSN: 1697-4840

CLEANING AND DESGASIFICACION OF TANKS
NAUTICAL SCIENCES AREA. SECURITY SUBAREA

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ABSTRACT

With the leak in vigour of the international code of step of the operational security of the ship (IGS) the assembly of the maritime international organization passed the A443 (XI) resolution. Also the A680 (17) resolution is passed.

In this one it works exposes to him the methodology to follow in the processes of cleaning and degasification of the tanks in general and the cleaning of the load tanks to carry out a change of cargo.

It is of supreme importance the metallization and the care in all the operations related with the cleaning and the degasification of the load tanks, as well as, for the additional risk of the toxic effects of the gasoline of the petroleum, the adoption of the maxims takes precautions possible in the operations of degasification.

Keywords: Tank, degasification, cleaning, security.

INTRODUCTION

With the leak in vigour of the international code of step of the operational security of the ship (IGS) that thinks object furnish an international norm on step for the operational security of the ship and the prevention of the contamination, the assembly of the maritime international organization passed the A443 (XI) resolution, by means of the who invited to all the rudders to that took the necessary measures to protect to the captain in the proper acting of his functions on the maritime security and the protection of the marine halfback.

Also the A680 (17) resolution is passed in she who moreover recognized to him the primordial importance of the step is duly organized to answers the necessities of the personnel of aboard with object of reaching and keep a high level of security and protection of the halfback gives atmosphere.

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As long as never two shipping or owning companies of ships is identical and that these operate in condition very diverse, the IGS code only establishes principles and objective general datas in wide terms to achieve the maximum application. Fit doubt of the different levels of step, is already on land or at sea, it will require diverse levels of knowledge and dominion of the subjects to that refers to him.

It understands for international code of step of the security (IGS code) to the international code of step of the operational security of the ship and the prevention of the contamination passed for the assembly, in the form that it can be altered for the organization.

The international code of step of the security thinks object guarantee the maritime security and that are avoided so much the personal injuries or losses of human lives like the damages to the halfback it gives atmosphere, concretely to the marine halfback.

One of the primordial objectives to reach to gets the security that tries to get the IGS code, it is carries out a good floor timber of maintenance in the ships, since with this gets to him, in great measure, the operational security and the prevention of the contamination of the marine halfback.

The shipping thing must adopt procedures to guarantee that the maintenance of the ships carry out to him in agreement with the corresponding rules and with the complementary dispositions that it itself establishes, and for it, the shipping will make sure that it is carry out inspections with the proper periodicity, notify to him all the cases of non-fulfillment and, if they know to him, his possible causes, take to him measured corrective appropriate, and keep to him the expedients of those activities

The shipping thing will adopt in the system of step of the security (SGS) procedures fitted to argue which is the elements of the equipment and the technical systems that, in the case of sudden average, can create dangerous situations. They will arbitrate also measured make concrete stationed ships to increase the reliability of this elements or systems. One of those measures will consist in the periodic test realization with the auxiliary devices, as well as with the elements of the equipment or the systems that are in use continually.

The objective is establish the criterions of quality and the precautions to carry out the cleaning and degasification of the load tanks, and other fenced-in gardens spaces, after the discharge of by-proucts products of the petroleum, to carry out change of cargo, it enters a tank or in a closed space, or carry out hardships instantly or in cold.

In this one it works describe to him the followed procedures for the ships (photo 1) operated for maritime distributor Petrogas, S.L.U., when they finds in the circumstances describe.

Photo 1. Ship Mencey, incendiary of new generation and of fold hull that entered service in 2004.

METHODOLOGY TO FOLLOW IN THE PROCESSES OF CLEANING

The procedure of cleaning of the load tanks to carry out a change of cargo, keeping in mind the previous cargo and the next, shows codified in the table 1, while that the description of the procedure of cleaning, identified for a specific code, reflected in the table 2.

POST LAST	NEXT CARGO					
	KERO	GNA	TO GO	DO	FO	NAPHTH A
KEROSENE	-----	1	1	1		
GASOLINE	4	-----	3	3	3	4
GASOLINE-OIL	4	2	-----	-----	1	4
DIESEL-OIL	6	2	1	-----	1	4
FUEL-OIL	NOT	NOT	5	5	-----	NOT
NAPHTHA	4	4	4	4	4	-----

Table 1.- Cleaning of tanks. The last product clewed up in the tank it is related in the column of the left. The next cargo to carry out finds in the superior row. And, the intersection of the horizontal line of the last product clewed up in the tank and the vertical line of the product to load indicates the code (1, 2, 3) of the procedure to follow to carry out the cleaning.

CODE	PROCEDURE OF CLEANING
1	When executing the discharge, it reduces the tanks correctly.
2	It reduces the tanks correctly. It causes something to lean its vertical position lines and dazed. Floor timber cleaning of the tank with jet of salt water. Reducing dazed shafts.
3	It reduces the tanks correctly. It causes something to lean its vertical position lines and dazed to the slop. It airs until a 10% LEL Control of atmosphere Circulating leak of sea for lines and bottom of tanks. Re-bale.
4	It reduces the tanks correctly. It causes something to lean its vertical position lines and dazed to the slop. It airs until a 10% LEL Control of atmosphere Circulating leak of sea for lines, tanks bottom and dazed. Re-bale. Cleaning with Butterworth machine with salt water (1 hour). Degasification. Reducing dazed aspiration shafts. To withering.

5	It reduces the tanks correctly. It causes something to lean its vertical position lines and dazed. Circulating leak of sea for lines and dazed. Re-bale. Cleaning with Butterworth machine with salt water (2 hours). Degasification. Extraction of sediments.
6	It reduces the tanks correctly. It causes something to lean its vertical position lines and dazed. Circulating leak of sea for lines, tanks bottom and dazed. Re-bale. Cleaning with Butterworth machine with salt water (2 hours). Cleaning with Butterworth machine with hot salt water (80ºC) (1 hour). Sweeten. Butterworth with hot fresh water (80ºC) (30 minutes). Reducing dazed aspiration shafts. To withering.

Table 2.- Procedure of cleaning. The code of the procedure to follow is in the column of the left. The procedure of cleaning it finds in the column of the right. The intersection of the horizontal line of the code with the vertical line indicates the procedure of cleaning that it is must follow.

Cleaning of simultaneous tanks with the manipulation of the load

As it rules general, the cleaning of tanks, NOT it must carry out simultaneously with the manipulation of the load. If for some reason this out necessary, must be consulted and move close to a so much accord with the responsible thing of the terminal as of the port authorities.

Must be verified the electric continuity in all the ventilation ducts (in a dry condition) that takes part in the cleaning of tanks, before your use, and in any case the resistance must be main of 6 ohms for meter of longitude.

It doesn't must overhaul nobody to any load tank, less than it have received, of the responsible officer, permission to make it and that have taken all the appropriate precautions, including the emission of a permission of leak in fenced-in gardens spaces, just as remains established in the manual of procedures P9N22, Leak in fenced-in gardens spaces.

In order to keeping an appropriate control of the atmosphere of the load tanks, aboard of the ships of maritime distributor Petrogás, S.L.U., it disposes of the following equipment of measure:

2 analyzers of atmosphere for the measurement of gasoline or evaporate inflammable and oxygen in the air.
1 Test of calibration of the analyzers of atmosphere.
1 Instrument capable of measure poison gas concentrations and of sulphydric acid (Tetraoxosulfate (VI) of hydrogen $H2SO4$).
All this one provisions will be identified in agreement with it specified in the manual of procedures P11.1 control of the inspection equipments, measurement and rehearse and controlled by means of the test of calibration carried out periodically in agreement with the instructions of the manufacturer and before beginning the operations of cleaning or degasification of the load tanks, and the certificates of routine inspection broadcasted for the authorized manufacturer or workshops each 12 months.

Operations of cleaning of tanks of load

The atmosphere in the tank can be understanded in the following groups:

Inert: A done unable atmosphere of blazing, if introduces you inert gas and it reduce you the total content of oxygen. The content of oxygen of the atmosphere of the tank must surpass of the 8% for volume.
Too much poor: An unable atmosphere of blazing, for the deliberate settlement of converted Indians of the content of hydrocarbons perfectly level for under the inflammable lower limit (LFL).
Too rich: An unable atmosphere of blazing, for keeping deliberately the content of hydrocarbons of the tank above the inflammable superior limit (UFL). See ISGOTT section 9.2.5.
Not controlled: An atmosphere that is not controlled can be for add, for below or in the inflammable rank.
In the section 10.6.8 of ISGOTT it is exposed the requests for the maintenance of an inert atmosphere and the precautions to be observed during the cleaning of tanks.

For the cleaning of tanks in an atmosphere too much poor, in agreement with ISGOTT (9.2.3), must observe to him the following precautions:

Before beginning the operations of cleaning the tank it must air in order to reduce the concentration of the atmosphere to the 10% or less than the inflammable limit inferior (LFL) [atmospheric control]. The samples of gasoline they must take to different levels.
During the cleaning it must be continued with the mechanical ventilation and take them of samples of gasoline. The ventilation must, in the possible, supply a free rise of air, from an extreme to the other of the tank.
In agreement with SINGLE (Enm. 2000, Cap. II-2, Rule 16), the inflammable steamer will unload to him first for the orifices of suitable airing in the rule 4.5.3.4 (respiration or valves masts P/V of high speed). When the concentration of inflammable vapours in the orifice of exit has remained reduced to the 30% of the LFL, the degasification is able to continue level with the deck of the load tanks.
Rinsing with waters and rebale the bottom of the tanks. Also it must be rinsed with waters the system of pipes, bridges and dazed of discharge, draining all on the designated tank to receive the dirty waters (slops).
If the tank has a system of sniffing people with those of other tanks, must insulate to him, in order to impede the leak of reasonable gasoline of the other tanks.
If machines are used of portable cleaning, before introducing the machine of cleaning in the tank, must mate to him all the ventilation ducts and verify the electric continuity between all the couplings and the machine. The ventilation ducts must be uncoupled until after having extracted the machine of the tank. To drain the ventilation duct, can be float free partially a coupling and later press again it before withdrawing the machine of the tank.

During the cleaning of tanks it must carry out to him, of regular form, measured of gasoline to different levels. It must be had in counting the possible effect of the leak on the efficiency of the equipment of measure of gasoline. If the concentration of gasoline reaches to the 50% of the LFL, must be stopped the cleaning of the tank and it renews the single when by means of an endless ventilation of the same thing has reduced the concentration of the gasoline to the 20% of the LFL and it is The Hague kept to that level (or in one more below).
During the cleaning the tank must be kept re-baled. It must be stopped the cleaning to eliminate any accumulation of leak.
For the cleaning of tanks is not must be accustomed leak of cleaning recycled.
It must not inject steamer in the tank.
They must take the same precautions, related with the introduction of sounding lines or other similar equipment, that when it is washing in an atmosphere not controlled (see section ISGOTT 9.2.4 (i)).
It can be employ chemical additives as long as the temperature of the leak of cleaning not surpasses of 60º C.
The leak of cleaning can be heat. In the case of the temperature of the leak of cleaning it is of 60º c or smaller, if the concentration of gasoline reaches the 50% of the LFL must interrupt to him the cleaning. If the temperature of the leak is for on the 60º c, the cleaning must interrupt if the concentration of gasoline reaches the 35% of the LFL.
In agreement with ISGOTT (9.2.4), in an atmosphere that is not controlled, the gasoline in the tank can be in the inflammable rank. The only form of guaranteeing that it cannot occur an explosion during the operations of cleaning, it is take all the necessary precautions, to make sure that don't exist sources of ignition.
They must take the following precautions to eliminate the risk of static currents:
They must not use machines of cleaning that have a superior wealth to 60 M3/h.
The of great volume total of leak of cleaning for tank of load, must be kept so below in any way whatever feasible and in any case it must surpass of 180m3/hour.
It must be used leak of cleaning recycled.
It must be used chemical additives.
The leak of cleaning can be heat as long as the temperature not surpasses of the 60ºC.
It doesn't must be injected steamer in the tank.
During the cleaning, the tank must be kept re-baled. The operations of cleaning must be stopped to reduce any accumulation of reasonable leak of the cleaning.
Before introducing the machine of cleaning in the tank it must mate to him and verify the electric continuity of all the connections of the ventilation ducts. The ventilation ducts must be uncoupled until the machine it has been withdrawed of the tank. To drain the ventilation ducts, can be float free partially a coupling and later press again it before withdrawing the machine of cleaning of the inside of the tank.
The introduction of sounding lines and other equipments must be carried out through a tube of sounding line if it is that is installed.
If you had not installed a tube of sounding line, it be indispensable that any component metal worker of the equipment of sounding line or other equipments, it is connected

to earth of a sure form before be introduced in the tank and that it staies set would that, connected to earth, until is withdrawed. This precaution it must keep during all the operations of cleaning and it extends the 5 hours more as of your finalization. However, if the tank is aired mechanically of endless form after the cleaning, this one period can be reduced to 1 hour. During this one period:

It can be use a detector of interface of metallic construction, if it is connected to earth with the ship by means of a nipperses or a metallic ear.

It can be use a metallic rod affirmed to the extreme of a metallic waleses that it is connected to earth (to knead) with the ship.

It must not use a suspended metallic rod of a rope of fiber, although the extreme perfectly level of deck is affirmed to the ship because a rope is not valid as conducting electric from setting to earth.

It can be accustomed, in general, it provisions fabricated completely of not metallic materials, such as a rod of wood it can be suspended of a rope, without that is setting to earth.

To introduce equipment in the load tanks they must not use fabricated ropes with polymerous synthetic.

In the chapter 20 of ISGOTT information more wide is offered on the electrostatic precautions that must observe to him during the operations of cleaning of tanks.

The procedure to make the atmosphere of the tank too rich and afterwards wash it with waters implies contradiction special measures stationed ships to impede the entrance of air. This method of wash of tanks can be carry out only when it is authorized for the assembler and below the supervision of a person that has received special training in this one procedures.

If the content of hydrocarbons of the atmosphere of the tank is lower to the 15% for volume, it must not begin to him the cleaning with waters or must interrupt to him or not re-start in the case of the operations it is in motion.

Portable machines of cleaning of tanks and ventilation ducts

The exterior incendiary bomb of the portable machines must be of a material which in contact with the internal structure of a tank of load it doesn't produce sparkles.

All the ventilation ducts of cleaning of tanks must have incorporated inwardly a wire of interconnection. The couplings of the extremes of the ventilation ducts must be connected to them of form someone that it remains secured, among them, an effective interconnection.

The coupling of the ventilation ducts must be someone that an effective connection is established between the machine of cleaning, the ventilation ducts and the fixed line of supply of leak for the cleaning of the load tanks.

The ventilation ducts they must take a bearing indelibly to permit your identification. Must be taken a register aboard that indicates the date and the result of the proofs of electric continuity.

The machines of cleaning must be electric connected to the ventilation duct, by means of an appropriate connection or for an external interconnected cable.

When the machines of cleaning are suspended in a tank of load, they must maintain by means of a rope and not by means of the ventilation duct that supplies them the leak.

Free drop (ISGOTT, 9.2.7)

It is indispensable avoid free the fall of leak or dirty waters in the receiving tank. The level of the liquid must be always someone that the mouths of the lines of discharge, in the reception tank, is decks at least a meter, to avoid the splashy thing. This is not necessary when the tanks of reception of dirty waters (|slops|) and of load are totally inertized.

Sprinkled with waters (ISGOTT, 9.2.8)

The dewy thing with waters in a tank that contains a substantial quantity of accumulating product of static currents it could cause the generation of static electricity in the liquid surface is already for agitation or for the simple deposit of the leak.
The tanks that contain an accumulating product of static currents must well always re-bale to him, before be washed with waters, to less than the tank it keeps in an inert condition (see section 7.4 of ISGOTT).

Vaporized of tanks

Due to the risks of static electricity, the introduction of steamer in a tank of load must be permitted if exist the risk of the presence of an inflammable atmosphere.
Discharge of blunder, cascarillas of oxidize and deposit as sediment
Before the manual discharge of blunder, cascarillas of oxidize and deposit as sediment, the atmosphere of the tank must be sure to carry out the leak and must broadcast to him a permission of leak in fenced-in gardens spaces. They must keep during the whole storm that lasts the work the precautions describe in the section 11.6.5 of ISGOTT and in the P9N22 Leak procedure in a closed space.
The equipment to be used in operations of cleaning of tanks, just as the discharge of solid remainders or products in tanks that it have been desgasificadoed, must be designed and built, and the used materials in the construction are so, that your use doesn't add no risk of ignition.
In agreement with the rule 20 of the annex I of the international agreement to prevent the contamination for the ships, 1973, in your modified form for the protocol of 1978, Marpol 73/78, the operations of cleaning of tanks of the incendiaries of brute equal or superior gauging to 150 tons, must be consigned in the book it registers of hydrocarbons (departs II).
to this one printed paper of book it registers of hydrocarbons (second revision) (departs II) adopted by means of the resolution MEPC.47 (31), you are assigned in the system of quality, security and intercede environment of maritime distributor Petrogás, S.L.U., the codification Doc.9N6.3 and the registers will be carried out following the established instructions in the referenced document.
The captain will inform to the department of security and intercede environment, monthly, of the amount of dirty waters (water of wash of tanks) and oleaginous remainders of bilges surrendered in receiving installations, specifying date and port, by means of the Doc.9N16.1 denominate Marpol action.

DESGASIFICATION OF TANKS

The additional risk of the toxic effects of the gasoline of the petroleum during this one period must be inculcated to all the implied contradiction in the operations.
It is indispensable that the possible care major is had in all the operations related with the cleaning and the degasification of the load tanks.

General procedure

Then the applicable recommendations are detailed to the degasification of tanks in general. In the agree 10 of ISGOTT it exposes to him additional considerations that apply to him when the tank is inertized.
The stramoniums of all the apertures of the tanks of load must keep to him closed until the ventilation of the tank is on the point of begin.
The portable ventilators of must only use if are driven hydraulics or pneumatic. His material of construction must be someone that doesn't anchor no risk of sparkles if for any reason the impeller blows the inside side of the incendiary bomb.
The capacitance and effectiveness of the portable ventilators must be someone, that all the atmosphere of the tank on she who employs to him the ventilator can be don't inflammable in the smaller possible storm.
In agreement with SINGLE (Enm. 2000, Cap. II-2, Rule 16), during the degasification, the blow of the inflammable gasoline carries out for the fixed system pass of the ship, flowing first for the orifices of suitable airing in the rule 4.5.3.4 (respiration or valves masts P/V of high speed). When the concentration of inflammable vapours in the orifice of exit has remained reduced to the 30% of the LFL, the degasification is able to continue level with the deck of the load tanks.
It takes him/her/it of the central system of air conditioning or those of those of mechanical ventilation it must fit to prevent the leak of the petroleum in the inside of the qualification, if it are possible recycling the air in the inside spaces of the ship.
If in any moment be suspicious that the gasoline is being dragged to the inside of the qualification of the ship, must stop to him the central system of air conditioning and those of mechanical ventilation and cover or close his aspirations.
The units of window type air conditioning that be certified as sure to be accustomed in the presence of inflammable gasoline or that it suck in air from the exterior side of the superstructure must be detached electric and close any external exit or aspiration.
In the where ships they are installed permanent ventilators to desgasificate the load tanks, must wrap up to him with blind flanges all the connections between the system of load and the ventilators except when the ventilators are in use.
Before putting in service such a system, must clean out to him totally with leak of sea the system of pipeses of load and re-bale the tanks. The valves of the system that are not the strictly used to carry out the operations of degasification, must close to him and secure.
The apertures of tanks in fenced-in gardens or partially fenced-in gardens spaces not they must float free until the tank has aired sufficiently by means of apertures of the tank that are outside of this one spaces.

When the level of the gasoline in the tank has gone down to the 25% of the LFL or less, it can be open the apertures in the fenced-in gardens or partially fenced-in gardens spaces, to complete the ventilation. In someone fenced-in gardens or partially fenced-in gardens spaces must also verify to him the existence of gasoline during this subsequent ventilation.

If the tanks are connected to a system of sniff people, each tank must be insulated to impede the transference of gasoline from or towards other tanks.

When be accustomed to him portable ventilators, must place to him in positions someone, and the apertures of ventilation of someone form, that all the abilities of the tank that are becoming aired are equal and in effect desgasificadassed. In general, the apertures of ventilation must be distant all the possible thing of the ventilators.

When they are accustomed to him portable ventilators must connect to the deck of form someone that exist an electric effective interconnection between the ventilator and the deck.

The fixed equipment to desgasificate can be use to free of gasoline simultaneously besides a tank, but is not must be accustomed with this one aim if the system it is using to air other tank is washing to him.

To the feign finalization of the degasification of any tank, before taking the final measures of gasoline, it is must leave pass a period of a few 10 minutes. This permits that develop to him condition relatively regular guest in the space of the tank. The measures of gasoline to different levels and, where the tank is subdivided for a transversal bulkhead of reinforcement, in every one of the compartments of the tank. In big compartments the measures they must carry out in positions amply separate.

If they don't obtain to him satisfactory readings of the not existence of gasoline, must renew to him the ventilation.

To the finalization of the degasification they must close all the apertures except those of the stramoniums of the tank.

when executing the degasification and cleaning of the load tanks, must carefully verify to him the system of blow, giving special attention to the efficient functioning of the P/V valves, including the valves of blow of high speed. If the valves or billiard pins of blow are provisioned with dispositives designed to impede the step of the flames, this one also must recognize to him and clean out.

The drainages of the tubes of blow must, if it conduct, clean out of leak, oxide and deposit as sediment and any connection is must satisfactorily try of suffocation of the tank.

Degasification for the reception of a cargo

A tank of the one which requires to him that it is gives birth of gasoline to receive a cargo, must air to him until the measures it confirm that the concentration of gasoline of hydrocarbons of an extreme to the other of that tank surpass of the 40% of the LFL.

Degasification for meddling and work in cold without get ready respiratory

to the end of a tank or space out is gives birth of gasoline for leak without get ready respiratory, you are must air until the proofs confirm that the concentration of gasoline of hydrocarbons, of an extreme to the other of the compartment, surpass the 1% of the LFL, and have carried out the additional proofs to verify the content of oxygenate and the presence of poison gases according to corresponds. It sees ISGOTT section 11.3 and P9N22 Leak procedures in fenced-in gardens spaces and P9N31 hardships in cold.

Degasification to work instantly

Besides collecting the requirements of section ISGOTT 9.3.4 and section 2.8, must them fulfill one's obligations to him specified in the manual of procedures of the system of step integrated (SGI) of the shipping, Procedure P9N30 hardships instantly.
The responsible thing of fulfilling and make fulfill this one procedures is the captain as responsible of the security of the ship whose gives the orders has knight-commander's assistant and the officers in the measure in which everyone of them/it has assigned functions in the procedures or arrange permanent waves of the captain.
Likewise, the registers that are must carry out are the floor timber of Charge/discharge of the ship, the log book of the ship, the book registers of hydrocarbons (departs II) operations of Charge/ballasted (Doc.9N6.3), the register of the proofs of electric continuity of the ventilation ducts of cleaning of tanks, the certificates of routine inspection of the equipments of measurement of gasoline, the register of the test of carried out calibration to the equipments of measurement of gasoline and the maintenance of the ship and provision (maintenance of the P/V valves).

CONCLUSIONS

Gradually it been gone increasing the interest for the labour security and for the protection of the halfback gives atmosphere, not remaining the maritime sector exempts of this common general. With the leak in vigour, of the 1 of July of 1998 of the international code of step of the Operational security of the ship and the prevention of the contamination (international code of step of the security (IGS) (A.741. (18)) an international norm is furnished on step for the operational security of the ship and the prevention of the contamination.

The IGS code only establishes principles and objective general datas, since never two shipping or owning companies of ships is identical nor it operate upon in the same conditions, for that motive, corresponds to each shipping establish a series of protocols or of procedures to carry out daily operations, among them those of cleaning and degasification of tanks of load and other spaces closed after the discharge of by-proucts products of the petroleum.

It is fundamental the metallization and preparation of the whole involved personnel in these operations, fundamentally when it deals with of degasification, for the additional risk of the toxic effects of the gasoline of petroleum.

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CLEANING AND DESGASIFICACION OF TANKS
NAUTICAL SCIENCES AREA. SECURITY SUBAREA.

RESUMEN

Con la entrada en vigor del Código Internacional de Gestión de la Seguridad operacional del buque (IGS) la Asamblea de la Organización Marítima Internacional aprobó la resolución A443 (XI). También se aprobó la resolución A680 (17).

En éste trabajo se expone la metodología a seguir en los procesos de limpieza y desgasificación de los tanques en general y la limpieza de los tanques de carga para efectuar un cambio de cargamento.

Es de suma importancia la mentalización y el cuidado en todas las operaciones relacionadas con la limpieza y la desgasificación de los tanques de carga, así como, por el riesgo adicional de los efectos tóxicos del gas del petróleo, la adopción de las máximas precauciones posibles en las operaciones de desgasificación.

METODOLOGÍA

Con la entrada en vigor del Código Internacional de Gestión de la Seguridad operacional del buque (IGS) que tiene por objeto proporcionar una norma internacional sobre gestión para la seguridad operacional del buque y la prevención de la contaminación, la Asamblea de la Organización Marítima Internacional aprobó la resolución A443 (XI), mediante la cual invitó a todos los gobiernos a que tomaran las medidas necesarias para proteger al capitán en el debido desempeño de sus funciones sobre la seguridad marítima y la protección del medio marino.

También se aprobó la resolución A680 (17) en la que además se reconocía la importancia primordial de que la gestión esté debidamente organizada para responder a las necesidades del personal de a bordo con objeto de alcanzar y mantener un elevado nivel de seguridad y protección del medio ambiente.

Dado que nunca dos compañías navieras o propietarias de buques son idénticas y que éstas operan en condiciones muy diversas, el Código IGS sólo establece principios y objetivos generales en términos amplios para lograr la máxima aplicación. No cabe duda de que los distintos niveles de gestión, ya sea en tierra o en el mar, requerirán diversos niveles de conocimiento y dominio de los temas a que se hace referencia.

El Código Internacional de Gestión de la Seguridad tiene por objeto garantizar la seguridad marítima y que se eviten tanto las lesiones personales o pérdidas de vidas humanas como los daños al medio ambiente, concretamente al medio marino.

Uno de los objetivos primordiales para llegar a conseguir la seguridad que pretende el Código IGS, es llevar a cabo un buen Plan de Mantenimiento en los buques.

Las navieras deberán adoptar procedimientos para garantizar que el mantenimiento de los buques se efectúe de conformidad con los reglamentos correspondientes y para ello, las navieras se asegurarán de que se efectúen inspecciones con la debida periodicidad.

El objetivo es establecer los criterios de calidad y las precauciones para efectuar la limpieza y desgasificación de los tanques de carga, y otros espacios cerrados, después de la descarga de productos derivados del petróleo, para efectuar cambio de cargamento, entrar en un tanque o en un espacio cerrado, o efectuar trabajos en caliente o en frío.

METODOLOGÍA A SEGUIR EN LOS PROCESOS DE LIMPIEZA

El procedimiento de limpieza de los tanques de carga para efectuar un cambio de cargamento, teniendo en cuenta el cargamento anterior y el próximo, se muestra codificado en la Tabla 1, mientras que la descripción del procedimiento de limpieza, identificado por un código específico, se refleja en la Tabla 2.

ÚLTIMO CARGAMENTO	PRÓXIMO CARGAMENTO					
	KERO	GNA	GO	DO	FO	NAFTA
KEROSENO	-----	1	1	1		
GASOLINA	4	-----	3	3	3	4
GAS-OIL	4	2	-----	-----	1	4
DIESEL-OIL	6	2	1	-----	1	4
FUEL-OIL	NO	NO	5	5	-----	NO
NAFTA	4	4	4	4	4	-----

Tabla 1.- Limpieza de tanques. El último producto cargado en el tanque se relaciona en la columna de la izquierda. El próximo cargamento a efectuar se encuentra en la fila superior. Y, la intersección de la línea horizontal del último producto cargado en el tanque y la línea vertical del producto a cargar indica el código (1, 2, 3, …) del procedimiento a seguir para efectuar la limpieza.

CÓDIGO	PROCEDIMIENTO DE LIMPIEZA
1	1. Al finalizar la descarga, achicar los tanques adecuadamente.
2	1. Achicar los tanques adecuadamente. 2. Desplomar líneas y bombas. 3. Limpieza plan del tanque con chorro de agua salada. 4. Achicar pocetos bombas.

3	1. Achicar los tanques adecuadamente. 2. Desplomar líneas y bombas al slop. 3. Ventilar hasta un 10% LEL 4. Control de atmósfera 5. Circular agua de mar por líneas y fondo de tanques. Reachicar.
4	1. Achicar los tanques adecuadamente. 2. Desplomar líneas y bombas al slop. 3. Ventilar hasta un 10% LEL 4. Control de atmósfera 5. Circular agua de mar por líneas, fondo tanques y bombas. Reachicar. 6. Limpieza con máquina butterworth con agua salada (1 hora). 7. Desgasificación. 8. Achicar pocetos aspiración bomba. 9. Secar.
5	1. Achicar los tanques adecuadamente. 2. Desplomar líneas y bombas. 3. Circular agua de mar por líneas y bombas. Reachicar. 4. Limpieza con máquina butterworth con agua salada (2 horas). 5. Desgasificación. 6. Extracción de sedimentos.
6	1. Achicar los tanques adecuadamente. 2. Desplomar líneas y bombas. 3. Circular agua de mar por líneas, fondo tanques y bombas. Reachicar. 4. Limpieza con máquina butterworth con agua salada (2 horas). 5. Limpieza con máquina butterworth con agua salada caliente (80ºC) (1 hora). 6. Endulzar. Butterworth con agua dulce caliente (80ºC) (30 minutos). 7. Achicar pocetos aspiración bomba. 8. Secar.

Tabla 2.- Procedimiento de limpieza. El código del procedimiento a seguir está en la columna de la izquierda. El procedimiento de limpieza se encuentra en la columna de la derecha. La intersección de la línea horizontal del código con la línea vertical indica el procedimiento de limpieza que se debe seguir.

Limpieza de tanques simultáneo con la manipulación de la carga

Como regla general, la limpieza de tanques, **NO SE DEBERÁ REALIZAR SIMULTÁNEAMENTE** con la manipulación de la carga.

CONCLUSIONES

Paulatinamente se ha ido incrementando el interés por la seguridad laboral y por la protección del medio ambiente, no quedando el sector marítimo exento de ésta corriente general. Con la entrada en vigor, del 1 de julio de 1998 del Código Internacional de Gestión de la Seguridad Operacional del Buque y la Prevención de la Contaminación (Código Internacional de Gestión de la Seguridad (IGS) (A.741.(18)) se proporciona una norma internacional sobre gestión para la seguridad operacional del buque y la prevención de la contaminación.

El Código IGS sólo establece principios y objetivos generales, ya que nunca dos compañías navieras o propietarias de buques son idénticas ni operan en las mismas condiciones, por ese motivo, corresponde a cada naviera establecer una serie de protocolos o de procedimientos para realizar operaciones cotidianas, entre ellas las de limpieza y desgasificación de tanques de carga y otros espacios cerrados después de la descarga de productos derivados del petróleo.

Es fundamental la mentalización y preparación de todo el personal implicado en estas operaciones, fundamentalmente cuando se trata de desgasificación, por el riesgo adicional de los efectos tóxicos del gas de petróleo.

Journal of Maritime Research, Vol. I. No. 3, pp. 37-50, 2004

ISSN: 1697-4840

FULL-SCALE MANOEUVERING TRIALS SIMULATION

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ABSTRACT

This paper describes the simulation of the behaviour of a ship in some of the most widely used sea trials: turning circle, pull-out, zig-zag, and direct and inverse spiral test. For the simulation, a full non-linear mathematical model with three degrees of freedom is used. The hydrodynamics coefficients used in the mathematical model were obtained from a physical scale model with a planar motion mechanism in a towing tank. The results obtained are satisfactory, supporting the proposal that these sea trial simulation tools should be used as an important part of the design stage in the building of a ship.

Key Words: Mathematical model. Ship movement. Manoeuvring. Simulation.

INTRODUCTION

Sea vessels must be able to maintain their course in the open sea, to manoeuvre safely in ports and restricted channels and to stop within a reasonable distance. These minimum capacities are required under any load condition, both at high speeds and at more moderate speeds associated with restricted waters and in both calm conditions and in windy or rough conditions.

This paper describes the sea trials widely used to determine a ship's manoeuvring characteristics. With these tests, it is possible to measure the ship's dynamic behaviour characteristics, to obtain an indication of its straight-line stability, to evaluate the robustness and the limitations of the control system and to assess the ship's behaviour in emergency situations.

Although these tests were carried out on a ship actually built and at sea, the ship's behaviour can be simulated in the design stage by means of simulation programmes using mathematical models. This paper presents the results of the sea trials of a ship. The simulation is performed with Matlab's Simulink simulation programme.

FULL-SCALE MANEUVERING TRIALS

Many of the sea maneuvering trials performed on most merchant ships before they are formally delivered to the ship owner are based on the verification of the maximum speed of the ship,

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on the functioning of the steering and radio communications systems, on the main engine and the ship steering equipment. In order to verify the ship's maneuvering characteristics, other standard ship manoeuvres can be performed allowing the ship's dynamic behaviour characteristics to be measured and the robustness and the limitations of the ship control system to be evaluated. The manoeuvring characteristics can be obtained by holding or changing a predetermined course and speed in a systematic way.

In accordance with the recommendations of the 14th "International Towing Tank Conference" (14th ITTC, 1975), Tests have to provide owners and builders with information on the operating characteristics of the ship. These must address the course-keeping, course changing and emergency manoeuvre characteristics. In order to determine the efficiency of the vessel in course-keeping, the tests methods proposed are: the direct or reverse spiral test and the zigzag manoeuvre test with small rudder angle. To determine the quality in the course changing behaviour, the zigzag manoeuvre test and the 15 degrees helm turning test and change of heading test are recommended. To determine the ship's capacity in the face of emergency manoeuvres, the most appropriate test methods proposed are the maximum helm turning test and the crash-stop astern test.

Vessels must have manoeuvring capacities which allow them to hold course, turn, test the turns, operate at an acceptably low speed and stop in a satisfactory way. Sea maneuvering trials are intended to provide a measurement of the following characteristics (Lewis, 1989):

- *Turning circle characteristics*: These can be determined by means of turning circle tests using a rudder angle of 35º.
- *Yaw checking ability*: This can be measured by obtaining the first overshoot angle and time to check the yaw in a zig-zag manoeuvre.
- *Initial turning ability*: This can be determined at the initial stage of the zig-zag manoeuvre with the ship's change of heading angle per unit of rudder angle, and the forward distances covered after executing a rudder command.
- *Coursekeeping ability*: No single measurement of coursekeeping ability has yet been developed. However, in the case of vessels whose type, size and speeds are comparable, this capacity can be evaluated through a comparison of the zig-zag direct or reverse spiral and pull-out tests.
- *Slow steaming ability*: The capacity to proceed at a steady slow speed is a desirable characteristic. It is generally determined using only the ship's speed associated with the lowest possible engine RPM.
- *Stopping ability*: This can be calculated using the distance that the ship travels along its track, once the crash-astern command has been given.

A description is given below of some of the standard ship maneuvers: turning circle, pull-out, zig-zag and direct and reverse spiral tests.

TURNING CIRCLE

This is the manoeuvre which has received the most attention from professionals in the field. It is used to determine the ship's steady turning radius and to verify the behaviour of the steering machine and rudder control during course-changing manoeuvres. Figure 1 shows a turning circle, indicating its characteristic stages and parameters. It should be performed to both port and starboard at maximum speed, with a maximum rudder angle and with a rudder angle of 15 degrees. It is necessary to do a turning circle of 540º at least to determine the main parameters of this trial.

This manoeuvre is also used to determine other characteristic parameters such as: the tactical diameter, advance, transfer, loss of speed on steady turn, and times to change heading 90º and 180º respectively, as can be seen in Figure 1. The maximum advance and maximum transfer can also be measured.

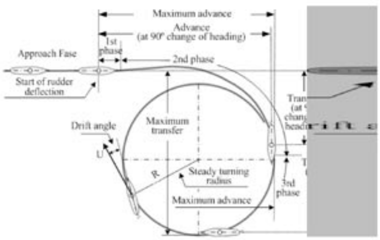

Figure 1: Terms used in turning circle.

As can be observed in Figures 1 and 2, the turning circle test is devised in the following phases:

- *Approach phase*: The ship sails in advance, in a straight line at a constant speed *U* and with the rudder in neutral position ($\delta = 0$). The linear and angular velocities and accelerations are: $v = \dot{v} = r = \dot{r} = 0$
- *Manoeuvre phase*: This begins when the constant rudder angle δ is applied at any of the sides. It is divided into three phases:

First phase: Starts at the instant the rudder begins to deflect from the neutral position and finishes when it reaches the desired δ value. During this stage, the speeds are practically null ($v \approx r \approx 0$). However, the accelerations have a value of $\dot{v} = 0$ and $\dot{r} = 0$ from the first moment.

Second phase: Here, the accelerations coexist with the speeds, that is, $v \neq \dot{v} \neq r \neq \dot{r} \neq 0$. In the last part of this stage, equilibrium is obtained between the forces intervening in the ship's turning circle and the accelerations tend to reduce to zero.

Third phase: When this equilibrium is reached, the ship begins to perform a turn of constant radius R, as shown in Figure 1. In this phase, $v \neq r \neq \dot{v} = \dot{r} = 0$ and the ship's speed is reduced by 60% from the speed it had when the turning circle was initiated (Bonilla, 1979).

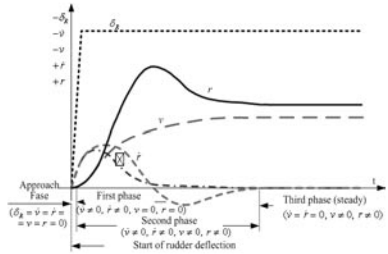

Figure 2: Characteristics of phases of a turning circle.

PULL-OUT MANOEUVRE

The pull-out manouevre is a simple test used to obtain a rapid indication of the stability of a straight-line course held by a ship.

A rudder angle of approximately 20º is applied and time is allowed to pass until the ship reaches a constant change of heading rate $r = \dot{\psi}$; at that instant, the rudder is returned to midships (neutral position). If the ship is stable, the speed will drop to zero both for port and starboard rudder changes. If the ship is unstable, the change of heading rate will drop to some residual speed rate.

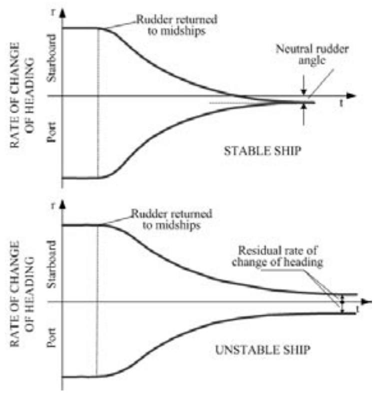

Figure 3: Presentation of results of the Pull-out manouevre.

This manoeuvre must be performed in both directions, port and starboard, to show any possible asymmetry. Figure 3 shows the results of a pull-out manoeuvre for a stable ship sailing in a straight line and for another unstable one.

KEMPF'S ZIG-ZAG MANOEUVRE

The zig-zag manoeuvre is obtained by inverting the rudder alternatively by δº to both sides, with a shift ofψ from the initial course. The typical procedure is as follows (Lewis, 1989):

Make the ship sail in advance and in a straight line at a predetermined speed for a certain time.
Place the rudder to the starboard side at the maximum speed for a predetermined quantity of δ, for example 10º, and maintain this value until the preselected (10º) course changing ψ occurs (10º) (first operation).
Place the rudder at the maximum speed on the opposite side (port) at the same angle (10º) (second operation). Maintain the rudder position and the ship continues to rotate in the original direction, at a rotation speed which drops gradually until the movement stops. Then, in response to the rudder, the ship turns to port. The rudder position is held until the preestablished course changing ψ^o is obtained on the opposite side (port). This completes the overshoot test.
To complete the zig-zag test, the rudder is again set at the maximum speed at the same angle (10º) on the initial side (starboard) (third execution). Continue until a total of 5 executions of the rudder are completed.
The normal course changing value ψ is 10º. A modified trial can also be taken into account with a course changing of 20º. The 14th ITTC conference recommends executing the manoeuvres at maximum approach speed and, if possible, also at medium speed.

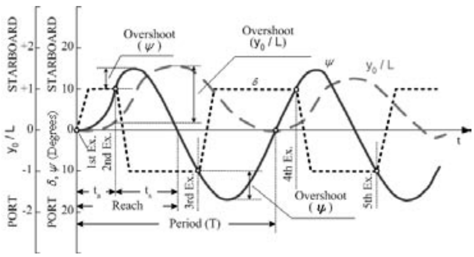

Figure 4: Zig-zag manoeuvre graph: rudder angle δ , ψ ship's course, yo/L normal distance to the initial trajectory divided by the ship's length.

The results of this manoeuvre are indicators of the capacity of the rudder to control the ship's heading. They can also be used to compare different ship manoeuvring capacities. It should be noted that, from the point of view of the interpretation of the international rules of sea sailing, the use of rudder angles δ to starboard to verify the turning capacity and heading control of a ship are recommended, since, in case of emergency, changes in heading must be made to starboard. For this reason, the normal zig-zag manoeuvre begins with the application of the rudder angle to starboard.

For a simple, initial analysis of the results, the characteristic heading values defined in Figure 3 can be used. The values are given as a function of rudder angle δ.

The main measurements obtained are:
- The time t_a it takes to reach the second execution of the heading, which indicates the capacity of the ship to change heading course or the efficiency of the rudder.
- The angle of overshoot in the heading.
- The overshoot of the trajectory obtained when performing the trial.

These latter two measurements are indicative of the amount of anticipation required by the helmsman to sail in restricted waters. In (Arentzen y Mandel, 1960), it is shown that the magnitude of the overshoot in the heading drops when the stability increases but increases when rudder efficiency increases. Also, the overshoot in the trajectory drops when either the dynamic stability or rudder efficiency.

The results of the zig-zag test depend on the ship's speed, since the time it takes to reach a given heading falls when this increases.

Direct and reverse spiral tests

These manoeuvres provide a qualitative measure of the directional stability of the ship in a straight line. For ships which show stable characteristics, the Dieudonné direct or Bech inverse spiral tests can be used to obtain the response to small rudder angles. For unstable ships, the 14th ITTC recommends the Bech inverse spiral test within the limits indicated by the results of the pull-out manoeuvres.

Dieudonné Direct Spiral Manoeuvre

The direct spiral manoeuvre is used to determine the directional stability characteristics of the vessel, and also provides information on the degree of stability and range of validity of the linear theory.

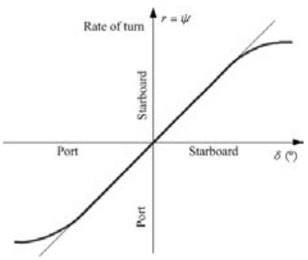

Figure 5: Graph of direct spiral manouevre of a stable, symmetrical vessel.

The procedure for performing the is as follows:

- Make the ship sail in advance with an initial straight course at constant speed.
- Set the rudder at an angle δ, of 25° to starboard and keep it there until the rate of change of heading is constant $r = \dot{\psi}$.
- Once a constant value is reached, the rudder angle δ is reduced by 5° and again held until steady conditions of turning have been obtained.
- This procedure is repeated until the rudder has run through all of the rudder angles from 25° to starboard to 25° to port and again to starboard.
- In the range of rudder angles from 5° on either side of zero or neutral rudder angle, the intervals must be reduced.

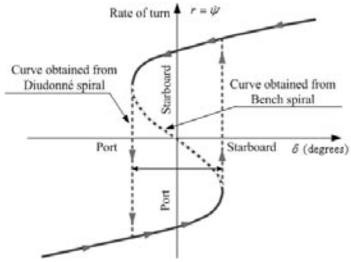

Figure 6: Graphs of the Diudonne and Bench spiral manouevres for an instable ship with a hysteresis cycle.

With this procedure, the ship performs a spiral movement. The graph shows the ship's yaw rate $r = \dot\psi$ as a function of each angle δ of the rudder, such as those shown in Figures 5 and 6. This manoeuvre should be carried out in still air and calm water conditions.

In carrying out the manoeuvre, it is essential to leave sufficient time to reach the stationary state at each angle the rudder is seta t. In (Lewis, 1989) the results of three tests performed with different time intervals between consecutive angles of rudder setting are presented (Strom-Tejsen, 1965). It is shown that to perform an exact study of the stability of a ship, it is essential not to limit the experimental time between the rudder angles.

An indication of the stability of the ship can be obtained from this graph. For example, if it is a single line that goes from starboard to port and is inverse, as shown in Figure 5, then the ship is stable (has stability in a straight course). However, if the graph presents two branches formed by a hysteresis cycle, the ship is unstable. The height and width of the cycle measure the degree of instability, so that the wider the hysteresis cycle, the more unstable the vessel.

Reverse spiral manoeuvre

Bech's reverse spiral manoeuvre is an alternative to the direct spiral manoeuvre (Bech, 1968). In this manoeuvre, the ship's course is set at a constant change of heading speed and the rudder angle δ required to produce this speed of change of heading $r = \dot\psi$ is also set. In this trial, the values of the points of the change of heading speed curve with respect to the rudder angle can be taken in any order.

The equipment required is a rate-gyro (alternatively, the heading ψ given by the gyrocompass can be differentiated to provide $r = \dot\psi$), and an exact indicator of the rudder angle δ. The accuracy of the trial can be improved if the information on the change of heading speed and the rudder angle are available continuously. If manual control is used, the helmsman can visualise the instantaneous change of heading speed in a register or indicator. The procedure originally proposed by Bech for obtaining a point in the curve is recommended and is outlined below.

The ship is made to approach the desired change of heading speed or "rate of turn", $r_0 = \dot\psi_0$, applying a moderate rudder angle. Once the desired change of heading rate is obtained, the rudder is activated to maintain this desired rate of change of heading as accurately as possible. The helmsman must attempt to maintain the desired change of heading rate using shorter and shorter rudder movements until constant values of the ship's speed and rate of change of heading are obtained. Normally, a stable change of heading rate is obtained quite fast, so that it is easier to perform the test using a rate-gyro than with a normal gyrocompass.

MANOEUVRE MODEL USED

For the simulation of the sea trials, the model of a "Mariner" class ship, widely used in the literature, has been selected. Data from the ship 'USS Compass Island' (Chiselett y Strom-Tejsen, 1965) have been used. The main characteristics of the ship are shown in Table 1.

Description	Symbol	Value	Units
Length overall	L	171,80	m
Length between perpendiculars	L_{pp}	160,93	m
Maximun beam	B	23,17	m
Design draft	D	8,23	m
Design displacement	∇	18541	m3
Design speed	U_0	20	knots
Max. design rudder angle	δ	40	deg
Max. design rudder rate	$\dot{\delta}_{\max}$	2,5 – 3,7	deg/sec

Table 1: Main dimensions of the "Mariner" class ship

The mathematical model used for the simulation with three degrees of freedom is:

$$\begin{bmatrix} m'-X'_{\dot{x}} & 0 & 0 \\ 0 & m'-Y'_{\dot{v}} & m'x'_G-Y'_{\dot{r}} \\ 0 & m'x'_G-N'_{\dot{v}} & I'_z-N'_{\dot{r}} \end{bmatrix} \begin{bmatrix} \dot{u}' \\ \dot{v}' \\ \dot{r}' \end{bmatrix} = \begin{bmatrix} X' \\ Y' \\ N' \end{bmatrix} \quad (1)$$

The non-linear forces X and Y and the hydrodynamic moment N are developed using the Abkowitz (1964) model.

To develop the simulation model, the cinematic equations must be added, giving:

$$\mathbf{M}\,\dot{\mathbf{v}}' = \boldsymbol{\tau}' \quad (2)$$

$$\dot{\boldsymbol{\eta}} = \mathbf{J}(\boldsymbol{\eta})\mathbf{v}' \quad (3)$$

To include the model of the rudder action, the simplified model suggested by Van Amerongen (1982) has been used, as indicated in Figure 7 where δ_c is the rudder angle demanded by the controller and δ is the real rudder angle. The typical saturation values of the rudder angle and turning speed are in the following value ranges: $\delta_{\max} = 35^{\circ}$ y $2.5^{\circ}/seg \le \dot{\delta}_{\max} < 7^{\circ}/seg$.

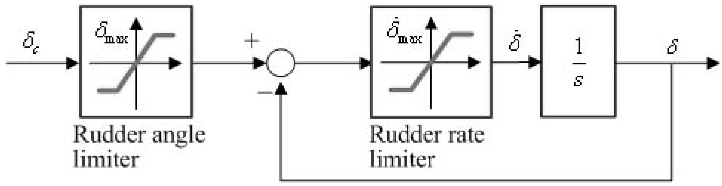

Figure: 7: Simplified Diagram of the rudder control loop.

In the development of this model, in accordance with the characteristics of the Mariner-type vessel, the rudder angle and rudder rate limits have been set at 30º and 4,6 /s respectively.

Description of the Simulink Model

The mathematical model has been developed in the Matlab-Simulink environment. Figure 8 shows the block diagram used. The main block receives as input the desired rudder angleδ_c and generates as output the ship's heading angle ψ . The model of the ship has been separated into two blocks. The first contains the rudder behaviour model and the second the ship dynamics model.

The ship dynamics model has been developed using an s function of Matlab which receives as input the rudder value δ and generates as output: the longitudinal advance speed u, the transversal speed v, the turning speed r, the heading ψ, the ship's position x, y, the rudder angle δ and the ship's speed U.

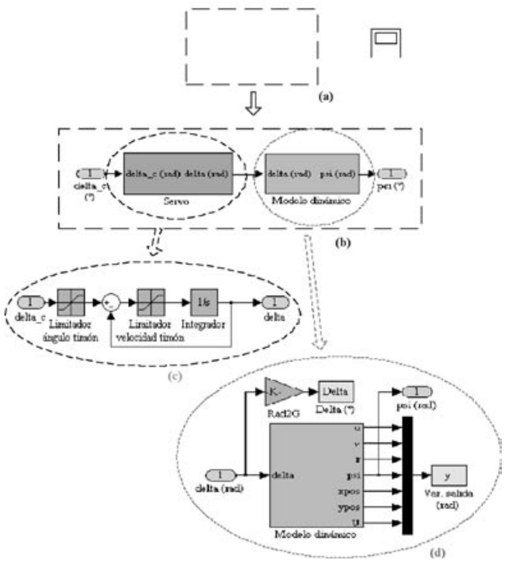

Figure 8: Simulink block diagrams used in simulation: (a) Main block of ship (b) Separation into two servo blocks and dynamic model. (c) Diagram of model used in rudder servo. (d) Block diagrams of dynamics model indicating output variables.

Sea trials simulation

Firstly, Figure 9 shows a graph of the rudder dynamics. It can be observed that a time of approximately 10 s is required to go from the neutral position of 0º to the maximum angle allowed (± 30º) and 19 s to make the maximum change from -30º to 30º which is a normal result in this type of vessels.

The turning circle, zig-zag and spiral tests have also been simulated. The results of the simulations can be used to obtain an initial estimate of the dynamics behaviour and the stability and manoeuvrability characteristics of the ship.

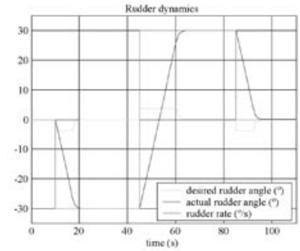

Figure.9: Rudder dynamics behaviour.

Figure 10 shows the turning circle for the rudder angles 5º, 10º, 15º, 20º and 25º. It can be observed that the gyro radius drops as the rudder angle δ increases.

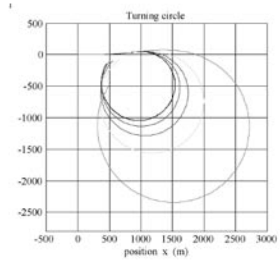

Figure 10: Turning circle for various rudder angles δ.

Figure. 11 shows the results of a zig-zag manoeuvre 20º/20º. The results of this trial are indicative of the manoeuvring capacity of the ship for a specified rudder angle.

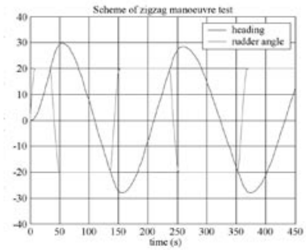

Figure 11: Zig-zag test 20º-20º.

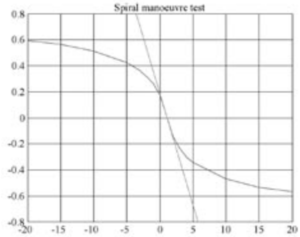

Figure 12: Graph with results of spiral test 20º/20º.

The simulation of t' l manoeuvre is shown in Figure 12, representing the reduction speed of the ship as a function of each angle δ set at the rudder. The graph obtained indicates that the ship has a stable behaviour on a straight course. The slope of the line tangent to the curve allows us to determine the gain in the linear approach over the Nomoto model. A stable behaviour of the ship is also observed in the results of the pull-out manoeuvre as can be seen in Figure 13.

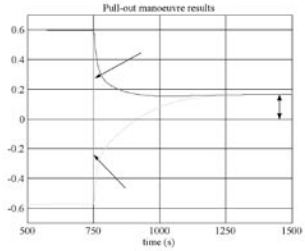

Figure 13: Pull-out manoeuvre

CONCLUSIONS

Although sea trials are carried out with the ship already built and at sea, it is useful to simulate the dynamic behaviour of the ship in the design stage using mathematical models.

Some of the most widely used sea trials have been simulated using a full, non-linear mathematical model with three degrees of freedom. The simulation results allow the ship's dynamic behaviour characteristics to be measured, an indication of its stability on a straight course to be obtained, its robustness and the limitations of the control system to be evaluated and its behaviour in emergency situations to be assessed.

The results obtained in the sea trial simulations indicate that sea trial simulation tools form an important part of the design stage in the building of a ship.

ACKNOWLEDGEMENTS

This work has been partially financed by the MCYT through project DPI2003-09745-C04-03.

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SIMULACIÓN DE PRUEBAS DE MAR

RESUMEN

En éste artículo, se simula el comportamiento de un buque en algunas de las pruebas de mar habituales, curva de evolución, pull-out, zig-zag, y prueba de espiral directa e inversa. Para la simulación se utiliza un modelo matemático no lineal completo con tres grados de libertad. Los coeficientes hidrodinámicos utilizados en el modelo matemático se habían obtenido a partir de un modelo físico a escala en el canal hidrodinámico. Los resultados obtenidos son satisfactorios, permitiendo proponer las herramientas de simulación de pruebas de mar como una parte importante del proceso de diseño previo a la construcción de un buque.

INTRODUCCIÓN

En este artículo se describen las pruebas de mar que se utilizan habitualmente para determinar las características de maniobra del buque. Estas pruebas permiten medir las características del comportamiento dinámico del buque, obtener una indicación de su estabilidad en línea recta, valorar la robustez y las limitaciones del sistema de control, y evaluar el comportamiento del buque en situaciones de emergencia.

Aunque las pruebas se desarrollan con el buque ya construido y en la mar, en el proceso de diseño se puede simular el comportamiento del buque mediante programas de simulación utilizando modelos matemáticos. En este artículo se presentan los resultados de la simulación de las pruebas de mar de un buque.

De acuerdo con las recomendaciones de la 14th ITTC (1975), las pruebas tienen que proporcionar a los armadores y a los astilleros información sobre las características de funcionamiento del buque. Estas deben abarcar las características de mantenimiento y cambio de rumbo y las maniobras de emergencia. Para determinar la eficacia del comportamiento del buque para el mantenimiento de rumbo las pruebas apropiadas propuestas son: prueba en espiral directa e inversa y maniobra de zig-zag con ángulos del timón pequeños. Para determinar la calidad del comportamiento en la maniobra de cambio de rumbo se recomiendan la maniobra de zig-zag, la prueba de evolución de 15º de timón y la maniobra de cambio del rumbo. Para determinar la capacidad del buque ante situaciones de emergencia, las pruebas de mar más convenientes propuestas son: prueba de evolución con el máximo timón y maniobra de parada de emergencia o "crash-stop".

La duración total de las pruebas de mar debe ser aceptable para los armadores y los astilleros.

METODOLOGÍA

Se simulan las pruebas de mar de un buque de la clase "Mariner", ampliamente utilizado en la literatura (Chiselett y Strom-Tejsen, 1965) utilizando el modelo matemático no lineal con 3 GDL:

$$\begin{bmatrix} m' - X'_{\dot{x}} & 0 & 0 \\ 0 & m' - Y'_{\dot{v}} & m'x'_G - Y'_{\dot{r}} \\ 0 & m'x'_G - N'_{\dot{v}} & I'_z - N'_{\dot{r}} \end{bmatrix} \begin{bmatrix} \dot{u}' \\ \dot{v}' \\ \dot{r}' \end{bmatrix} = \begin{bmatrix} X' \\ Y' \\ N' \end{bmatrix} \tag{1}$$

Las fuerzas X e Y y el momento hidrodinámico N se desarrollan utilizando el modelo de Abkowitz. (1964).

En el modelo de simulación, se incluyen las ecuaciones cinemáticas, resultando:

$$\mathbf{M}\,\dot{\mathbf{v}}' = \boldsymbol{\tau}' \tag{2}$$

$$\dot{\boldsymbol{\eta}} = \mathbf{J}(\boldsymbol{\eta})\mathbf{v}' \tag{3}$$

Como modelo del comportamiento del timón se utiliza el modelo simplificado sugerido por Van Amerongen (1982).

En primer lugar, se simula el comportamiento dinámico del timón. Se puede apreciar que necesita aproximadamente un tiempo de 10 s para pasar de la posición neutral de 0º al valor máximo (± 30º) y de 19 s para realizar el cambio máximo de -30º a 30º que es un resultado normal en este tipo de buques.

Se obtienen las curvas de evolución para distintos ángulos del timón, y se puede observar que el radio de giro disminuye a medida que aumenta el ángulo δ del timón.

Los resultados de la prueba de Zig-Zag 20º/20º son indicativos de la capacidad de maniobra del buque para el ángulo de timón especificado.

La prueba en espiral obtenida indica que el buque tiene un comportamiento estable en línea recta. La pendiente de la recta tangente a la curva nos permite determinar la ganancia de la aproximación lineal del modelo de Nomoto. El comportamiento estable del buque se observa también de los resultados de la maniobra de Pull-Out.

CONCLUSIONES

Aunque las pruebas de mar se desarrollan con el buque ya construido y en la mar, resulta conveniente simular el comportamiento dinámico del buque en la fase previa de diseño utilizando modelos matemáticos.

Se han simulado algunas de las pruebas de mar habituales utilizando un modelo matemático no lineal completo con tres grados de libertad. Los resultados de la simulación permiten medir las características del comportamiento dinámico del buque, obtener una indicación de su estabilidad en línea recta, valorar la robustez y las limitaciones del sistema de control, y evaluar el comportamiento del buque en situaciones de emergencia.

Los resultados obtenidos en la simulación de las pruebas de mar indican que las herramientas de simulación de pruebas de mar representan una parte importante del proceso de diseño previo a la construcción de un buque.

Journal of Maritime Research, Vol. I. No. 3, pp. 51-66, 2004

ISSN: 1697-4840

MODELING SHIP'S ROUTE BY THE ADAPTATION OF HOPFIELD -TANK TSP NEURAL ALGORITHM

Sanja Bauk y Nataša Kova

ABSTRACT

This paper considers determining the optimal linear ship's route by the application of the Hopfield-Tank neural network algorithm adaptation for solving well known traveling salesman problem (TSP). In the paper proposed mathematical approach to the Hopfield-Tank TSP neural algorithm realization is primarily based upon faster generating zero-one matrices of suboptimal solutions.

1. INTRODUCTION

It is known that the route planing is the beginning of all operations in marine shipping, particularly linear one. Since route of linear ship provides a cycle voyage, it is naturally compared with well-defined general traveling salesman problem (TSP) [1]. According to this problem, navigator has to complete a round trip of a set of ports, visiting each one only once in such a way as to minimize total sailing distance. This kind of problem is computationally very difficult and it is shown that the time to find a solution grows exponentially with number of visiting ports. The solution of the problem is in the *nutshell* and that is where the application of the artificial intelligence becomes interesting. Besides simulated annealing and genetic algorithms, Hopfield-Tank recurrent neural network application to the TSP is one of the most interesting methodologies. This solution may not be the best and the fastest obtained one, but undoubtedly gains insight to the marrow of the problem.

The remaining part of the paper is organized in the following manner:

(1) the second part is addressed to some basic remarks to the TSP formulation and chronology of its most important solutions;
(2) the third part describes TSP model adaptation to Hopfield recurrent neural network architecture;
(3) the fourth part considers the shortest sailing path between two distant ports on the Earth surface;
(4) the fifth part contains the original mathematical approach to the Hopfiel-Tank TSP neural algorithm implementation and the numerical results for TSP in the case of relatively large number of ports being arbitrary chosen, and finally
(5) the last one contains some conclusion remarks and further investigation directions.

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2. TSP OVERVIEW

The origins of the traveling salesman problem (TSP) are obscure. The mathematical problems related to it were treated firstly by the Irish mathematician William Rowan Hamilton and by British mathematician Thomas Penyngton Kirkman (1800's). The description of this early work of Hamilton and Kirkman can be found in [2]. The mathematician and economist Karl Menger publicized it among his colleagues in Vienna, in 1930's [3]. Later, the chronology of the most significant TSP solutions has been going as follows: Dantzing, Fulkerson and Johnson (1954) solved it for 49 nodes; Held and Karp (1971) for 64 nodes; Camerini, Fratta and Maffioli (1975) for 100 nodes; Grotschel (1977) for 120 nodes; Crowder and Padberg (1980) for 318 nodes; Padberg and Rinaldi (1987) for 532 nodes; Grotschel and Holland (1987) for 666 nodes; Padberg and Rinaldi during the same year for 2 392 nodes; Applegate, Bixby, Chvatal and Cook (1994) for 7 397 nodes, and four years later, for even 13 509 nodes, etc. In the recent years Applegate, Bixby, Chvatal and Cook (2001) have solved TSP for impressive number of 15 112 nodes. But nobody was able to come up with an algorithm for solving the traveling salesman problem (TSP) that does not show an exponential growth of run time with a growing number of nodes. There is a strong belief that there is no algorithm that will not show this behavior, but no one was able to prove it completely. But one was able to prove that the TSP is a kind of prototypical problem for a big class of nondeterministic polynomial (NP) time hardness problem and a lot of artificial intelligent methods have been developed in aim to solve it exactly or approximately. Hopfield (1986) has explored an innovative method to solve it by the electronic circuit that produces approximate solutions quite effectively. Later, Hopfield and Tank (1987) have improved this neural network based method for TSP implementation and its more efficiently solving.

Our intention here is the Hopfield-Tank TSP neural algorithm adaptation to the liner ship's routing problem, in a mathematical sense. But firstly, some remarks to the functional equivalence between Hopfield-Tank network energy function and TSP model are given. Then some elements of the shortest path estimation between a pair of ports on the Earth surface are examined, by the roles of sphere trigonometry. Finally, some remarks to the software realization of the Hopfield-Tank TSP neural algorithm are discussed. The results being obtained through the adequate example(s) are also presented, numerically and graphically.

3. FUNCTIONAL EQUIVALENCE BETWEEN HOPFIELD-TANK NEURAL NETWORK AND TSP MODEL

Neural networks are very important in many scientific disciplines in solving previously *unsolvable* problems, like in a way the TSP of larger dimensions is. Among many neural network schemes that have been proposed and investigated, the Hopfield-type neural network remains an important one due its applicability in solving associative memory, pattern recognition, and optimization problems, with ease of VLSI implementation [4]. The first neural algorithm for combinatorial optimization was the simulated annealing method.

In this algorithm one of the neurons is selected randomly and the state of the selected neuron is updated to reduce the energy of the network. Therefore the state transitions of the system must be operated serially though the network itself has parallel architecture. Hopfield and Tank used analog neurons and continuous dynamics for energy reduction. In this manner becomes possible to operate calculation in parallel. Although to simulate continuous dynamics with digital computers, many iterations are required before reaching low or minimum energy state [5].

Namely, the Hopfield-Tank neural network optimization algorithm is based on the fact that weights of the network are to be made so that the optimal solution is located in the lower energy area of the state space. In other words, the neural network optimization problem is based upon minimization of energy function given by (1):

$$E(x)=-\frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}x_i x_j + \sum_{i=1}^{N}\theta_i x_i \tag{1}$$

where x_i - state of the i-th neuron; θ_i - threshold of the i-th neuron and w_{ij} - weight of the connection from the j-th neuron to i-th neuron ($w_{ij} = w_{ji}$). A candidate of the solution is represented by one of the state vectors $x = (x_1, x_2, \ldots x_N)$. The energy function (1) consists of two parts, cost (2) and penalty (3):

$$E_c(x)=-\frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}^{(c)}x_i x_j + \sum_{i=1}^{N}\theta_i^{(c)} x_i \tag{2}$$

$$E_p(x)=-\frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}^{(p)}x_i x_j + \sum_{i=1}^{N}\theta_i^{(p)} x_i \tag{3}$$

Both of them, in addition, are to be reduced as much as possible, according to the aim of $E(x)$ minimization. The second one is to be reduced to zero in the optimal solution. TSP could be formulated in a following way: the shortest round tour, which covers all P nodes (here ports) salesman (here navigator) is to visit, has to be found. The problem of P nodes may be coded into P -by- P network. Each row of the network corresponds to a node and the ordinal position of the node in the tour is given by the node at the place outputting a high value (i.e. one), while rest are all at very low values (i.e. zero). The nodes of the network are unipolar sigmoidal activation units where ai-th unit has output $x_{ai}=1$, if, and only if, node a is visited i-th in the tour and output $x_{ai}=0$, if a is not visited i-th in the tour [6.7]. The distance between nodes a and b is denoted as d_{ab} and the energy function, that is its cost part, takes the form (4):

$$E_c(x)=\frac{D}{2}\sum_{a}\sum_{b\neq a}\sum_{i} d_{ab}x_{ai}\left(x_{b,i+1}+x_{b,i-1}\right) \tag{4}$$

where indexes are cyclic, that is $P+1=1$, $1-1=P$, and D is positive constant. Constrains that must be satisfied are: only one node can be visited at the same time; each node is visited only once and every node must be visited in the tour. These constrains could be formulated in the following way (5):

$$E_p(x)=\frac{A}{2}\sum_a\sum_i\sum_{j\neq i}x_{ai}x_{aj}+\frac{B}{2}\sum_i\sum_a\sum_{b\neq a}x_{ai}x_{bi}+\frac{C}{2}\left(\sum_a\sum_i x_{ai}-P\right)^2 \quad (5)$$

where A, B and C are positive coefficients. From the energy function weight matrix can be obtained (6):

$$w_{aibj}=-A\delta_{ab}(1-\delta ij)-B\delta_{ij}(1-\delta_{ab})-C-Dd_{ab}(\delta_{j,i+1}+\delta_{j,i-1}) \quad (6)$$

where $\delta i_1 i_2=1$, if $i_1=i_2$ and $\delta i_1 i_2=0$, if $i_1\neq i_2$. In accordance with original Hopfield and Tank adaptation [8] coefficients A, B, C and D take values 500, 500, 200 and 500, respectively. The neural network with the above weights has a tendency to give solutions that do not cover all P nodes (here ports). Kakeya [5] suggested certain improvements by introducing new parameters r and α into the original Hopfield and Tank recurrent neural network optimization model. Penalty term of energy function $(C/2)(\Sigma_a \Sigma_i x_{ai} -P)^2$ was replaced by $(C/2)(\Sigma_a \Sigma_i x_{ai} - \alpha P)^2$ where $\alpha>1$, in order to increase firing rate of the neuron. While the weight vector takes new form $w^{(c)}=D(r-d_{ab})(\delta_{j,i+1}+\delta_{j,i-1})$, where $r > 0$. By allowing the network to run under its dynamics, the energy minimum is to be reached. This energy minimum corresponds to the solution of the problem. What is meant here under solution is to be qualified. Hopfield-Tank network is not guaranty to produce the shortest round tour, but only those that are close to the shortest one. The TSP requires large number of iterations because number of possible tours is equal to $(P-1)!$ when the problem is asymmetrical and $(P-1)!/2$ when it is symmetrical, that is when $d_{ab}=d_{ba}$. Besides subcycles are to be dismissed because the continual round tour has to be found as the optimal one. Thus, the computational complexity of the problem, particularly when the number of visiting ports is large, does not vanish so simply [8,9]. In aim to find the shortest linear ship's route, in the next sections we shall firstly give some remarks to the manner(s) of estimating the shortest path between each pair in the given set of ports on the Earth sphere surface. Then, we shall realize the software adaptation of the Hopfield-Tank TSP neural algorithm to the problem of the optimal linear ship's route modeling.

4. THE SHORTEST PATH ON THE EARTH BETWEEN EACH PAIR IN THE GIVEN SET OF PORTS

The navigation between two distant points (here ports) on the Earth is possibly done in three ways: orthodrome navigation, loxodrome navigation and combined navigation. The shortest way from departure to arrival position is a shorter section of the great circle arc, that is orthodrome. Such navigation is difficult to achieve since the orthodrome intersects the meridians at different angles, so it would require constant, precisely defined change of course. In the case when course is constant, that is easily achievable in practice, navigator follows a curve asymptotically approaching nearer pole. Such a curve on the surface of the Earth is called a loxodrome. In the case of combined navigation, a standard orthodrome is replaced by two orthodrome tangents to the boundary parallel and a loxodrome between them. The dangerous areas that could be reached by following strictly the orthodrome navigation are avoided by applying the technique of combined navigation [10].

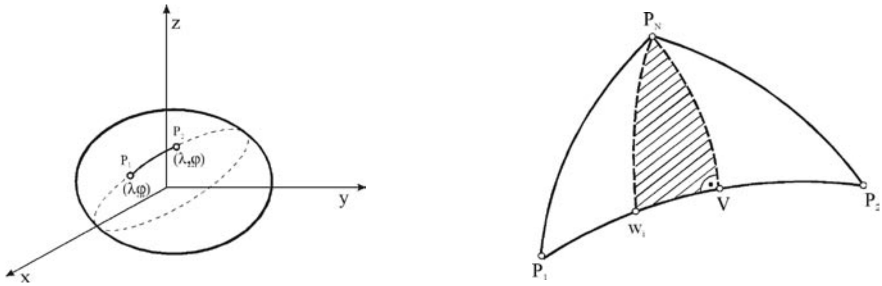

Figure 1. Orthodrome and waypoint sphere triangle

4.1. The orthodrome approximation by the loxodrome

The orthodrome is the shortest path between two distant points on the surface of the Earth (figure 1.a). Therefore, the aim of orthodrome navigation is the shortest path and the least traveling time, resulting invariably in cost effectiveness. Since strict orthodrome navigation is difficult to achieve in practice, it is divided into a finite number of waypoints between which loxodrome navigation is applied. Thus certain number of shorter loxodromes approximates the orthodrome, where the common positions are determined waypoints. For the purpose of waypoints coordinates calculation the right angle sphere triangle whose vertices are: the pole closer to the orthodrome vertex, the orthodrome vertex and the waypoint, is taken into consideration (figure 1.b). The labels of the sphere triangle in figure are: P_N - North Pole; P_1 -departure port; P_2- port of arrival; w_i -i-th waypoint ($i=\overline{1,N}$, where N is number of waypoints) and V - the orthodrome vertex. The waypoints (w_i) may be selected symmetrically to the orthodrome vertex, or by orthodrome division into finite number of equal sections. The orthodrome division is arbitrary and may be 1,2,3,... degrees, depending on the orthodrome length. We suggest the second approach, since it is much more appropriate to computation. Upon the determination of waypoints number through adequate simulation process [10,11], waypoints geographical coordinates, the appropriate loxodrome courses and distances can be calculated by application of the adequate sphere trigonometry rules. The difference (d) between the sum of the loxodrome distances and orthodrome one, expressed in nautical miles, is to be reduced as much as possible (7):

$$min\, d = \sum_{j=1}^{n} d_{lox}(j) - d_{ort} \tag{7}$$

where d_{lox} is loxodrome distance for $j=\overline{1,N}$, ($n=N+1$, N is number of waypoints) and d_{ort} is orthodrome distance between endpoints. Through the process of waypoints number optimization this could be achieved [10]. In case of orthodrome intersection with Equator or Greenwich (figure 2), first of all points of intersection are to be determined, then on each orthodrome segment, former meant procedure of waypoints number optimization is to be done.

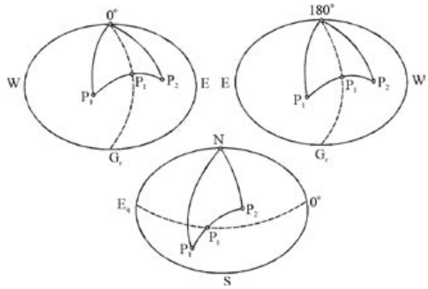

Figure 2. The orthodrome and its intersection with Greenwich and Equator

In the paper has been assumed that the distances between each pair of ports are orthodrome, that is absolutely the shortest ones, but in the practical navigation, they should be replaced with the optimal number of the loxodrome, with the appropriate loxodrome courses. The deviations are also to be involved in aim to avoid obstacles and to enable the eventually predicted route tracking.

Now, let us introduce some mathematical adaptations of the Hopfield-Tank TSP neural algorithm applied to the process of linear ship's route modeling. It must be pointed out that through the detailed survey of ship routing and optimization problems given in [12] by Christiansen, Fagerholt and Ronen (2003), becomes obvious that nobody has treated linear ship's TSP routing problem and its proper modifications by means of neural networks. Namely, this problem has been mostly treated as integer that is binary programming one. Although this approach based upon neural networks is in a way more sophisticates, since it reduces number of boundaries and enables easier subcycles dismissing.

5. THE MATHEMATICAL APPROACH TO THE HOPFIELD-TANK TSP NEURAL ALGORITHM

The traveling salesman problem (TSP) is a classic example of a nondeterministic polynomial (*NP) complete* problem. A problem is assigned to the NP class if it is verifiable in polynomial time by a nondeterministic *turing machine*. While, a nondeterministic *turing machine* is a "parallel" *turing machine* which can take many computational paths simultaneously, with the restriction that the parallel *turing machines* cannot communicate. A problem is said to be NP hard if an algorithm for solving it can be translated into one for solving any other NP problem. It is much easier to show that a problem is NP than to show that it is NP hard. A problem which is both NP and NP hard is called a NP complete problem. Essentially, the only way known to solve NP complete problem, is to compute the costs (here distances) of all tours [13].

There are fiew assumptions in this paper:

1. P represents the number of nodes, and mark the nodes with numbers 1,2,3,... P;
2. We assume that the distances between P nodes are specified in a matrix of distances that specifies the non-negative orthodrome distances between any pair of ports and this matrix is symmetrical: for each pair $(i,j) \in PxP$ distance between node i and node

j is same as distance between node *j* and node *i*. All entries in the matrix have some distance and the distance on the main diagonal are set to zero.

3. Each port must be visited exactly once and no port can be skipped.

The tour is represented as 0 - 1 matrix with *P* rows and *P* columns. If number 1 is in matrix on positin *(i,j)*, that means that the *i*-th node is on the *j*-th position in the tour. There is a variable named *minControl* representing a distance that is assossiated to the tour *1,2,3K,P* which is propagated as the optimal one, in the first run. This is a first tour that is examinated with the algorithm and it is represented with matrix with ones on the main diagonal. After that, algorithm find a next tour, compute the distance, and compare it with a *minControl* that is find so far. If a new generated tour has a distance *d,* and *d* is a smaller distance then *minControl*, we will introduce *d* as a best tour and refresh *minControl* with this computed minimum distance. This proccess continues for all possible tours. If there are *P* ports, then there are *P!* possible tours, so the number of tours to be checked grows very large and very quickly. Exploring all tours is called a "*brute force*" approach or exhaustive search. This algorithm generate a 0 - 1 matrix so that every row and every column has exactly one 1, and every generated matrix is treated as a subomptimal solution. This aproach is implemented within the next pseudo-code:

```
const
  MaxPortNumber = 9;
  D = 500;
  C = 200;
Type
  PortMatrix = array [1..MaxPortNumber, 1..MaxPortNumber] of integer;
  PortMatrixReal = array [1..MaxPortNumber, 1..MaxPortNumber] of real;
  order = array [1..MaxPortNumber] of integer;
var
  matrix : PortMatrix;
  distance : PortMatrixReal;
  tour : order;
  k, m, P: integer;
  s, min, Ec, w: real;
```

{mark that in the algorithm s represents a distance of courent tour, previously in the work labeld as d}

```
procedure Visit (var matrix : PortMatrix; row, col : integer);
var i, j : integer;
        help: order; {generated tour derived from 0-1 matrix}
begin
   if done one solution then
      begin
        for i := 1 to P do
```

```
            for j := 1 to P do
                if matrix[i,j]=1 then
                    help[i] := j;
        s := 0; {compute the curent cost}
        for i := 1 to P-1 do
            s := s + distance[help[i],help[i+1]];
        s := s + distance[help[1],help[n]];
        if s < minControl then
          begin
            min := s;
            best := help;
          end;
      end
    else
  repeat
      clear all colums after used column
      if Put (row, col) then
        begin
   matrix [row, col] := 1;
   Put (1, next column in matrix);
        end;
      go to next row in matrix
  until last row;
  end;
```

Put(i,j) is a function implemented to check if 1 can be in the 0 – 1 matrix on the *(i,j)* position. *Help* array is formed only for better understanding of the algorithm, since the total distance of tour can be computed from the *matrix*. In the main program we must specify *P* and input the distances into distance matrix. After that program will call the esential procedure *Visit* wich will find the best tour. The exponential search space can be seen in the figures 3, 4 and 5, for ten, twelve and fourteen nodes with linear and semilogarithm coordinate axis, respectively.

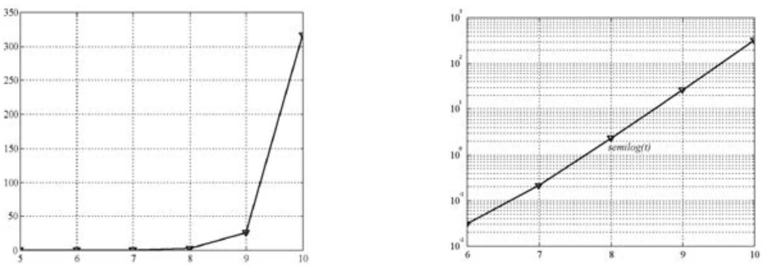

Figure 3. The exponential search space in the case of ten nodes

Lets remark that the 0 - 1 matrix represents a permutation of ports. It is not important which port will be the first one in the optimal tour, since we can rearrange the optimal tour to start from the desired one. If *P=5* and the optimal tour is e.g. 1 5 3 2 4, but if it is necessary to start from node 3, the rearranged tour is 3 2 4 1 5. Here, we will use only those tours that start from node 1. The goal is to find the sequence of ports that starts and ends with city 1 such that the overall passed distance of the tour is minimized. In this case, for *P* ports, it is enough to examine *(P-1)!* suboptimal 0-1 matrices. Pseudo-cod for this improvement is same as the previous one because this is the case where the program generates all permutations for ports *2,3,4,…,P* and puts the port 1 on the first position in each permutation.

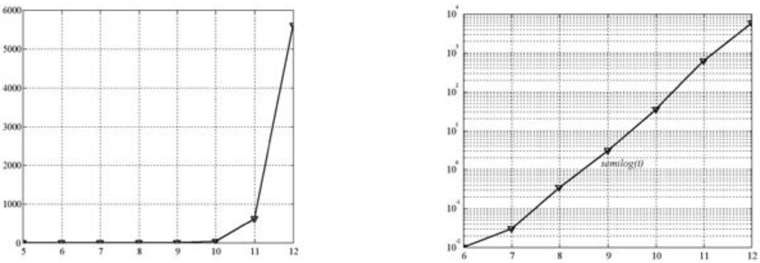

Figure 4. The exponential search space in the case of twelve nodes

Assume that we have to investigate problem of *P=5* ports, and that the total distance d_{total} is computed for the tour 1 2 3 4 5. In the symmetrical TSP case all tours with same adjacency of nodes in tour have the same distance d_{total} , so it is not necessary to compute the distance of the tour 1 5 4 3 2, since we know that the total distance of this tour is also d_{total} . This leads to improving the search space, since only *(P-1)!/2* permutations have to be examined. It is convenient to generate all permutations in lexicographical order.

There is still no algorithm, which can, in general, find the optimal solution for the TSP without suffering from exponentially growing complexity. Further researchers must examine efficient pruning methods for search tree, some kind of branch and bound method, or try to use fast algorithms for generating lexicographical permutations to cut a running time for TSP algorithm. If it is not so important to obtain a true minimal length tour, it is possible to investigate a different heuristic methods which will lead to tour that is near to the optimal one.

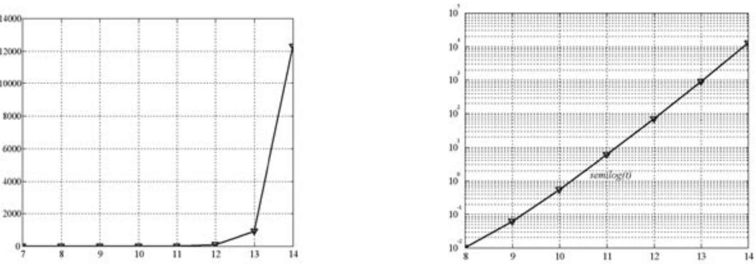

Figure 5. The exponential search space in the case of fourteen nodes

6. THE NUMERICAL EXAMPLES AND SIMULATION RESULTS

The problem being considered here is to find the exact shortest linear ship's round tour visiting fourteen arbitrary chosen ports on the Earth north-east hemisphere in accordance with previously proposed mathematical adaptation of Hopfield-Tank algorithm to the TSP. The observed ports geographical coordinates, that is their latitudes and longitudes are given in degrees and minutes in table 1.

No.	Port	Latitude φ (° ′ S)	Longitude λ (° ′ E)
1.	P_1	45° 20′	14° 20′
2.	P_2	44° 05′	15° 05′
3.	P_3	43° 25′	16° 20′
4.	P_4	42° 45′	18° 05′
5.	P_5	42° 05′	19° 10′
6.	P_6	41° 10′	16° 50′
7.	P_7	42° 35′	14° 03′
8.	P_8	43° 35′	13° 20′
9.	P_9	43° 53′	12° 55′
10.	P_{10}	44° 03′	12° 45′
11.	P_{11}	43° 40′	15° 58′
12.	P_{12}	43° 30′	16° 18′
13.	P_{13}	41° 15′	16° 35′
14.	P_{14}	42° 00′	14° 58′

Table 1. The observed ports geographical coordinates

The distances between each pair of ports can be calculated as the orthodrome one by means of the sphere trigonometry rules, that is by the equation (8):

$$d_{ort}(i,j) = \arccos\left(\sin\varphi_i\varphi_j + \cos\varphi_i\varphi_j \cos\Delta\lambda_{i,j}\right) \text{ for } (i,j)\in P \qquad \textbf{(8)}$$

where φ_i and φ_j are endpoints, i.e. endports, latitudes and $\Delta\lambda_{i,j}$ is an absolute value of the difference between endports longitudes. The problem has been treated as a symmetrical one. Namely, the distances between ports are the orthodrome in both directions while the initial orthodrome courses are different for the opposite directions. The matrix representation of the orthodrome distances between each pair in given set of ports is presented in table 2. The distances are given in nautical miles [Nm] and it is clear that it is not possible to sail from a certain port to itself, that is $d(i,j)=\infty$, if $i=j$. Since it is not possible to represent ∞ in a proper way within the algorithm, this has been achieved by replacing ∞ with zero values. Finally, by the application of in the paper proposed mathematical adaptation of the Hopfield-Tank neural algorithm, the exact optimal TSP solutions, for the cases when *1,2,…,14* ports are to be visit, have been found and given in table 3. It is to be pointed out that the number of possible combinations in the last case is even *(14-1)/2=3113510400.*

The obtained results have been presented through the optimal round tour, its total length and required time for its determination and given in table 3. While in the figure 6 are given the Hopfield-Tank neural network outputs in the case of optimal solution for fourteen ports, as well as, the scheme of linear ship's optimal route for the given ports arrangement. It is to be mentioned that all results are obtained by running executable Free Pascal programs on a 600 MHz Pentium 2 machine with 192 MB of RAM operating under

Windows 2000 system. By the obtained optimal TSP results it becomes possible to calculate Hopfield-Tank recurrent neural network energy minimum and related weight vector (table 4). This is of great importance since it allows the Hopfield-Tank neural network usage in finding the approximately optimal solutions for the similar distances between each pair of ports to those in the given example. Thus, we are in position to use this neural network for solving almost the same problem, with satisfying accuracy, when deviations and other corrections are involved in the calculations of the distances between ports.

	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}
P_1	∞	81.53	143.45	223.97	286.20	272.79	165.45	133.39	105.97	102.41	122.00	138.56	263.94	201.87
P_2	81.53	∞	67.34	153.26	215.40	191.28	100.66	81.46	94.30	100.61	45.65	63.25	182.41	125.10
P_3	143.45	67.34	∞	86.49	148.25	136.81	111.97	130.94	150.94	159.91	21.89	5.20	130.47	104.18
P_4	223.97	153.26	86.49	∞	62.47	110.15	178.20	213.76	235.52	245.18	107.66	90.12	112.12	145.27
P_5	286.20	215.40	148.25	62.47	∞	118.21	228.88	271.91	294.72	304.90	169.75	152.15	126.11	187.19
P_6	272.79	191.28	136.81	110.15	118.21	∞	150.61	212.31	237.77	249.82	154.83	141.98	12.34	97.55
P_7	165.45	100.66	111.97	178.20	228.88	150.61	∞	67.72	92.40	104.70	106.15	112.95	138.52	53.66
P_8	133.39	81.46	130.94	213.76	271.91	212.31	67.72	∞	25.50	37.70	114.47	129.11	200.77	119.14
P_9	105.97	94.30	150.94	235.52	294.72	237.77	92.40	25.50	∞	12.32	132.76	148.56	226.26	144.47
P_{10}	102.41	100.61	159.91	245.18	304.90	249.82	104.70	37.70	12.32	∞	141.04	157.28	238.36	156.77
P_{11}	122.00	45.65	21.89	107.66	169.75	154.83	106.15	114.47	132.76	141.04	∞	17.60	147.54	109.24
P_{12}	138.56	63.25	5.20	90.12	152.15	141.98	112.95	129.11	148.56	157.28	17.60	∞	135.58	107.47
P_{13}	263.94	182.41	130.47	112.12	126.11	12.34	138.52	200.77	226.26	238.36	147.54	135.58	∞	85.33
P_{14}	201.87	125.10	104.18	145.27	187.19	97.55	53.66	119.14	144.47	156.77	109.24	107.47	85.33	∞

Table 2. The distances between ports – symmetrical problem

Number of ports	The optimal tour	Total distance [Nm]	Required time [sec]
1	-	-	-
2	1-2	81.533	0.000
3	1-2-3	148.875	0.000
4	1-4-3-2	459.335	0.000
5	1-2-3-5-4	583.572	0.000
6	1-2-6-5-4-3	683.448	0.010
7	1-2-3-4-5-6-7	732.117	0.000
8	1-2-3-4-5-6-7-8	767.781	0.010
9	1-2-3-4-5-6-7-8-9	765.859	0.060
10	1-2-3-4-5-6-7-8-9-10	774.625	0.540
11	1-2-11-3-4-5-6-7-8-9-10	774.833	5.880
12	1-2-11-12-3-4-5-6-7-8-9-10	775.750	70.620
13	1-2-11-12-3-4-5-6-13-7-8-9-10	776.010	896.130
14	**1-2-11-12-3-4-5-6-13-14-7-8-9-10**	**776.485**	**12 289.430**

Table 3. The optimal round tours and required time for their determination

Number of ports		14	
Energy minimum		-194121.25	
Weight vector			
w [1,2]	-40966.50	w [6,13]	-6371.50
w [2,11]	-23028.50	w [13,14]	-42867.50
w [11,12]	-9002.00	w [14,7]	-27034.00
w [12,3]	-2803.00	w [7,8]	-34061.00
w [3,4]	-43445.00	w [8,9]	-12950.50
w [4,5]	-31435.50	w [9,10]	-6360.50
w [5,6]	-59308.50	w [10,1]	-51408.50

Table 4. The Hopfield-Tank network energy minimum and the optimal weight vector in the case of fourteen ports

On the basis of the proposed method for solving TSP we are in position to solve successfully linear ship's routing problem. But it must be pointed out that it is still only one of many much more complex problems that must be solved previously, as well. Among these problems the most important are scheduling problems, supply and demand requirements, the optimal speed and weather routing, the optimal loading (unloading) problems, etc. Solving some of these problems separately or in combination undoubtedly requires the appropriate modifications of Hopfield-Tank TSP model. These modifications might be realized by adding for example some benefit, risk or cost coefficients to the route legs' distances in aim to emphasize how a certain route legline is convenient or not. After the proper modifications have been realized, it can be possible to apply here proposed TSP method, in the same or very similar manner, at the final stage of solving real, much more complex linear shipping problems.

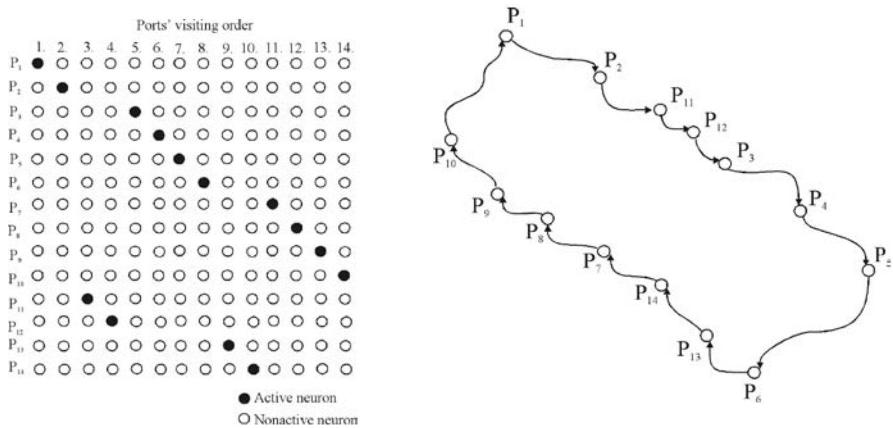

Figure 6. The TSP optimal solution in the case of fourteen ports arbitrary chosen on the Earth north-east hemisphere

CONCLUSIONS

The adaptation of the Hopfield-Tank TSP neural network algorithm to the linear ship's route modeling problem, in the mathematical sense, has been examined in some details. The main differences between classical and here presented TSP are that nodes of the network are given in sphere coordinates (by longitude and latitude) and that distances between them are not linear but nonlinear (orthodrome). The numerical results for the optimal linear ship's round tour, the energy minimum of the Hopfield-Tank neural network and the appropriate weight vector have been given for the case of enough large number of arbitrary chosen ports on the Earth north-east hemisphere. Once trained Hopfield-Tank network for a certain number of nodes, can be used for successful determination of the nearest solution to the optimal one or those that are very near to the optimal one for distances between ports being changed for the values of deviation or some other route corrections.

Although this approach is rather theoretical than practical in nature, it could be undoubtedly useful one in some kind of combination with the restrictions like demand between port pairs, weather and speed conditions are, even in the practical linear ship's route modeling. Namely, some route legs might have a certain priority over the others from some reasons. By adding to the each route legline some benefit, risk or cost coefficients, in aim to emphasize how they are convenient or not, it becomes possible to modify properly the proposed ship's routing model based upon Hopfield-Tank TSP neural algorithm.

It must be concluded, as well, that there is yet no algorithm capable of finding the optimal solution for the TSP without suffering from exponentially growing complexity. Thus, the further research work in this field, in general, independently of linear ship's route modeling, should be oriented toward efficient pruning methods for search tree, that is to some kind of branch and bound method, or to the usage of fast algorithms for generating lexicographical permutations to cut a running time for TSP algorithm.

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LA FORMACIÓN DE LA TRAYECTORIA DEL BUQUE A TRAVÉS DE LA ADAPTACION DEL HOPFIELD - TANK TSP ALGORITMO NEURAL

RESUMEN

En este trabajo se revisa el modo de la fijación de la trayectoria optimal del buque de la línea a través de la aplicación del Hopfield - Tank TSP algoritmo neural, ajustado a la solución del bien conocido problema del viajante de negocios (TSP). La proposición presentada en el trabajo consiste en el acceso matemático a la realización Hopfield - Tank TSP algoritmo neural. Esta principalmente basada en el modo más rápido de como engendrar zero-uno matrices de las soluciones sub-optimales.

Las palabras claves: formación de la trayectoria del buque,TSP - problema del viajante de negocios, Hopfield - Tank TSP algoritmo neural

INTRODUCCIÓN

Como es sabido, con el planeamineto de la trayectoria del buque comienzan todas las operaciones en la navegación marítima, lo que ale especialmente por la navegación de la línea. Como la trayctoria del buque de la línea es circular, se ofrece la comparación con bien estructuradoy común problema del viajante commercial - TSP (Hua - An Lu, 2002). Según este problema, el navegador tiene que completar la vuelta sobre un grupo de los puertos, visitando cada puerto exactamente una vez para disminuir la trayctoria superada. Este tipo del problema se muestra como muy complicado desde punto de la vista del cálculo. Se mostró de que el tiempo para la búsqueda de la solución optimal va creciendo con el crecimiento del número de los puertos visitados. La solución del problema se encuntra escondida; se trata de la solución donde se viene a la interesante aplicación de la inteligencia arteficial. Además de la colada simulada ("simulated annealing") y los algoritmos genéticos, la aplicación de la red Hopfield - Tank recurrente y neural en la solución del problema del viajante de negocios, una es de las metodologias más interesantes. La solución de este tipo no tiene que ser la más optima i no se atraviesa, necesariamente, en el tiempo más corto, pero con certeza penetra en la esencia del problema.

METODOLOGÍA: EL HOPFIELD - TANK TSP ALGORITMO NEURAL

Este trabajo contiene un acceso matemático a la implicación del Hopfield - Tank TSP algoritmo neural y "brute force" búsqueda en hallar de la solución TSP optima entre todas las soluciones sub- optimales posibles.

De acuerdo con Hopfield - Tank neural red para la optimización, TSP de P nudos (en este caso: puerto) puede ser codeada con la red PxP, quiere decir red de las unidades unipolares, sigmoidales y activantes, en la que cada unidad tiene salida uno si el puerto fue visitado, en el contrario tiene salida zero. Las redes corresponden a los puertos, mientras las columnas corresponden al orden de la visita. Cada línea z cada columna tienen que tener exactamente un neutrón que en la salida da uno, en el marco del cada solución sub - optimal u optimal. La solución optimal coresponde al minimo energético de la red Hopfield - Tank.

En el trabajo se presenta la realisación del engendramiento uno - zero más rápido de la matriz para las soluciones sub optimales. Mientras la técnica "brute force" esta aprovechada en la búsqueda de la optimal, quiere decir exacta TSP solución entre las soluciones posibles sub - optimales.

El método aprovechado esta testificado en el ejemplo numérico correspondente de los catorce puertos en el hemisferio nordeste y brinda una solución optimal del TSP en en plazo relativamente breve.

CONCLUSIONES

El ajustaje del Hopfield - Tank TSP algoritmo neural al problema de la formación de la trayectoria del buque de línea esta bien tratado e investigado en el sentido matemático. Las diferencias principales entre el problema TSP clasico y aquí presentado consiste en el hecho de que los nudos de la red son dados en las coordenadas de la esfera (longitudines y latitudines), así como en el hecho que las distancias recorridas entre ellas no son líneares, sino alíneares (ortodromas). Se presentan los resultados matemáticos para la trayectoria optimal del buque de la línea, el mínimo energético y el vector del peso correspondente para el caso del número suficiente grande de los puertos casualmente eligidos en el hemisferio nordeste. Una vez entrenada, la red Hofield - Tank para un número determinado de los nudos puede ser aprovechada con éxito para la destinación de la solución más cercana al mejor o aquellas soluciones que se encuentran cerca del óptimo para las distancias entre los puertos aplicadas para los datos de las virajes o otros cambios de la trayectoria.

Aunque se trata se un acceso en su naturaleza más teórico que práctico, este podria ser aprovechado, sin duda, en una especie de la combinación con las limitaciones como la búsqueda entre los puertos, limitaciones de tiempo i de la velocidad, incluso en la formación de la trayectoria del buque de línea. Es decir, algunos de los segmentos de la traectoria bueden ser de preferidas a los otros, por alguna razón. Si se al cada segmento de la trayectoria añade alguno *benefit*, *risk* ya que *cost* coeficiente, para que se ponga de relieve su conveniencia o inconveniencia, se puede, en modo apropiado, modificar el modelo de la trayectoria del buque basada en el Hopfield - Tank TSP algoritmo neural.

Tambien, se impone la conclusión como todavía no hay algoritmo para el hallazgode la solución del TSP sine crecimiento exponente de la complejidad del cálculo. por esta razón, la investigación siguiente de este campo, en común, independiente de la formación de la trayectoria del buque de línea, tendria que dirigirse a los mètodos de como reducir los árboles de la búsqueda loq signifia alguna especies del algoritmo de la ramificación y limitación, o sea el aprovechamiento de los algoritmos rápidos acortando, de este modo, el tiempo gastado para la solución de TSP.

Journal of Maritime Research, Vol. I. No. 3, pp. 67-84, 2004

ISSN: 1697-4840

REGULAR SHIPPING LINES: COLLUSION OR COMPETITION?
THE TRAFFIC BETWEEN THE CANARY ISLANDS AND THE SPANISH PENINSULA

Carlos Perez-Labajos y Beatriz Blanco

ABSTRACT

The shipping companies which operate regular lines are allowed to reach legal agreements aimed at making a rational use of their resources. It is common, therefore, for shipping companies to form 'fleet conferences' on a regular line, if this allows them to optimise their activity on it. This paper addresses the real problem of the rationalisation of the sea transport services between The Canary Islands and The Peninsula. Can these services be optimised through agreements? In order to find answers of a qualitative nature, the existing resources are analysed. Three models which are alternatives to the present situation are developed by means of perfection heuristics, taking into account both the most suitable itineraries and the composition of the fleet in keeping with the real transport needs. The comparison of these results confirms that the current model is inefficient and invites both the shipping companies and the users of this form of transport to reflect upon the need to initiate a debate on the joint use of resources.

Key words: Marine Policy of Alliances, Policy agreement, Joint operation

1. INTRODUCTION

The shipping companies which operate regularly between The Canary Islands and The Peninsula monopolise part of the so-called 'national coastal trade sea traffic' [1].

For the Canary Islands, the strategic importance of such regular lines is great, since they form the main channels of freight transport to and from the peninsula. All of the cargo transported is unitised, so all of the shipping companies operating on them use container ships or RoRo (Roll on Roll off) systems.

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Historically, this traffic has been reserved for ships with Spanish flags, so that the sub-sector was completely closed to foreign competition. Perhaps for this reason, few Spanish shipowners foresaw the liberalisation of the coasting trade, even though a number of events pointed towards it. It was felt that the liberating dynamics would only affect international traffic [2].

Those who were most convinced that the coasting trade was 'a different matter' thought, in keeping with the community doctrine, that this was a domestic matter and should thus be governed in the internal context of each national territory.

But the liberalisation of the coasting trade was only a matter of time. On June 23rd, 1992, the Council of the EEC approved the text of the Act of Liberalisation of the coasting trade by a qualified majority and with the votes against of Great Britain, Denmark and Ireland.. Hence, on December 7 of that same year, The EEC published the Act by virtue of which the principle of the free provision of sea transport services within the member states was applied. The Act contemplated 5 stages in the liberalisation. The first began on January 1st, 1993 and the last came into effect on January 1st, 1999, the year in which all the coasting trade traffic in the EEC was liberalised, all cargo reserves disappearing [3].

Faced with this new scenario, what did the shipping companies do and how did the Spanish shipping sector respond to the new challenge?

Between 1997 and 1999 there was a rapid growth in the sea transport capacities offered, well above the amount of demand, both measured in Tm x miles (Tonnes transported times miles covered).

In the period analysed (1997-2001) a substantial growth was observed in the capacity of the fleet on offer, both in the form of container ships and RoRo ships. The technical file on the average craft in those years is shown in Table 1.

Table 1: Evolution of the average craft in traffic between The Canary Islands and the Peninsula

Characteristics average craft	1997	1998	1999	2000
Gross tonnage (GT)	6.550	7.038	8.420	9.007
Deadweight	7.112	8.003	9.107	9.692
Container ships (TEUS)	480	548	583	632
Ro-Ro (Linear metres)	1.333	1.333	1.830	1.723

Elaborated by authors

This explains in part the high degree of non-occupation of the fleet during this period. In 1999, the total occupation of the fleet was below 40%. However, given the asymmetry of the traffic, the results are very different for the up-flow (cargoes from The Canary Islands to the Peninsula) and for the down-flow (cargoes Peninsula to The Canary Islands), as can be observed in Table 2.

Table 2: Occupation of fleet in regular sea traffic between Canary Islands and Peninsula

Traffic	% occupation of fleet			
	1997	1998	1999	2000
Península-Canaries	84,0%	71,2%	60,8%	75,3%
Canaries-Península	34,1%	28,5%	23,2%	40,4%
Total	57,2%	47,7%	39,9%	54,6%

Elaborated by authors

It would seem that the outlook for the future along with the good economic situation of those years led the Spanish shipowners to the conviction that it was a good time to invest in new and/or second-hand ships of greater capacity. In the year 2000, just after the liberalisation, the companies focused again on the profitability of the lines. The elimination of the excess of offer would allow an important, though insufficient, recovery of the sector, which now finds itself in a situation of strong competition and a certain degree of atomisation.

In this context, we believe that a change in the approach of the companies that operate in this sector would be beneficial both for themselves and their users (User Board). We understand that the 'ordering' of this traffic requires a series of agreements and actions aimed mainly at rationalising the resources and defining the type of craft most suitable for each operation [4].. The first step is to create consortiums [5] in order to make a joint use of the crafts of the different companies [6,7, 8]. The so-called fleet conferences are common practice among regular line operators [9]. Secondly, the renovation of the fleet should be made by substituting the old units with crafts which are suitably adapted to the requirements of the traffic [10]. This should be a gradual process allowing the old units to be renewed by larger ones, specially designed for each kind of traffic, with advanced technology, smaller crews and better operative resources for handling merchandise.

We understand that the combination of such actions would allow the appearance of scale economies. This would mean an increase in the size of the crafts and a reduction in the number of ports, with modifications in itineraries and frequencies [11,12, 13, 14].

Moreover, substantial savings could be achieved leading to both an improvement in the economic results of the shipping companies and a reduction in their fares (negotiated with the User's Board). In short, the result would be a greater efficiency in the sector and an improvement in its competitiveness which would, in turn, allow it to hold its own in the face of increasing international competition.

The main aim of the present work is to establish alternatives to the real sea freight transport situation on regular lines between The Canary Islands and the Peninsula, in order to minimise or reduce transport costs by means of different assignations of fleets and itineraries.

To this end, we shall first analyse the existing resources. Next, we shall estimate the costs of the real situation and formalise alternative models taking into account the most suitable itineraries and the composition of the fleet in keeping with the real needs.

2. METHODOLOGY

Assuming the existence of a policy of alliances, the shipping companies could jointly exploit their resources, determining the types and number of crafts which would allow the routes, itineraries and number of crafts to be determined on the basis of the services (demand). In this context, the idea would be to solve the twofold problem of the optimisation of routes and the composition of a fleet in accordance with the real needs.

There are many algorithms which can resolve both accurately and approximately the problem of the design of vehicle routes in the fields of transport and delivery. The exact methods [15] provide solutions which are optimal but which are difficult to put into practice in certain real situations. For this reason, perhaps, the approximate methods have come to be more widely used in recent years. Heuristic methods, in particular, have been the subject of much of the research in the field [16].

According to Fagerholt [17], the basic problem of the shipping line crafts is similar to that of the design of multitrip vehicle routing design (MVRD). The standard route design problem, known as the Vehicle Routing Problem (VRP), has been dealt with extensively in the literature. Laporte and Osman [18] present 500 bibliographical references on the subject. The VRP can be described as follows: from a set of known demand nodes and of vehicles of a known capacity, determine the delivery routes, from a central depot, which will minimise the total distance covered and the costs [19].

MVRD is studied by Taillard and others [20] and by Brandao and Mercer [21], and these latter authors later designed heuristic taboo searches to solve the problem [22].

The researchers have paid less attention to the problem of determining the most efficient composition of a fleet when it comes to establishing optimal routes. This is somewhat surprising in the sea transport business, where the costs of capital make up some of the most substantial layouts.

Etezadi and Beasley [23] distinguish between the problems of the size of the vehicle fleets (number) and their composition (type). The pioneering work of Dantzig and others [24, 25] addresses a similar problem area though with only one type of vehicle whose number is to be minimised. Ball and others [26] study the problem of deciding the size of a fleet of vehicles, both self-owned and hired, under the option of a common carrier. The authors determine which journeys should be served by the self-owned fleet and which by the common carrier. Bodín and others [27] use a heuristic approach to address the problem of the size of the fleet and the itineraries of each vehicle. This method is an extension of the well-known VRP savings algorithm [28]. Addressing the problem of fleet size Desrochers and Verhoog [29] also use a savings heuristic, in this case based on a successive fusion of routes. However, the references indicated do not include the possibility of multiple routes characteristic of MVRD. Murotsu and Taguchi [30] consider the problem of deciding the optimal composition of the fleet. They determine the craft types, represented by the load capacity and the speed of service, and the number of each type.

However, they only consider the transport between two ports, one loading port and the other the unloading port.

Fagerholt proposes the same generic objective as us: to reduce transport costs. He also addresses the problem of optimal fleet size and the optimal routes in the real context of regular line sea traffic between Norway, Europe and the United Status. The algorithm he formalises can be considered as an MVRD since it determines the weekly routes of the crafts on the line. It undoubtedly constitutes a work which is close to reality in its conception. However, it does not take into account the composition of the fleet, since it only uses one type of craft.

As outlined in the introduction, we believe that the type of craft is crucial to the real problem that we aim to address in the present work. The crafts must adapt to the needs of the line and to the characteristics of the ports, and not the other way round. From our point of view, any approximate approach is questionable as regards its practical implementation. In this sense, it should be pointed out that we have not found any work that deals jointly with the problems of fleet composition (type and number of crafts) and with the optimisation of routes in a real case.

Bearing in mind the above, we shall attempt to reach our objective in two steps. Firstly, starting from the existing situation of the freight transport carried by the shipping companies on regular lines between The Canaries and The Peninsula, we shall estimate the real costs of the fleet. The results obtained will be used as an initial solution to our problem. In the second stage, we shall propose alternative models using perfection heuristics in order to improve the initial situation.

3. THE INITIAL SOLUTION: REAL SEA TRANSORT COSTS

On the basis of the characteristics of the itineraries, routes, the loads generated, the ports visited and the crafts available, the shipping companies organise their regular sea transport services between the Canaries and the Peninsula [31].

These coasting trade lines are traditionally articulated around three main routes linking the Canary Islands directly with ports located in three clearly differentiated coasts of the Peninsula: north, south and Mediterranean. Some companies operate on all three routes while others do so on only one or two of them. All of the companies have weekly services but, depending on the distance to The Canaries, it is sometimes necessary to use at least two crafts to serve the line.(see Figure 1)

On all of the regular lines, the shipping companies land at the main ports of Tenerife and Las Palmas. When they do not serve smaller Canary Islands ports, transfers are made to other ships of the same or another company.

In reality, the organisations which serve the various lines are not totally fixed; rather, there is a certain movement between the companies. This allows crafts to be used on different routes in response to the demands of each moment.

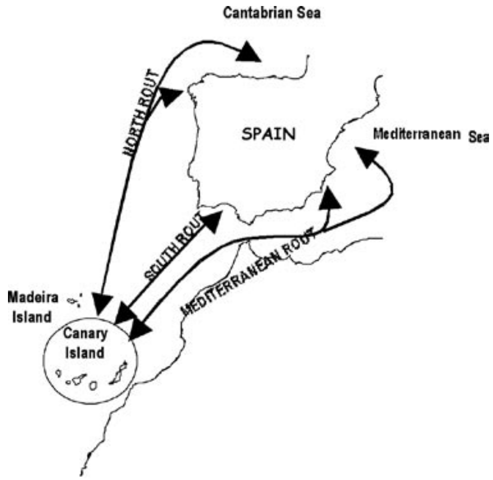

Figure 1: The traffic between the Canary Islands and the Spanish Peninsula. Elaborated by authors

We shall now formalise the organisation of the services offered on the regular coast trading lines between the Canaries and the Peninsula. The year 2,000 was chosen as a reference as the data available for estimating the costs was for this year. In that year, there were 8 shipping companies operating with a total of 30 crafts and 286,353 Deadweight Tonnes. The weekly transport capacity offered by these companies is 15,169 container ships of 20 feet or equivalent units (TEUS: Twenty Equivalent Units) and 13,415 linear cargo metres [[32]].

The annual costs for each of the 30 crafts that transported freight in the Canaries-Península during the year 2000 have been determined, on the basis of their real technical and operating characteristics. The shipping company costs, those of the itinerary and finally those of the routes will also be determined.

The information used for this process was highly diverse, four clearly differentiated sources being distinguishable. The first is that of the data on the consumption of the crafts themselves, the distances covered and the prices in The Canaries of the various products consumed (fuels, oils and water). Secondly, we had access to some information from the shipping companies on fixed expenses. A third source of information was that which provided us with the 'official' fares applied at the ports of the different lines. Finally, information was obtained on the scale costs of loading and unloading on the different regular lines, thanks to the valuable help of the shipping agents who operate at the different ports used on the three routes.

The costs for each of the ships are determined using a process of simulation of the real operations.

Table 3 shows the results obtained from this process, as well as the costs structure both for routes as for the total transport between The Canary Islands and The Peninsula.

Table 3: Costs structure for sea transport between Canary Islands and Spanish Peninsula in 2000

CONCEPTS	TOTALS	Northern route	Southern route	Mediterranean Route
Stopover	4,32	3,29	4,74	4,39
Loading and unloading	36,00	34,65	34,62	38,19
Consumption en route and in port	20,38	20,12	21,99	18,73
TOTAL VARIABLE COSTS	60,69	58,07	61,35	61,31
Crew	7,13	5,83	7,54	7,35
Maintenance services	5,32	4,66	4,75	6,29
Supplies and gear	5,39	4,73	4,93	6,22
Insurance	3,40	4,55	3,74	2,42
Hire costs	6,27	17,67	3,33	3,66
Repayments	11,80	4,49	14,35	12,74
TOTAL FIXED COSTS	39,31	41,93	38,65	38,69
TOTAL COSTS (%)	100,00	100,00	100,00	100,00
TOTAL COSTS (thousands €)	220.220	43.234	92.610	84.377
Participation in COSTS (%)	100,00	19,63	42,05	38,31

Elaborated by authors

4. ALTERNATIVE MODELS

Under the assumption of the possible formation of business alliances, we propose three alternatives to the present model, using perfection heuristics whose aim is to reduce transport costs. In these models we redimension the fleet and propose alternative itineraries, which, in all cases, fulfil the condition of transporting the freight to the port of delivery on a weekly basis. The alternative models are designed to verify the following hypotheses:

HYPOTHESIS 1: Under the assumption of invariability of the tonnes transported on a regular line and the maintenance of routes, itineraries and frequencies, an increase in the size of the crafts which operate on the line together with a reduction in their number will reduce the operating costs of the shipping companies involved.

HYPOTHESIS 2: Under the assumption of invariability of the tonnes transported on a regular line and the maintenance of routes and frequencies, a reduction in the itineraries together with an increase in the size of the crafts which operate on the line and a reduction in their number will reduce the operating costs of the shipping companies involved.

In order to verify these hypotheses, three alternative models have been developed. The itineraries, lines and routes for these models are shown in Table 4.

Model 1: Variation in number of crafts

In this first model, we either vary the present situation, in which all of the crafts of a certain traffic must go to all of the ports, for one in which the new larger crafts go to the larger ports where there are big loads and other smaller crafts travel to the smaller ports according to the limitations on draughts. In short, the same weekly services are maintained with fewer crafts.

Model 2: Variation in crafts and ports, maintaining the lines.

In model 1, a high number of small crafts was necessary to be able to enter ports of low draughts. In Model 2, these ports are eliminated and the load is concentrated in larger main ports. This allows us to increase the number of larger crafts and thus reduce the total number of crafts. In order to maintain the services to the final destination, the freight has to be transported via land between the main ports and those which have been eliminated.

The ports defined as main ports on the Peninsula were Bilbao and Vigo on the Northern route, Algeciras (container ships) and Cádiz (RoRo) on the southern route and Barcelona and Valencia on the Mediterranean route. In The Canaries, the main ports were Las Palmas de Gran Canaria and Santa Cruz de Tenerife for the containers. However, some smaller crafts which have time left over will also go to the smaller islands. The RoRo have no problems as these are fast crafts with accessibility to all ports. In this way, transfer costs are avoided in The Canary Islands.

Model 3: Variation in ports, crafts and lines.

This model contemplates only lines from the south of the Peninsula, which allows a great reduction in the number of crafts. The base ports are now only two on the peninsula: Algeciras for container ships and Cádiz for RoRo crafts. In the Canaries, the base ports are Santa Cruz de Tenerife and La Palmas de Gran Canaria for container ships, while RoRo crafts reach all ports. This is a technically possible alternative which would avoid any transfers to other interinsular crafts and, thus, additional expenses.

Table 4: Itineraries for the alternative models

	Traffic (Routes)	Lines	Itineraries
MODEL 1	North 1	North 1.1	Bilbao- Vigo- Tenerife- Las Palmas
		North 1.2	Gijón- Marín- Tenerife- Las Palmas- Arrecife- Pto. Rosario
	South 1	South 1.1	Algeciras- Las Palmas- Tenerife
		South 1.2	1. Cádiz- Las Palmas- Tenerife- La Palma- Tenerife- Las Palmas- Arrecife 2. Cádiz- Las Palmas- Arrecife- Pto del Rosario 3. Cádiz- Las Palmas- Tenerife- La Palma 4. Cádiz- Las Palmas- Tenerife
		South 1.3	Sevilla- Las Palmas- Tenerife
	Mediterranean1	Mediterranean 1.1	Barcelona- Valencia- Las Palmas- Tenerife
		Mediterranean 1.2	Tarragona- Alicante- Cartagena- Arrecife- Las Palmas- Tenerife- La Palma
		Mediterranean 1.3	Barcelona- Valencia- Algeciras- Arrecife- La Palmas- Tenerife- La Palma
MODEL 2	North 2	North 2.1	Bilbao- Vigo- Tenerife- Las Palmas
	South 2	South 2.1	Algeciras- Las Palmas- Tenerife
		South 2.2	1. Cádiz- Las Palmas- Tenerife- La Palma- Tenerife- Las Palmas- Arrecife 2. Cádiz- Las Palmas- Arrecife 3. Cádiz- Las Palmas- Tenerife- La Palma 4. Cádiz- Las Palmas- Tenerife
	Mediterranean2	Mediterranean 2.1	Barcelona- Valencia- Las Palmas- Tenerife
MODEL 3	South 3	South 3.1	Algeciras- Las Palmas- Tenerife
		South 3.2	1. Cádiz- Las Palmas- Tenerife- La Palma- Tenerife- Las Palmas- Arrecife 2. Cádiz- Las Palmas- Arrecife 3. Cádiz- Las Palmas- Tenerife- La Palma 4. Cádiz- Las Palmas- Tenerife

Elaborated by authors

The process through which the type of craft is selected is developed for each itinerary. To this end, the characteristics of the itinerary are analysed on the basis of the distance sailed and the frequency of the service, the characteristics of the cargo to carry between the Canary Islands and the Peninsula (both directions), and the characteristics of the ports where they dock as regards the limitations in draughts and mooring lines. Bearing in mind these aspects, the appropriate crafts are defined and their trips are simulated in order to estimate the costs. (see Figure 2).

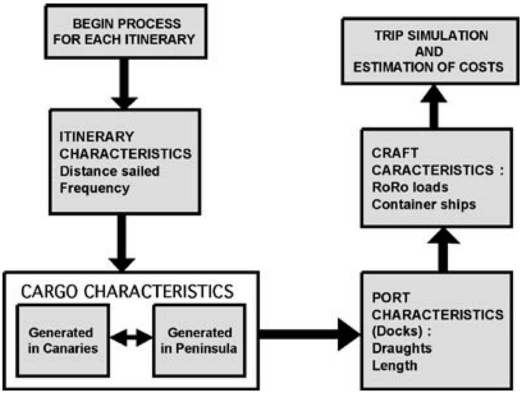

Figure 2: Selection process for craft type per itinerary. Elaborated by authors

All of the figures on the loads handled by the ports and their technical characteristics were obtained from the information published in the records of those ports and from that provided directly by the Port Authorities.

As results of the process of analysis for each itinerary applied to the three models proposed, a series of crafts (types) and a number have been selected, defining the composition of the fleet for each alternative. Among those found most suitable are some crafts which are already operating on the lines. The crafts used in the alternative models proposed are shown in Table 5.

Table 5: Crafts required for the different models proposed

Craft type: Series and year (year of construction)	Nº crafts		
	Model 1	Model 2	Model 3
SSW Super 25 (2002)	3	6	4
Kindia (2002)	5	2	1
Nenúfar (1996 y 2002)	2		3
Express (1984 y 1983)	3		
Sister (1993)	1	1	
Levante (2001)	1		
Superfast (1997, 1998 y 2002)	2	3	
TOTALS	17	12	8

Elaborated by authors

Although the year of construction of some of the crafts is later than 2000, it has been assumed that these were available in this year for the purposes of simulating the trips and estimating the costs. In any case, the evaluation of these costs refers to the year 2000.

5. RESULTS OF ALTERNATIVES

The effect of the different models on the composition of the fleet and some of its characteristics are shown in Table 6. The variation in the number of crafts and in the capacities of the fleet with respect to those of the year 2000 can be observed.

Table 6: Effects of models on fleet capacities and variations (Var) with respect to the year 2000

Characteristics (number)	Real Situation 2.000	Model 1		Model 2		Model 3	
		Fleet	Var	Fleet	Var	Fleet	Var
Crafts	29	17	-41,4%	12	-58,6%	8	-72,4%
DWT	281080	272159	-3,2%	283633	0,9%	176893	-37,1%
TEUS	15169	17914	18,1%	18140	19,6%	9960	-34,3%
lcm	13343	13343	0,0%	9450	-29,2%	9450	-29,2%

Elaborated by authors

DWT: Deadweight Tonnes
TEUS: Twenty Equivalent Units
lcm: Linear Cargo Metres
Var: Variation on Real Situation

With respect to the real situation for the year 2000, all of the models achieve a reduction in the number of crafts used and a relative increase in the average capacity of the crafts measured in DWT. In Model 1, the capacity for transporting TEUS is increased and the capacity for transporting RoRo cargoes is maintained. In Model 2, there is also an increase in the capacity for transporting containers but the capacity for transporting RoRo cargoes is reduced. In Model 3, there is a reduction in all capacities. The reductions in capacities for models 2 and 3 are due to the change in itineraries, which means that part of the transport will be on land.

Once the crafts were selected for each model, the costs were then estimated for each of the itineraries established for the different alternatives (see Table 7). The results obtained together with those corresponding to the real situation are shown in Table 8. We have differentiated between the fixed costs and the variable costs of sea transport and those of land transport in the relevant models.

Table 7: Comparison of transport costs

ALTERNATIVES	Fixed costs	Variable Costs	Transport Costs	Additional Land Transport	Total Costs
Real 2000	86.567	133.654	220.220	0	220.220
Model 1	89.110	119.294	208.404	0	208.404
Model 2	72.412	110.407	182.819	4.911	187.731
Model 3	48.342	104.825	153.167	49.666	202.833

Values in thousands € — Elaborated by authors

All of the models led to an improvement in the real situation both in absolute terms (Table 7) and in relative terms (Table 8).

Model 2 is the model with the lowest total costs even though it includes the expense of land transport, due to the haulage required from the main ports to the smaller ones. The total savings with respect to the real situation are 14.75%. Model 1 is the one with the worst results since these are distorted by its high fixed costs. It should be pointed out that this is due to the increase in the number of new crafts, so that as well as a saving of 5.37% we have a young fleet.

Model 3 is the most efficient in terms of the running costs, which are reduced by over 30%. The land transport carries a lot of weight in the total costs, so that, in the end, these are only reduced by around 8%. However, the possibility of making contracts to transport large load volumes by land can lead to important discounts in the costs, higher than those of around 25% considered in the present work.

Table 8 shows a relative view of the results obtained for the different alternatives in relation to the real situation.

Table 8: Variations in the models with respect to the real situation of 2.000

ALTERNATIVES	*Fixed costs*	*Variable Costs*	*Transport Costs*	*Additional Land Transport*	*Total Costs*
Real 2000	86.567	133.654	220.220	0	220.220
Model 1	89.110	119.294	208.404	0	208.404
Model 2	72.412	110.407	182.819	4.911	187.731
Model 3	48.342	104.825	153.167	49.666	202.833

Values in thousands € Elaborated by authors

Model 1 confirms hypothesis 1. Models 2 and 3 confirm hypothesis 2.

CONCLUSIONS

1. The current model of freight transport on the regular sea lines between the Canary Islands and the Peninsula is inefficient. The three alternatives to this model proposed here lead to savings of 5.37% (model 1), 14.75% (model 2) and 7.90% (model 3). In all cases, there is a reduction in the number of crafts used and possibly an improvement in the quality of services offered since most of the units used are new.

2. The current situation of strong competition, atomisation of business and excess of capacity describes a scenario where the shipping companies are having great difficulties in recovering their investments. This prevents the necessary and constant revision of the fleet units from being effected. Thus, some shipping companies maintain old units, low quality services and certain risks of damage and/or loss to the loads transported. The policy of maintaining these services, which are cheaper, with the insurance coverage is no solution.

The problems caused by a load which reaches its destination in bad condition due to inadequate transport are not covered by any insurance. The immediate gains received by the 'exporter' can, in the long term, be transformed into substantial and costly losses, sometimes leading to a continued rejection of services or even the total loss of clients.

3. The results obtained for the different alternatives show that a rationalisation of resources by means of the formation of fleet conferences or 'pool' type agreements would allow the shipping companies to reduce their costs drastically, to increase their profit margins and to establish lower fares. Moreover, the shipping companies would then regularly dispose of renewed and operative units.

AKNOWLEDGEMENTS

The present work has been possible thanks to the financial support of the Foundation for The Professional Training and Development, FYDE-Cajacanarias, and the Tax and Economy Office of The Autonomous Government of The Canary Islands (Spain).

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[2]Council Regulation (EEC) No 4055/86 of 22 December 1986 applying the principle of freedom to provide services to maritime transport between Member States and between Member States and third countries [Official Journal L 378 of 31.12.1986].

The approval of Act 4055/86 imposed the application of the principle of the free provision of services between member states and member states and third countries. This Act established the progressive elimination of cargo reserves in international traffic in three stages. The last stage came into effect on January 1st 1992.

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Similar actions were proposed in the context of the Merchant Navy viability plans in order to respond to the problem of the regular coasting traffic lines.

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These business alliances have normally had negative connotations, since it was felt that their sole function was to limit competitieveness by controlling the market, prices and distribution channels. However, nowadays, these alliances are reaching a new dimension as a response to the phenomenon of globalisation. The companies opt for associations rather than absorptions as this avoids the disappearance of the absorbed company and avoids all the work of integration. In the world of big businesses, maintaining a dominant position on an international scale is not easy for relatively small companies. Cooperation by means of alliances can be a solution..

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LINEAS MARÍTIMAS REGULARES ENTRE CANARIAS Y LA PEININSULA ¿COLUSIÓN O COMPETENCIA?.

RESUMEN

A las navieras que operan en líneas regulares se les permite llegar a acuerdos legales encaminados a racionalizar sus recursos. Por eso es habitual que las navieras constituyan "conferencias de fletes" en una línea regular, si ello permite optimizar la actividad de las mismas.

El trabajo que se presenta aborda el problema real de racionalización de los servicios de transporte marítimo regular entre Canarias y la Península. ¿Pueden optimizarse dichos servicios mediante acuerdos?. Con el fin de encontrar respuestas de carácter cuantitativo, se analizan los recursos existentes y su organización. Se desarrollan tres modelos alternativos a la situación actual, mediante heurísticas de perfeccionamiento, que tienen en cuenta tanto los itinerarios más adecuados como la composición de la flota de acuerdo con las necesidades reales de transporte. Los resultados comparados permiten afirmar que el modelo actual es ineficiente e invitan a la reflexión -tanto de navieras como de los usuarios que operan en dichos tráficos- sobre la conveniencia de iniciar un proceso de acuerdos que permita la utilización conjunta de recursos.

1. INTRODUCCIÓN

Las empresas navieras que operan regularmente entre Canarias y Península canalizan parte del denominado tráfico marítimo de cabotaje nacional.

Para Canarias, la importancia estratégica de dichas líneas regulares es vital ya que articulan las arterias más importantes de transporte de mercancías con el territorio peninsular. La totalidad de la carga transportada está unitizada. Por ello todas las navieras que operan en las mismas utilizan portacontenedores o RoRo (Roll on Roll off).

En dicho contexto, creemos que un cambio en el planteamiento de las empresas que operan en el sector supondría grandes ventajas tanto para las mismas como para sus usuarios. Entendemos que la "ordenación" de dichos tráficos precisa de una serie de acuerdos y acciones encaminados principalmente a racionalizar los recursos y definir el tipo de buque más adecuado para cada tráfico. En el primer caso, creando consorcios con el fin de utilizar de forma conjunta los buques de diferentes empresas. Las denominadas conferencias de fletes (cárteles) son una práctica habitual en líneas regulares marítimas. En la segunda línea de acción, la renovación de la flota deberá realizarse sustituyendo las unidades antiguas por buques que se adapten correctamente a los requerimientos de los tráficos. Se trata de un proceso gradual que permitiría ir renovando las unidades antiguas por otras de mayor tamaño especialmente diseñadas para cada tráfico, con tecnología avanzada, tripulaciones reducidas y medios más operativos para la manipulación de mercancías. Es probable que la conjunción de tales acciones permitiría la aparición de economías de escala. Pero ello supondría incrementar el tamaño de los buques y reducir su número, concentrar cargas y reducir el número de puertos, y modificar itinerarios y frecuencias.

En última instancia se podrían conseguir ahorros sensibles que permitirían tanto una mejora de los resultados económicos de las navieras como una reducción de sus tarifas. En definitiva, una mayor eficiencia en dicho sector y una mejora de su posición competitiva que permita –a su vez- afrontar con garantías la creciente competencia internacional.

Teniendo en tales aspectos nos hemos planteado como objetivo del presente trabajo: formalizar modelos alternativos a la situación actual, más eficientes, que permitan reducir los costes mediante la racionalización de los recursos utilizados por las navieras.

2. METODOLOGÍA

El principal objetivo del presente trabajo es establecer alternativas a la situación real de transporte marítimo de mercancías en línea regular entre Canarias y Península cuya organización ha sido abordada anteriormente. Mediante diferentes asignaciones de flotas e itinerarios pretendemos minimizar o reducir los costes del transporte.

Bajo el supuesto de una política de alianzas, las navieras podrían explotar en común sus recursos, determinando los tipos y número de buques que permitieran establecer de forma coherente las rutas, los itinerarios y las frecuencias en base a los servicios necesarios (demandados). En dicho contexto, se trataría de resolver un doble problema de optimización de rutas y de composición de una flota de acuerdo con las necesidades reales.

Existen multitud de algoritmos que resuelven de manera exacta y aproximada el problema de diseño de rutas de vehículos en los ámbitos del transporte y la distribución. Los métodos exactos (Golden y Assad, 1988) proporcionan soluciones óptimas pero son de difícil implementación práctica en determinadas situaciones reales. Quizá por ello los métodos aproximados se han desarrollado con mayor profusión en los últimos años. Pero en particular, los heurísticos han constituido el grueso de la investigación realizada (Laporte, 1992).

Según Fagerholt (1999) el problema fundamental de los buques de línea es similar al de diseño de rutas de vehículos multiviaje VRPMT (Vehicle Routing Problem Multitrayet). El problema estándar de diseño de rutas conocido como VRP (Vehicle Routing Problem) ha sido extensamente tratado en la literatura. Laporte y Osman (1995) presentan 500 referencias bibliográficas sobre la materia. El VRP puede describirse de la siguiente manera: a partir de un conjunto de nodos de demanda conocida y de vehículos de capacidad también conocida, se pretende determinar las rutas de reparto -desde un almacén central- que minimice la distancia total recorrida y los costes.

El VRPMT es estudiado por Taillard y otros (1996) y por Brandao y Mercer (1997), posteriormente estos últimos autores desarrollan búsquedas heurísticas tabú para resolver el problema (Brandao y Mercer, 1998).

Los investigadores han prestado menos atención al problema de determinar la composición eficiente de una flota a la hora de establecer las rutas óptimas. Aspecto sorprendente especialmente en el negocio del transporte marítimo, donde los costes de capital constituyen una de las partidas más significativas.

Etezadi y Beasley (1983) distinguen entre los problemas del tamaño de la flota de vehículos (número) y su composición (tipo). El trabajo pionero de Dantzig y otros (1954) aborda una problemática similar aunque con un solo tipo de vehículo cuyo número pretende minimizarse. Ball y otros (1983) estudian el problema de decidir el tamaño de una flota de vehículos propios y arrendados bajo opción de portador común. Los autores determinan qué viajes deben ser atendidos por su propia flota y cúales por el portador común. Bodín y otros (1983) utilizan un enfoque heurístico para abordar el problema del tamaño de la flota y los itinerarios de cada vehículo. Dicho método es una extensión del conocido algoritmo de ahorros para el VRP (Clarke y Wright, 1964). Para abordar el problema del tamaño de la flota Desrochers y Verhoog (1991) también utilizan una heurística de ahorros -aunque- basada en una sucesiva fusión de rutas. Sin embargo, las referencias indicadas no incluyen la posibilidad de viajes múltiples propias del VRPTM. Murotsu y Taguchi (1976) consideran un problema de decidir la óptima composición de la flota marítima. En tal sentido determinan los tipos de barcos, representados por la capacidad de carga y la velocidad de servicio, y el número de cada tipo. Sin embargo sólo consideran el transporte entre dos puertos, uno de carga y otro de descarga.

Fagerholt (1999) en su trabajo se plantea el mismo objetivo genérico que nosotros: reducir los costes del transporte. Además aborda el problema del tamaño óptimo de la flota y las rutas óptimas en el contexto real de los tráficos marítimos de línea regular entre Noruega, Europa y Estados Unidos. El algoritmo que formaliza se puede considerar como un VRPTM ya que determina las rutas semanales de los buques de línea. Sin duda, se trata de un trabajo muy próximo a la realidad en su concepción. Sin embargo, no tiene en cuenta la composición de la flota ya que utiliza un sólo tipo de buque.

Como ya se ha indicado en la introducción, nosotros creemos que el tipo de buque es crucial en el problema real que pretendemos tratar en el presente trabajo. Los buques deben adaptase a las necesidades de la línea y a las características de los puertos y no al revés. Desde nuestro punto de vista cualquier planteamiento aproximado es cuestionable en cuanto a su implementación práctica. En tal sentido, debemos puntualizar que no hemos encontrado ningún trabajo que trate conjuntamente los problemas de la composición de la flota (tipo de buques y número) con la optimización de rutas en un caso real.

Teniendo en cuenta lo anterior, intentamos alcanzar nuestro objetivo en dos fases. En la primera, a partir de la situación existente de transporte de mercancías realizado por navieras en línea regular entre Canarias y Península tratado en epígrafes anteriores, estimamos los costes reales de la flota. Los resultados obtenidos se utilizarán como solución inicial de nuestro problema. En la segunda fase, planteamos modelos alternativos mediante heurísticas de perfeccionamiento con el fin de mejorar la situación inicial.

CONCLUSIONES

1. El actual modelo de transporte de mercancías en líneas regulares marítimas entre Canarias y Península es ineficiente. Las tres alternativas planteadas a dicho modelo suponen ahorros del 5,37% (modelo 1), 14,75% (modelo 2) y 7,90% (modelo 3). En todos los casos se produce una disminución del número de buques utilizados y posiblemente una mejora en la calidad de los servicios ofertados ya que se utilizan unidades en su mayoría nuevas.

2. La actual situación de fuerte competencia, atomización empresarial y exceso de capacidad describe un escenario donde las navieras tienen grandes dificultades para recuperar adecuadamente la inversión. Ello impide acometer la necesaria y constante renovación de sus unidades de flota. Así, algunas navieras siguen manteniendo unidades viejas, servicios de baja calidad y riesgos ciertos de daños y/o pérdidas de las cargas transportadas. La política de mantener dichos servicios –más baratos- con la cobertura de un seguro no es la solución. Los "trastornos" originados por una carga que llega en mal estado -debido a un transporte inadecuado- no son cubiertos por los seguros. Las ganancias inmediatas que experimenta un "exportador" pueden trasformarse en el largo plazo en importantes y costosos daños que pueden ir desde el rechazo reiterado de envíos hasta la pérdida de clientes.

3. Los resultados obtenidos en las diferentes alternativas nos permiten afirmar que una racionalización de los recursos mediante la formación de conferencias de fletes o acuerdos tipo "pool" permitiría a la navieras reducir drásticamente sus costes, incrementar sus márgenes y establecer tarifas más bajas. Además las navieras podrían disponer -con cierta estabilidad- de unidades renovadas y operativas.

Journal of Maritime Research, Vol. I. No. 3, pp. 85-104, 2004

ISSN: 1697-4840

PORTS ECONOMIC IMPACT: LITERATURE REVIEW AND ALTERNATIVE PROPOSAL

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ABSTRACT

A review is undertaken in this article of the different alternatives which have been included in the literature applied to the analysis of the economic impact of port activity, detecting the main advantages and disadvantages of each of them, and confirming that the applications based on Input-Output tables are by far the most used, both nationally and internationally.

In the light of the review undertaken an alternative procedure is proposed which, including the main advantages of input-output methodology, allows for the systematic application to all Spanish regions and the regional location of the different impacts; direct, indirect and induced.

Key words: Input-Output tables, Economic impact of ports, Regionalisation.

This work falls within a broader project for the systemisation of the analysis of the economic impact of ports financed by the State Public Ports Authority and carried out in collaboration with TYPSA.

1 INTRODUCTION

The general objective of the analysis of the macroeconomic impact of the ports is part of a global trend to deepen the knowledge and quantification of economic phenomena in general, the origin of which we could establish at the beginnings of economic science itself, and was extensively developed alongside the large systems of national accounts.

In this general environment, and now that the systems of national accounts have been sufficiently standardised in most of the developed economies, the interest of the analysts has moved from large aggregates to levels closer to each of the specific economic activities, going from this macroeconomic level to what we could call a "metzo-economic" analysis, which would include both the analysis of more limited spatial units (regional or local analysis), and of specific economic branches or sectors (sectorial analysis).

In addition to this global interest, which is shared with the other economic activities, the implementation and management of ports has special characteristics which by themselves provide more than sufficient justification for the development of specific analyses of their economic impact.

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As with other large infrastructures for social facilities (airports, railways, main roads, etc.), ports must therefore generally be financed through large public investments which are placed at the disposal of society as a whole without being directly subject to a specific profitability analysis in the way that other types of private investments in activities which are completely subject to market mechanisms would.

For this reason, evaluating the profitability of these investments in public infrastructures cannot be limited to the mere comparative analysis of capital employed and returns received but should be studied thoroughly in areas such as the total contribution to the economic and social development of the specific commercial activity and irrespective of the specific commercial activity developed with these investments.

In addition, these large infrastructures usually generate a series of negative environmental externalities, which are geographically concentrated and whose acceptance by the groups affected may be made easier if they are presented along with the economic benefits resulting from them.

Finally, we could add a third factor of interest which in this case specifically affects port activity, and refers to the size of the economic activity linked to the port as regards the local economies.

By way of example, whilst the direct weight of the activities linked to sea transport and fishing would equate to slightly less than 0.5% of Spanish GDP, for some specific provinces this direct contribution would amount to over 2% of their total income.

Having established the specific interest of the analysis of the macroeconomic impact of ports we must define the different stages to be tackled in this type of study.

Firstly an estimation of the economic activity directly linked to this port activity should be made, where the fundamental tasks to be carried out will consist of the definition of this activity, the compilation of the economic information relating to the group of agents involved in it, and the consolidation of all the information included in accordance with preestablished standards. This procedure could be compared to the accounting consolidation in a multifunctional company.

In the second stage we would proceed with the definition of the level of interrelation in this activity compared to the rest of the branches of production which make up the economic system. In order to do this it would be necessary to carry out an additional structural analysis of clients and suppliers, in such a way that the possible "drag" effects on the rest of the economic system, as well as the possible potentialities and risks faced by this activity, could be defined.

Thirdly, in order to adequately evaluate the implied profitability of the investments in port infrastructures, an analysis should be carried out of the multiplying effects of this activity, including not only the direct contribution, but also all the possible indirect effects which are generated as a consequence of the establishment and development of the port activity. In this case, the tasks to be carried out should include the development of some type of model of interaction between the different production branches which enables the direct effects to be transferred to the rest of the economic system and for all the possible indirect effects to then be evaluated.

Finally, in order to complete the analysis of the social effects of these investments, the induced effects on the geographical area in which these installations are located should be studied. An estimation will therefore be required of the possible induced effects, fundamentally in terms of income, which are generated in this geographical area and which allow for a comparison between the possible costs and benefits obtained by the community as a result of the port activity.

As a complementary action another type of alternative analysis could be considered on the effects which certain action taken concerning the port activity itself would generate on the rest of the economic system. The study of the effects of the expansion of the port infrastructure, the limitation or contraction of the services on offer or possible variations in pricing policies could thus be considered as possible alternative objectives.

2. METHODOLOGICAL APPROACH AND REVIEW OF LITERATURE

The calculation of the economic effects of a particular company or sector on the economic system as a whole has been the object of numerous studies throughout the history of applied economics and there are many alternative approaches which have been suggested in order to tackle these issues.

The main problem revolves around the establishment of a reasonable balance between the level of specific or microeconomic detail with which these studies are tackled and the possibilities of establishing sufficiently representative conclusions on a macroeconomic level.

This appropriate level of integration between micro and macroeconomic information can be found, as we hinted in the introduction, in what has become known as "metzo-economic" analysis, and the methodology based on Input-Output tables has become one of the most internationally widespread tools[1].

In the specific field for the study of the analysis of the economic impact of port activity, and as is shown in the review we present below, it is precisely this methodology based on Input-Output tables which has enjoyed great popularity. The alternative proposal which we will present in the following sections of this article is therefore fully justified.

For the purposes of facilitating the monitoring of the different methodological proposals reviewed we will begin by including those which are internationally recognised in order to subsequently show the different contributions made in our country.

The first works that we can strictly identify as an analysis of the impact of port activity are to be found in the second half of the 1960's in the United States and the majority of the studies consulted agree in highlighting the pioneering work carried out half-way through the above mentioned decade by the New York –New Jersey port authorities[2]

The concern with measuring the effects that port activity generates on the economy is already made clear in these first studies, fundamentally relating to the local or regional economy, where the ports are located, as well as the non-existence of a unanimously accepted method or procedure for this to be carried out.

In the second half of the 1970's, a certain amount of debate was generated about the usefulness of these studies and the methodology usually used for them to be carried out, which was mostly based on the development of the Input-Output model.

Thus, in 1977 Robert C. Waters[3] published an article in the *Transportation Journal* questioning the reliability of the numerous studies carried out up to that point which used the multiplier methodology derived from the Input-Output tables as the basis for the calculation of the economic impact of port activity.

The main doubts which the aforementioned author made clear, many of which have still not been completely resolved in subsequent studies, referred to the lack of dynamism in the procedure used, which did not take into account the possible benefits generated by the accumulation of capital, or the improvements in the transport infrastructure, or the possible technological changes undergone by production processes in general and by the transport systems in particular.

In addition, the representativeness of the results obtained was questioned as the assumptions of revenue generation and distribution resulting from port activity are, in general, excessively simplistic and do not adequately reflect the processes of the replacement of local production by imports as a consequence of the port activity itself, or the changes in pricing structures. This invalidated the possible use of these approximations to carry out an adequate evaluation of the profitability or real benefit resulting from possible actions to expand or close port installations.

One year later, Semoon Chang[4] published an article in reply to this in the same magazine in which, accepting most of the criticisms established by Waters, he makes a defence of the methodology used up to that time and proposes a complementary model in order to overcome some of the doubts raised by said author.

Cheng concludes that whilst not being exempt from difficulties of interpretation or inaccuracies in the results finally obtained, the studies of the economic impact of ports carried out using the Input-Output methodology are a very useful tool, both for the social justification of port infrastructures, and the planning by the corresponding authorities.

In any case, this interest in the methodological development of the analysis of the impact of port activity using methodologies based on Input-Output tables, led the American port authority, Maritime Administration MARAD, dependent on the North American Department of Transport, to begin a project for the harmonisation of the analysis methodology, in the second half of the seventies, which culminated in the first version of the **MARAD Port Kit**. This was software especially developed to carry out this type of analysis of the regional impacts of port activity and is currently still being developed in collaboration with *A. Strauss-Wider, Inc. (ASWinc)* and the *Center for Urban Policy Research* (CUPR) of Rutgers University in New Jersey.

This ***MARAD Port Kit*** is a system which integrates most of the basic aspects to be taken into account in an analysis of port activity including everything from the economic quantification of the port activities, both in terms of employment, added value, revenues or taxes, to the evaluation of the economic implications of potential investments or new business lines for the ports, including the analysis of interrelations with the other branches of activity, or the possibility of carrying out simulations of "What if?" hypothetical situations.

The methodology that it uses is based on an Input-Output model which today differentiates between a total of 517 sectors, plus those corresponding to specific port activities, and whose coefficients are based on the Input-Output table of the North American economy for 1992, updated to 1998.

The model is designed so that it can be applied to any port in the United States and uses, in all cases, the same technical coefficients, or multipliers deduced from the aggregated IOT (input-output table).

The regionalisation or localisation of the effects is obtained using regional purchase coefficients, obtained from the proportion of regional demand which it is assumed can be supplied by production from the region itself, and which are used to transform the implied multipliers of the aggregated model.

Despite this effort made by the North American government, this is not a debate which has been completely closed, and new critical references to the impact analysis methodology based on Input-Output tables can be found, as seen in Benacchio and others (2000), which are summarised in Table 1.

Even with all the necessary methodological nuances, it seems that the analysis of the macroeconomic impact of port activity is still a subject of special interest internationally. There is a constant flow of contributions to be found, from the beginnings of these types of applications to current day, as is shown in table 2 below, which has been produced for demonstrative purposes and is not by any means an exhaustive list of all the contributions made.

Table 1. Critical references and methodological contributions to the study of impacts

Authors	References
Waters, R.C. (1977)	"*Port Economic Impact Studies: Practice and Assessment*". Transportation Review. Pages 14-18.
Chang, S. (1978)	"*In Defence of Port Economic Impact Studies*". Transportation Journal. Pages 79-85.
Davis C. H. (1983)	"Regional Port Impact Studies: a critique and suggested methodology", *Transportation Journal*, Vol. 17, 61-71
Yochum G.R., Agarwal V.B. (1987)	"Economic impact of a port on a regional economy", Growth and Change, n.2, 74-87
Randall, J.E. (1988)	"Economic development and non-marine initiatives at American seaports", *Maritime Policy and Management*, Vol. 15, 225-240
Yochum G.R., Agarwal V.B. (1988)	"Static and changing port economic impact", Maritime Policy and Management, Vol.15, 157-171
Warf B., Cox J. (1989)	"The changing economic impacts of the port of New York", in *Maritime Policy and Management*, vol.16, pages 3-11
DeSalvo J., Fuller D. (1994)	"Measuring the direct impacts of a port", *Transportation Journal*, Vol. 33, 33-42
DeSalvo J., Fuller D. (1995)	"The role of price elasticities of Demand in the economic impact of a port", *Review of Regional Studies*, 25, 13-35
Gripaios P., Gripaios R. (1995)	"The impact of a port on its local economy: the case of Plymouth", *Maritime Policy and Management*, Vol. 22, 13-23
Verbeke A., Debisschop K. (1996)	"A Note on the Use of Port Economic Impact Studies for the Evaluation of Large Scale Port Projects", *International Journal of Transport Economics*; 23(3), October 1996, 247-66.
Castro Villaverde J., Millan Coto P. (1998)	"Port economic impact: methodologies and application to the port of Santander", *International Journal of Transport Economics*, Vol. XXV-2, 159-179
Gripaios P. (1999)	"Ports and their influence on local economies - a UK perspective", *The Dock & Harbour Authority* Vol. 79:894, March/April 99
Hoyle, B.S. (1999)	"Scale and sustainability: the role of community groups in Canadian port-city waterfront change", Journal of Transport Geography, vol.7, n.1, pages 65-78
Musso E., Benacchio M., Ferrari C. (1999)	The economic impact of ports on local economies: a technique for employment assessment, in Dombois R., Heseler H. (eds.), *Seaports under the conditions of globalisation and privatisation*, Bremen: Universität
Source: Benacchio, M, Ferrari, C., Haralambides, H.E. and Musso, E. (2000): *"On the Economic Impact of Ports: Local vs. National Costs and Benefits"* INTERNATIONAL WORKSHOP Genoa - June 8-10, 2000. Special Interest Group on Maritime Transport and Ports, a member of the WCTR Society	

The literature on the analysis of the impact of port activity in Spain is slightly more modern than that which we present internationally and the oldest references are from the beginnings of the nineties.

Although some contributions of a methodological type can be found, such as those made by Villaverde, J and Coto, P. (1998)[5], the majority of the studies consulted focus their interest on the estimation of the economic contributions of ports on the local, regional or national economy as a whole.

A large part of the works analysed tend to reproduce, with more or less original contributions, the methodological proposal included in the pioneering work in our country produced by the TEMA Consultancy Group in 1994 and 1995, for the analysis of the economic impact of the ports of Galicia[6]. We could therefore consider this work to be the basic point of reference for the group of applications carried out in our country and which use the Input-Output methodology as a central element of the study.

Table 2. List of international applications of economic impact of ports

Year	Title	Authors
In the United States		
1964	Measuring the impact of the waterborne commerce of the ports of Virginia on employment, wages and other key indices of the Virginia economy, 1953-1962	University of Virginia, Bureau of Population and Economic Research
1979	Port Economic Impact Kit	U.S. Maritime Administration (MARAD), Office of Port and Intermodal Development, Washington DC
1982	The regional Port impact model Handbook (guide for preparing Economic Impact Assessments Using Input-Output Analysis)	Maritime Administration U.S. Department of Transportation
1987	MARAD Port Kit	The Maritime Administration (agency of the U.S)
1989	South Carolina State Ports Authority: Economic Impact Study	South Carolina State Ports Authority
1990	Economic impact of the industry on the New York-New Jersey metropolitan region	The port Authority of New York-New Jersey Office of Business Development.
1991	Port of Halifax Economic impact Study.	Gardner Pinfold Consulting Economists Limited
1995	Economic impact of the industry on the New York-New Jersey metropolitan region	The port Authority of New York-New Jersey Office of Business Development.
2001	The economic impact of the Port of Esperance, 1999/00	Esperance Port Authority
2001	The economic impact of Connecticut's Deepwater Ports: An IMPLAN and REMI Analysis	Connecticut Center for Economic Analysis.
2001	Economic and Fiscal Impact Assessment: Port of Detroit Project.	Patrick L. AndersonIihan K. Geckil.
2002	Economic Evaluation of the Impact of Waterways on the State of Arkansas.	Heather Nachtmann, PhD.
In Europe		
	Economic impact of Dublin Port on its Hinterland 1st draft.	Simon Behan B. Comm.
	The future of the Dutch shipping sector: Economic Impact Study and policy analysis	DR. C. Peeters Drs. K. Debisschop P. Vandendriessche Dr. Ir. N. Wijnolst
1988	Anvers (BE)	
1991	Rouen (France)	
1991	Genova (Italy)	
1993	Dunkirk (France)	
1994	The Flemish Port sector – Economic structure and significance.	Ministry of the Flemish Community. Department of the Environment and Infrastructure.
1995	Nantes/St. Nazaire (FR)	
1995	Ghent (Belgium)	
1995	Bruges (Belgium)	
1996	Value added port of Rotterdam	Netherlands Economisch Instituut
2000	Srima dell`impatto economico ed occupazionale delle attivita´del porto di Genova.	
1996	London	
1996	Southampton (UK)	
1996	Liverpool (UK)	
1989	Plymouth (UK)	
2000	The Economic Contribution of the Port of Cork to the Irish Economy	Moloney, R., W. Sjostrom, and R. Burke The Port of Cork Company

Source: In-house development

As can be seen in table 3, the majority of the applications carried out in our country, concentrated in the second half of the nineties and the last few years, have used this methodology, based on Input-Output tables, in order to determine the economic impact of ports, although there are some references to direct estimations, econometric models or simulation models, as basic or complementary tools of this analysis.

In the aforementioned table 3, the main applications that it has been possible to identify have been included, indicating the year of publication of the study, its title and authors, together with an indication of the methodology used and, if Input-Output methodology has been used, the corresponding table used.

Table 3. Applications carried out in Spanish ports

Year	Title	Authors	Basic methodology	TIO Used
1992	Impact of the port of Santander on the Cantabrian economy.	J. Villaverde and P. Coto	Input-Output°	Spain 1989
1992	The port of El Ferrol and its influence on the economy of the region	J.Fraga and J.A.Seijas	Measurement of the direct impacts	
1994	Economic activity and cost structure of the port of La Luz and Las Palmas.	G. de Rus., C. Román and L. Trujillo.	Activity accounting	
1994	Evaluation of the impact of the activity of the ports of Galicia on the economy of the region.	TEMA Consultancy Group.	Input-Output	Galicia 1990 updated to 1992
1995	Evaluation of the impacts of the activity of the ports of Galicia on the national economy.	Tema Consultancy Group.	Input-Output	Galicia 1990 updated to 1992
1995	Study of the economic impact of the Port of Bilbao on the Basque Country.	BILBAO PLAZA MARÍTIMA, S.L.	Input-Output	Basque Country 1990
1995	Study of the economic and social impact of the port of Motril.	TYPSA consultancy group.	Simulation and use of indices	
1996	Economic impact of the expansion of the bay port of Algeciras.	State Ports	Input-Output	Andalusia 1990
1998	Study of the economic impact of the port of Marín in Galicia and the province of Pontevedra in 1996.	BILBAO PLAZA MARÍTIMA, S.L.	Input-Output	Galicia 1990
1999	Analysis of the economic impact of the ports of Barcelona and Tarragona.	Consultrans-centre for economic studies / Tomillo Foundation	Input-Output + Econometric model	Catalonia 1987 updated to 1995
2000	Economic impact of the port of Castellón.	A. Cuadros, J.I Fernández, A.M Fuertes, L. García	Input-Output	Valencia Region 1990, updated to 1997
2000	Port Growth and Regional Development: An application to the Port of Santander.	P. Coto, J L. Gallego and J. Villaverde	Input-Output	Spain 1994 regionalised for Cantabria
2001	Analysis of the economic activity of the port of Seville and its provincial influence.	L.López, J.I. Castillo Man	Input-Output	Andalusia 1990 + localisation quotient
2001	The economic impact of the port of Almería on the Almerian and Andalusian economy.	M. Jaén, F. Fernández J. de Pablo, I. Amate L. Piedra and E. Acien	Input-Output	Andalusia 1995
2002	Study of the evaluation of the impact of the activities of the port of Cartagena on the economy.		Input-Output	Spain 1995
2002	Evaluation of the economic impact of the port of the bay of Cadiz.	J. M. Rey	Input-Output	Andalusia 1995

As can be seen, the applications for the analysis of port activity carried out in our country cover a large part of the Spanish port structure; Thus, of the 54 commercial ports which are spread across our country, slightly less than half (20 ports) have been the object of analysis in the last few years.

In fact, 17 of the 27 port authorities into which our marine system is structured have carried out, on some occasion, an analysis of the impact of their respective ports on the regional or local economy as a whole. 8 of the 12 autonomous regions and cities which have port installations already therefore have some measurement of the effect of this port activity on their respective economies.

Only the autonomous regions of Asturias and the Balearics, along with the autonomous cities of Ceuta and Melilla, have not been the object of analysis to date.

This interest in the study of the economic impact of port activity in Spain is still alive today, to the extent that the State Port Authority itself, just as the American administration did in its time, has made an effort to standardise this type of analysis by producing a Guide for the Evaluation of the Economic Impact of Ports, produced together with the consultancy company TYPSA, and the direct participation of the authors of this article has been used as the basis for it to be written.

From the review of all the studies carried out, both national and international, we can draw some basic conclusions which we have used to develop our alternative proposal for the analysis of the macroeconomic impact of ports, which we can specify in the following points:

- The methodology based on Input-Output tables, with all the nuances related to their limited dynamism or the excessively simplistic scenarios with which certain aspects of the analysis are approached, seems to be the most appropriate for carrying out the studies of the economic impact of ports.
- The majority of the studies make clear the time limitation involved when working with tools, such as the Input-Output tables, which have, in general, a fairly significant time lag (the most common situation is to have an Input-Output table available around five years after the period to which it refers). On most occasions it is therefore necessary to carry out a process to update these tables in order to bring them into line, in terms of time, with the period in which the investigation or direct evaluation of the port activity is being carried out.
- In the same way, the different studies carried out underline the problem of the spatial assignment of the effects induced by port activity, and it is necessary to construct Input-Output tables which are specific to the geographical area referred to, usually regions. These regional tables have the special characteristic of differentiating the interior sector and the sector of the region referred to from the rest of the national territory, and from the rest of the world, so that all the direct, indirect and induced effects can be located within the region itself or in the rest of the national territory, this being understood as a total aggregate, without it generally being possible to differentiate the specific effects in the rest of the regions.

- Likewise, from the analysis of the different works consulted it seems a process of action can be deduced, fairly well divided, which would start from the need to disaggregate and specifically identify the port activity within table I-O, which, in most cases, is not strictly considered, and for which specific field work is carried out that enables the main cost components of the companies linked to the port activity to be differentiated (IOT columns), as well as the main clients of these companies or users of the services linked to the port activity (IOT Rows).
- In addition, it is important to consider the so-called induced effects or effects of the income generated as a consequence of the port activity. In this sense, if we analyse the different calculations made in the different studies we can see that there are two alternative ways in which port activity ends up affecting the economic system as a whole, and which we could respectively call direct transactions and induced transactions. In the first group we would include the operations which are originated directly by the agents included in the aggregate of port activity, which would include both the purchases of normal goods and services, and the investments made by these agents and would generate what we have called direct effects. On the other hand, the second type of transactions would be those which are generated as a consequence of income resulting from this direct activity, and which would correspond to what we have called induced effects.

In view of these basic features identified in the main studies consulted on the analysis of the macroeconomic impact of ports, we have designed our alternative proposal for the determination of these impacts which is based on the construction and use of a Multi-regional Multi-sector Input-Output Table (IOT-RS) whose basic features are outlined below.

3. PROPOSAL FOR THE CONSTRUCTION OF A MULTI-REGIONAL MULTI-SECTORIAL TABLE.

Indeed, as can be deduced from the bibliographical review undertaken, carrying out an adequate analysis of the impact of port activity must necessarily include the availability of an Input-Output table adapted to both the geographical area and the time at which the analysis is intended to be carried out.

However, we consider establishing the analysis of port activity behaviour, even if it differentiates different activities, to be a short-sighted view, particularly from an aggregated perspective, and all the more so if this methodology is intended to be applied to regionally specific and localised port structures, which would be expected to have a specific structure as regards the different services on offer.

Moreover, this structure for the services on offer will not only be conditioned by the sectorial composition of its regional economy, or by the economic development of the area, (an analysis which could be established by developing, updating or generating the corresponding regional IOT), but it's higher or lower level of specialisation, efficiency, quality, etc., allows it the possibility of gaining new market shares in inter-regional and international trade. That is to say, the differential growth of the sector, whichever it may be, in any region can and must affect the port activity which is being analysed in each case.

It is precisely this second element which invites an innovative methodological approach such as the one we propose, through which it is intended to generate a sectorised regional macro Input-Output table, derived from the latest available national table, produced with direct information (1995), which incorporates the information on the production structure included in the different available regional IOT's, consistent with the information on Regional Accounting and includes the estimation of the flows of trade between the different regions and sectors.

In a first approximation, and considering the current availability of regional information, a regional-sectorised IOT could be considered which would include 26 branches of activity, prior to the differentiation of port activity, and 19 regions, corresponding to the 17 Autonomous Regions, plus the aggregate of the two extra-peninsular autonomous cities (Ceuta and Melilla), and non-regionalised public activities (Extra-Regio), following the usual Regional Accounting structure of the INE (National Statistics Institute), and which maintains the classic concept of row and column symmetry, as this format facilitates the development of the classic applications of the Input-Output methodology.

In accordance with this proposal, our matrix will be composed of the usual three sub-matrices of intermediate consumption, primary inputs and final demand, each one of them having the classic characteristics of the Input-Output structure.

The most obvious advantage of this procedure, compared to others where only the table for the region where the port which is intended to be analysed is located is used, rests on the possibility of simulating impacts on the growth of other regions and/or sectors which are unconnected, or at least remote from the main activity of the port which is the object of the study, where it is possible not only to analyse the incidence of a change in port activity from the demand perspective, but also when this is a consequence of induced growth in any region or sector of the Spanish economy.

In summary, the methodology used has a clearly applied and fundamentally general use, in the sense that it is valid for it to be applied in any point of our national territory, with any of the analyses which the Input-Output methodology establishes (links, direct, indirect and induced effects) being obtained as output.

Below we move on to briefly describe the content and structure of each one of the sub-matrices which would make up this new IOT-RS.

Intermediate inputs matrix

Matrix with S x R columns and S x (R+1) rows, with S being the total number of sectors considered 27 and R the total of regions 19, given that to the 17 Autonomous Regions is added an aggregate of the extra-peninsular autonomous cities, Ceuta and Melilla, and another for non-sectorised public activities (Extra-Regio) following the usual Regional Accounting structure of the INE.

The fact that one more row is included would make it necessary to incorporate the imported inputs for each region and sector.

In this way each cell of the intermediate consumption matrix of the national IOT which is taken as a point of reference would be disaggregated into 19 columns, one for each region considered, and 20 rows, adding to the 19 regions the row corresponding to the intermediate consumption imported for each region.

Within each of these expanded cells, and considering each of the columns (regions), the main diagonal would be made up of the interior intermediate consumption of each of the regional IOT's, the imports row would be the one corresponding to consumption imported from the rest of the world in the regional tables, and the total of the rest of regions would be that equivalent to the consumption imported from the rest of the national territory.

Taking 4 regions and 5 sectors as an example, the intermediate consumption matrix proposed would be formed as is shown in table 4, its characteristic element being of the type:

$$a_{sr,sr}$$

Where **s** and **r** represent respectively the sectors and regions considered

Table 4. SIntermediate Inputs Matrix

Sectors Regions	1 1	1 2	1 3	1 4	2 1	2 2	2 3	2 4	3 1	3 2	3 3	3 4	4 1	4 2	4 3	4 4	5 1	5 2	5 3	5 4
1.1	$A_{11.11}$	$a_{12.11}$	$a_{13.11}$	$a_{14.11}$	$a_{21.11}$	$a_{22.11}$	$a_{23.11}$	$A_{24.11}$	$a_{31.11}$	$a_{32.11}$	$a_{33.11}$	$a_{34.11}$	$a_{41.11}$	$a_{42.11}$	$a_{43.11}$	$a_{44.11}$	$a_{51.11}$	$a_{52.11}$	$a_{53.11}$	$a_{54.11}$
1.2	$A_{11.12}$	$a_{12.12}$	$a_{13.12}$	$a_{14.12}$	$a_{21.12}$	$a_{22.12}$	$a_{23.12}$	$A_{24.12}$	$a_{31.12}$	$a_{32.12}$	$a_{33.12}$	$a_{34.12}$	$a_{41.12}$	$a_{42.12}$	$a_{43.12}$	$a_{44.12}$	$a_{51.12}$	$a_{52.12}$	$a_{53.12}$	$a_{54.12}$
1.3	$A_{11.13}$	$a_{12.13}$	$a_{13.13}$	$a_{14.13}$	$a_{21.13}$	$a_{22.13}$	$a_{23.13}$	$A_{24.13}$	$a_{31.13}$	$a_{32.13}$	$a_{33.13}$	$a_{34.13}$	$a_{41.13}$	$a_{42.13}$	$a_{43.13}$	$a_{44.13}$	$a_{51.13}$	$a_{52.13}$	$a_{53.13}$	$a_{54.13}$
1.4	$A_{11.14}$	$a_{12.14}$	$a_{13.14}$	$a_{14.14}$	$a_{21.14}$	$a_{22.14}$	$a_{23.14}$	$A_{24.14}$	$a_{31.14}$	$a_{32.14}$	$a_{33.14}$	$a_{34.14}$	$a_{41.14}$	$a_{42.14}$	$a_{43.14}$	$a_{44.14}$	$a_{51.14}$	$a_{52.14}$	$a_{53.14}$	$a_{54.14}$
1.m	$A_{11.1m}$	$a_{12.1m}$	$a_{13.1m}$	$a_{14.1m}$	$a_{21.1m}$	$a_{22.1m}$	$a_{23.1m}$	$A_{24.1m}$	$a_{31.1m}$	$a_{32.1m}$	$a_{33.1m}$	$a_{34.1m}$	$a_{41.1m}$	$a_{42.1m}$	$a_{43.1m}$	$a_{44.1m}$	$a_{51.1m}$	$a_{52.1m}$	$a_{53.1m}$	$a_{54.1m}$
2.1	$A_{11.21}$	$a_{12.21}$	$a_{13.21}$	$a_{14.21}$	$a_{21.21}$	$a_{22.21}$	$a_{23.21}$	$A_{24.21}$	$a_{31.21}$	$a_{32.21}$	$a_{33.21}$	$a_{34.21}$	$a_{41.21}$	$a_{42.21}$	$a_{43.21}$	$a_{44.21}$	$a_{51.21}$	$a_{52.21}$	$a_{53.21}$	$a_{54.21}$
2.2	$A_{11.22}$	$a_{12.22}$	$a_{13.22}$	$a_{14.22}$	$a_{21.22}$	$a_{22.22}$	$a_{23.22}$	$A_{24.22}$	$a_{31.22}$	$a_{32.22}$	$a_{33.22}$	$a_{34.22}$	$a_{41.22}$	$a_{42.22}$	$a_{43.22}$	$a_{44.22}$	$a_{51.22}$	$a_{52.22}$	$a_{53.22}$	$a_{54.22}$
2.3	$A_{11.23}$	$a_{12.23}$	$a_{13.23}$	$a_{14.23}$	$a_{21.23}$	$a_{22.23}$	$a_{23.23}$	$A_{24.23}$	$a_{31.23}$	$a_{32.23}$	$a_{33.23}$	$a_{34.23}$	$a_{41.23}$	$a_{42.23}$	$a_{43.23}$	$a_{44.23}$	$a_{51.23}$	$a_{52.23}$	$a_{53.23}$	$a_{54.23}$
2.4	$A_{11.24}$	$a_{12.24}$	$a_{13.24}$	$a_{14.24}$	$a_{21.24}$	$a_{22.24}$	$a_{23.24}$	$A_{24.24}$	$a_{31.24}$	$a_{32.24}$	$a_{33.24}$	$a_{34.24}$	$a_{41.24}$	$a_{42.24}$	$a_{43.24}$	$a_{44.24}$	$a_{51.24}$	$a_{52.24}$	$a_{53.24}$	$a_{54.24}$
2.m	$A_{11.2m}$	$a_{12.2m}$	$a_{13.2m}$	$a_{14.2m}$	$a_{21.2m}$	$a_{22.2m}$	$a_{23.2m}$	$A_{24.2m}$	$a_{31.2m}$	$a_{32.2m}$	$a_{33.2m}$	$a_{34.2m}$	$a_{41.2m}$	$a_{42.2m}$	$a_{43.2m}$	$a_{44.2m}$	$a_{51.2m}$	$a_{52.2m}$	$a_{53.2m}$	$a_{54.2m}$
3.1	$A_{11.31}$	$a_{12.31}$	$a_{13.31}$	$a_{14.31}$	$a_{21.31}$	$a_{22.31}$	$a_{23.31}$	$A_{24.31}$	$a_{31.31}$	$a_{32.31}$	$a_{33.31}$	$a_{34.31}$	$a_{41.31}$	$a_{42.31}$	$a_{43.31}$	$a_{44.31}$	$a_{51.31}$	$a_{52.31}$	$a_{53.31}$	$a_{54.31}$
3.2	$A_{11.32}$	$a_{12.32}$	$a_{13.32}$	$a_{14.32}$	$a_{21.32}$	$a_{22.32}$	$a_{23.32}$	$A_{24.32}$	$a_{31.32}$	$a_{32.32}$	$a_{33.32}$	$a_{34.32}$	$a_{41.32}$	$a_{42.32}$	$a_{43.32}$	$a_{44.32}$	$a_{51.32}$	$a_{52.32}$	$a_{53.32}$	$a_{54.32}$
3.3	$A_{11.33}$	$a_{12.33}$	$a_{13.33}$	$a_{14.33}$	$a_{21.33}$	$a_{22.33}$	$a_{23.33}$	$A_{24.33}$	$a_{31.33}$	$a_{32.33}$	$a_{33.33}$	$a_{34.33}$	$a_{41.33}$	$a_{42.33}$	$a_{43.33}$	$a_{44.33}$	$a_{51.33}$	$a_{52.33}$	$a_{53.33}$	$a_{54.33}$
3.4	$A_{11.34}$	$a_{12.34}$	$a_{13.34}$	$a_{14.34}$	$a_{21.34}$	$a_{22.34}$	$a_{23.34}$	$A_{24.34}$	$a_{31.34}$	$a_{32.34}$	$a_{33.34}$	$a_{34.34}$	$a_{41.34}$	$a_{42.34}$	$a_{43.34}$	$a_{44.34}$	$a_{51.34}$	$a_{52.34}$	$a_{53.34}$	$a_{54.34}$
3.m	$A_{11.3m}$	$a_{12.3m}$	$a_{13.3m}$	$a_{14.3m}$	$a_{21.3m}$	$a_{22.3m}$	$a_{23.3m}$	$A_{24.3m}$	$a_{31.3m}$	$a_{32.3m}$	$a_{33.3m}$	$a_{34.3m}$	$a_{41.3m}$	$a_{42.3m}$	$a_{43.3m}$	$a_{44.3m}$	$a_{51.3m}$	$a_{52.3m}$	$a_{53.3m}$	$a_{54.3m}$
4.1	$A_{11.41}$	$a_{12.41}$	$a_{13.41}$	$a_{14.41}$	$a_{21.41}$	$a_{22.41}$	$a_{23.41}$	$A_{24.41}$	$a_{31.41}$	$a_{32.41}$	$a_{33.41}$	$a_{34.41}$	$a_{41.41}$	$a_{42.41}$	$a_{43.41}$	$a_{44.41}$	$a_{51.41}$	$a_{52.41}$	$a_{53.41}$	$a_{54.41}$
4.2	$A_{11.42}$	$a_{12.42}$	$a_{13.42}$	$a_{14.42}$	$a_{21.42}$	$a_{22.42}$	$a_{23.42}$	$A_{24.42}$	$a_{31.42}$	$a_{32.42}$	$a_{33.42}$	$a_{34.42}$	$a_{41.42}$	$a_{42.42}$	$a_{43.42}$	$a_{44.42}$	$a_{51.42}$	$a_{52.42}$	$a_{53.42}$	$a_{54.42}$
4.3	$A_{11.43}$	$a_{12.43}$	$a_{13.43}$	$a_{14.43}$	$a_{21.43}$	$a_{22.43}$	$a_{23.43}$	$A_{24.43}$	$a_{31.43}$	$a_{32.43}$	$a_{33.43}$	$a_{34.43}$	$a_{41.43}$	$a_{42.43}$	$a_{43.43}$	$a_{44.43}$	$a_{51.43}$	$a_{52.43}$	$a_{53.43}$	$a_{54.43}$
4.4	$A_{11.44}$	$a_{12.44}$	$a_{13.44}$	$a_{14.44}$	$a_{21.44}$	$a_{22.44}$	$a_{23.44}$	$A_{24.44}$	$a_{31.44}$	$a_{32.44}$	$a_{33.44}$	$a_{34.44}$	$a_{41.44}$	$a_{42.44}$	$a_{43.44}$	$a_{44.44}$	$a_{51.44}$	$a_{52.44}$	$a_{53.44}$	$a_{54.44}$
4.m	$A_{11.4m}$	$a_{12.4m}$	$a_{13.4m}$	$a_{14.4m}$	$a_{21.4m}$	$a_{22.4m}$	$a_{23.4m}$	$A_{24.4m}$	$a_{31.4m}$	$a_{32.4m}$	$a_{33.4m}$	$a_{34.4m}$	$a_{41.4m}$	$a_{42.4m}$	$a_{43.4m}$	$a_{44.4m}$	$a_{51.4m}$	$a_{52.4m}$	$a_{53.4m}$	$a_{54.4m}$
5.1	$A_{11.51}$	$a_{12.51}$	$a_{13.51}$	$a_{14.51}$	$a_{21.51}$	$a_{22.51}$	$a_{23.51}$	$A_{24.51}$	$a_{31.51}$	$a_{32.51}$	$a_{33.51}$	$a_{34.51}$	$a_{41.51}$	$a_{42.51}$	$a_{43.51}$	$a_{44.51}$	$a_{51.51}$	$a_{52.51}$	$a_{53.51}$	$a_{54.51}$
5.2	$A_{11.52}$	$a_{12.52}$	$a_{13.52}$	$a_{14.52}$	$a_{21.52}$	$a_{22.52}$	$a_{23.52}$	$A_{24.52}$	$a_{31.52}$	$a_{32.52}$	$a_{33.52}$	$a_{34.52}$	$a_{41.52}$	$a_{42.52}$	$a_{43.52}$	$a_{44.52}$	$a_{51.52}$	$a_{52.52}$	$a_{53.52}$	$a_{54.52}$
5.3	$A_{11.53}$	$a_{12.53}$	$a_{13.53}$	$a_{14.53}$	$a_{21.53}$	$a_{22.53}$	$a_{23.53}$	$A_{24.53}$	$a_{31.53}$	$a_{32.53}$	$a_{33.53}$	$a_{34.53}$	$a_{41.53}$	$a_{42.53}$	$a_{43.53}$	$a_{44.53}$	$a_{51.53}$	$a_{52.53}$	$a_{53.53}$	$a_{54.53}$
5.4	$A_{11.54}$	$a_{12.54}$	$a_{13.54}$	$a_{14.54}$	$a_{21.54}$	$a_{22.54}$	$a_{23.54}$	$A_{24.54}$	$a_{31.54}$	$a_{32.54}$	$a_{33.54}$	$a_{34.54}$	$a_{41.54}$	$a_{42.54}$	$a_{43.54}$	$a_{44.54}$	$a_{51.54}$	$a_{52.54}$	$a_{53.54}$	$a_{54.54}$
5.m	$A_{11.5m}$	$a_{12.5m}$	$a_{13.5m}$	$a_{14.5m}$	$a_{21.5m}$	$a_{22.5m}$	$a_{23.5m}$	$A_{24.5m}$	$a_{31.5m}$	$a_{32.5m}$	$a_{33.5m}$	$a_{34.5m}$	$a_{41.5m}$	$a_{42.5m}$	$a_{43.5m}$	$a_{44.5m}$	$a_{51.5m}$	$a_{52.5m}$	$a_{53.5m}$	$a_{54.5m}$

Primary Inputs Matrix

Matrix with S x R (27 x 19) columns in which both the rows and the elements are intended to differentiate in the primary input matrix. (Initially only the main elements, production, added value and equivalent imports were disaggregated)

Thus, starting from the national IOT each one of the columns in 19 Regions is disaggregated, where the only difference with the national tables is the disaggregation of the row of imports between a row of imports from the rest of the world, which would be equivalent to the national one, and a row of imports from the rest of the national territory, which would include the total flows of inter-regional trade.

This matrix thus defined, again using the simplification of 5 sectors and 4 regions would be formed, in a minimum specification, as is shown in table 5:

Table 5. Primary Inputs Matrix

Sectors	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	5	5	5	5
Regions	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Int. Growth Rate	TCI_{11}	TCI_{12}	TCI_{13}	TCI_{14}	TCI_{21}	TCI_{22}	TCI_{23}	TCI_{24}	TCI_{31}	TCI_{32}	TCI_{33}	TCI_{34}	TCI_{41}	TCI_{42}	TCI_{43}	TCI_{44}	TCI_{51}	TCI_{52}	TCI_{53}	TCI_{54}
VAT	IVA_{11}	IVA_{12}	IVA_{13}	IVA_{14}	IVA_{21}	IVA_{22}	IVA_{23}	IVA_{24}	IVA_{31}	IVA_{32}	IVA_{33}	IVA_{34}	IVA_{41}	IVA_{42}	IVA_{43}	IVA_{44}	IVA_{51}	IVA_{52}	IVA_{53}	IVA_{54}
Net Imports	IN_{11}	IN_{12}	IN_{13}	IN_{14}	IN_{21}	IN_{22}	IN_{23}	IN_{24}	IN_{31}	IN_{32}	IN_{33}	IN_{34}	IN_{41}	IN_{42}	IN_{43}	IN_{44}	IN_{51}	IN_{52}	IN_{53}	IN_{54}
S.Salaries	SS_{11}	SS_{12}	SS_{13}	SS_{14}	SS_{21}	SS_{22}	SS_{23}	SS_{24}	SS_{31}	SS_{32}	SS_{33}	SS_{34}	SS_{41}	SS_{42}	SS_{43}	SS_{44}	SS_{51}	SS_{52}	SS_{53}	SS_{54}
E.B.E. (Gross Operating Surplus)	EBE_{11}	EBE_{12}	EBE_{13}	EBE_{14}	EBE_{21}	EBE_{22}	EBE_{23}	EBE_{24}	EBE_{31}	EBE_{32}	EBE_{33}	EBE_{34}	EBE_{41}	EBE_{42}	EBE_{43}	EBE_{44}	EBE_{51}	EBE_{52}	EBE_{53}	EBE_{54}
VAB. (Gross Value Added)	VA_{11}	VA_{12}	VA_{13}	VA_{14}	VA_{21}	VA_{22}	VA_{23}	VA_{24}	VA_{31}	VA_{32}	VA_{33}	VA_{34}	VA_{41}	VA_{42}	VA_{43}	VA_{44}	VA_{51}	VA_{52}	VA_{53}	VA_{54}
Effective Production	PE_{11}	PE_{12}	PE_{13}	PE_{14}	PE_{21}	PE_{22}	PE_{23}	PE_{24}	PE_{31}	PE_{32}	PE_{33}	PE_{34}	PE_{41}	PE_{42}	PE_{43}	PE_{44}	PE_{51}	PE_{52}	PE_{53}	PE_{54}
Total Imp.	MT_{11}	MT_{12}	MT_{13}	MT_{14}	MT_{21}	MT_{22}	MT_{23}	MT_{24}	MT_{31}	MT_{32}	MT_{33}	MT_{34}	MT_{41}	MT_{42}	MT_{43}	MT_{44}	MT_{51}	MT_{52}	MT_{53}	MT_{54}
Exter. Imp.	ME_{11}	ME_{12}	ME_{13}	ME_{14}	ME_{21}	ME_{22}	ME_{23}	ME_{24}	ME_{31}	ME_{32}	ME_{33}	ME_{34}	ME_{41}	ME_{42}	ME_{43}	ME_{44}	ME_{51}	ME_{52}	ME_{53}	ME_{54}
Nat. Imp.	MN_{11}	MN_{12}	MN_{13}	MN_{14}	MN_{21}	MN_{22}	MN_{23}	MN_{24}	MN_{31}	MN_{32}	MN_{33}	MN_{34}	MN_{41}	MN_{42}	MN_{43}	MN_{44}	MN_{51}	MN_{52}	MN_{53}	MN_{54}
T. Inputs	TE_{11}	TE_{12}	TE_{13}	TE_{14}	TE_{21}	TE_{22}	TE_{23}	TE_{24}	TE_{31}	TE_{32}	TE_{33}	TE_{34}	TE_{41}	TE_{42}	TE_{43}	TE_{44}	TE_{51}	TE_{52}	TE_{53}	TE_{54}

Final Demand Matrix

The final demand matrix has dimensions of S*S x (R+1) rows (23^2 x 20) and D x R columns, with D being the number of differentiated components of the final demand, which were initially the Households and IPSFL's (Non-profit-making organisations) Expenditures, the Final Expenditures of the Public Administrations, the Gross Fixed Capital Formation, the Change in Inventories and the Exports to the rest of the world.

The rows would be the same as those for the intermediate inputs matrix, whilst the columns would be the result of regionally disaggregating each of the columns of the national IOT.

Following this proposal, each cell of the national IOT would be disaggregated into a new expanded cell where each column would include the value of the final demand component of each region which is acquired in each of the regions included in the different rows or in the additional row corresponding to the imports from the rest of the world.

The exports column would not have to be regionally disaggregated as it would only include the values exported to the rest of the world, as the inter-regional exports would be included in the rest of the final demand matrix and in the intermediate consumption matrix.

Using the simplified example, the final demand matrix would end up as is shown in table 6.

Table 6. Final Demand Matrix

Components / Regions	Households Expen.				Public Administrations Expenditures				Total Investment				Exp.	Total Outputs
	1	2	3	4	1	2	3	4	1	2	3	4		
1.1	$C1_{11}$	$C2_{,11}$	$C3_{,11}$	$C4_{,11}$	$G1_{,11}$	$G2_{,11}$	$G3_{,11}$	$G4_{,11}$	$I1_{,11}$	$I2_{,11}$	$I3_{,11}$	$I4_{,11}$	$X_{,11}$	TE11
1.2	$C1_{12}$	$C2_{,12}$	$C3_{,12}$	$C4_{,12}$	$G1_{,12}$	$G2_{,12}$	$G3_{,12}$	$G4_{,12}$	$I1_{,12}$	$I2_{,12}$	$I3_{,12}$	$I4_{,12}$	$X_{,12}$	TE12
1.3	$C1_{13}$	$C2_{,13}$	$C3_{,13}$	$C4_{,13}$	$G1_{,13}$	$G2_{,13}$	$G3_{,13}$	$G4_{,13}$	$I1_{,13}$	$I2_{,13}$	$I3_{,13}$	$I4_{,13}$	$X_{,13}$	TE13
1.4	$C1_{14}$	$C2_{,14}$	$C3_{,14}$	$C4_{,14}$	$G1_{,14}$	$G2_{,14}$	$G3_{,14}$	$G4_{,14}$	$I1_{,14}$	$I2_{,14}$	$I3_{,14}$	$I4_{,14}$	$X_{,14}$	TE14
1.m	$C1_{1M}$	$C2_{,1m}$	$C3_{,1m}$	$C4_{,1m}$	$G1_{,1m}$	$G2_{,1m}$	$G3_{,1m}$	$G4_{,1m}$	$I1_{,1m}$	$I2_{,1m}$	$I3_{,1m}$	$I4_{,1m}$	$X_{,1m}$	TE1m
2.1	$C1_{21}$	$C2_{,21}$	$C3_{,21}$	$C4_{,21}$	$G1_{,21}$	$G2_{,21}$	$G3_{,21}$	$G4_{,21}$	$I1_{,21}$	$I2_{,21}$	$I3_{,21}$	$I4_{,21}$	$X_{,21}$	$TE21_{,21}$
2.2	$C1_{22}$	$C2_{,22}$	$C3_{,22}$	$C4_{,22}$	$G1_{,22}$	$G2_{,22}$	$G3_{,22}$	$G4_{,22}$	$I1_{,22}$	$I2_{,22}$	$I3_{,22}$	$I4_{,22}$	$X_{,22}$	TE22
2.3	$C1_{23}$	$C2_{,23}$	$C3_{,23}$	$C4_{,23}$	$G1_{,23}$	$G2_{,23}$	$G3_{,23}$	$G4_{,23}$	$I1_{,23}$	$I2_{,23}$	$I3_{,23}$	$I4_{,23}$	$X_{,23}$	TE23
2.4	$C1_{24}$	$C2_{,24}$	$C3_{,24}$	$C4_{,24}$	$G1_{,24}$	$G2_{,24}$	$G3_{,24}$	$G4_{,24}$	$I1_{,24}$	$I2_{,24}$	$I3_{,24}$	$I4_{,24}$	$X_{,24}$	TE24
2.m	$C1_{2M}$	$C2_{,2m}$	$C3_{,2m}$	$C4_{,2m}$	$G1_{,2m}$	$G2_{,2m}$	$G3_{,2m}$	$G4_{,2m}$	$I1_{,2m}$	$I2_{,2m}$	$I3_{,2m}$	$I4_{,2m}$	$X_{,2m}$	TE2m
3.1	$C1_{31}$	$C2_{,31}$	$C3_{,31}$	$C4_{,31}$	$G1_{,31}$	$G2_{,31}$	$G3_{,31}$	$G4_{,31}$	$I1_{,31}$	$I2_{,31}$	$I3_{,31}$	$I4_{,31}$	$X_{,31}$	TE31
3.2	$C1_{32}$	$C2_{,32}$	$C3_{,32}$	$C4_{,32}$	$G1_{,32}$	$G2_{,32}$	$G3_{,32}$	$G4_{,32}$	$I1_{,32}$	$I2_{,32}$	$I3_{,32}$	$I4_{,32}$	$X_{,32}$	TE32
3.3	$C1_{33}$	$C2_{,33}$	$C3_{,33}$	$C4_{,33}$	$G1_{,33}$	$G2_{,33}$	$G3_{,33}$	$G4_{,33}$	$I1_{,33}$	$I2_{,33}$	$I3_{,33}$	$I4_{,33}$	$X_{,33}$	TE33
3.4	$C1_{34}$	$C2_{,34}$	$C3_{,34}$	$C4_{,34}$	$G1_{,34}$	$G2_{,34}$	$G3_{,34}$	$G4_{,34}$	$I1_{,34}$	$I2_{,34}$	$I3_{,34}$	$I4_{,34}$	$X_{,34}$	TE34
3.m	$C1_{3M}$	$C2_{,3m}$	$C3_{,3m}$	$C4_{,3m}$	$G1_{,3m}$	$G2_{,3m}$	$G3_{,3m}$	$G4_{,3m}$	$I1_{,3m}$	$I2_{,3m}$	$I3_{,3m}$	$I4_{,3m}$	$X_{,3m}$	TE3m
4.1	$C1_{41}$	$C2_{,41}$	$C3_{,41}$	$C4_{,41}$	$G1_{,41}$	$G2_{,41}$	$G3_{,41}$	$G4_{,41}$	$I1_{,41}$	$I2_{,41}$	$I3_{,41}$	$I4_{,41}$	$X_{,41}$	TE41
4.2	$C1_{42}$	$C2_{,42}$	$C3_{,42}$	$C4_{,42}$	$G1_{,42}$	$G2_{,42}$	$G3_{,42}$	$G4_{,42}$	$I1_{,42}$	$I2_{,42}$	$I3_{,42}$	$I4_{,42}$	$X_{,42}$	TE42
4.3	$C1_{43}$	$C2_{,43}$	$C3_{,43}$	$C4_{,43}$	$G1_{,43}$	$G2_{,43}$	$G3_{,43}$	$G4_{,43}$	$I1_{,43}$	$I2_{,43}$	$I3_{,43}$	$I4_{,43}$	$X_{,43}$	TE43
4.4	$C1_{44}$	$C2_{,44}$	$C3_{,44}$	$C4_{,44}$	$G1_{,44}$	$G2_{,44}$	$G3_{,44}$	$G4_{,44}$	$I1_{,44}$	$I2_{,44}$	$I3_{,44}$	$I4_{,44}$	$X_{,44}$	TE44
4.m	$C1_{4M}$	$C2_{,4m}$	$C3_{,4m}$	$C4_{,4m}$	$G1_{,4m}$	$G2_{,4m}$	$G3_{,4m}$	$G4_{,4m}$	$I1_{,4m}$	$I2_{,4m}$	$I3_{,4m}$	$I4_{,4m}$	$X_{,4m}$	TE4m
5.1	$C1_{51}$	$C2_{,51}$	$C3_{,51}$	$C4_{,51}$	$G1_{,51}$	$G2_{,51}$	$G3_{,51}$	$G4_{,51}$	$I1_{,51}$	$I2_{,51}$	$I3_{,51}$	$I4_{,51}$	$X_{,51}$	TE51
5.2	$C1_{52}$	$C2_{,52}$	$C3_{,52}$	$C4_{,52}$	$G1_{,52}$	$G2_{,52}$	$G3_{,52}$	$G4_{,52}$	$I1_{,52}$	$I2_{,52}$	$I3_{,52}$	$I4_{,52}$	$X_{,52}$	TE52
5.3	$C1_{53}$	$C2_{,53}$	$C3_{,53}$	$C4_{,53}$	$G1_{,53}$	$G2_{,53}$	$G3_{,53}$	$G4_{,53}$	$I1_{,53}$	$I2_{,53}$	$I3_{,53}$	$I4_{,53}$	$X_{,53}$	TE53
5.4	$C1_{54}$	$C2_{,54}$	$C3_{,54}$	$C4_{,54}$	$G1_{,54}$	$G2_{,54}$	$G3_{,54}$	$G4_{,54}$	$I1_{,54}$	$I2_{,54}$	$I3_{,54}$	$I4_{,54}$	$X_{,54}$	TE54
5.m	$C1_{5M}$	$C2_{,5m}$	$C3_{,5m}$	$C4_{,5m}$	$G1_{,5m}$	$G2_{,5m}$	$G3_{,5m}$	$G4_{,5m}$	$I1_{,5m}$	$I2_{,5m}$	$I3_{,5m}$	$I4_{,5m}$	$X_{,5m}$	TE5m

Although the specific details for the estimation and updating of these types of tables by far exceed the objectives and limitations of this article, we can say that these tables have been estimated for the year 1995 and updated to 2002.They are based on the official information available, and specific analyses of port activity impact have already been carried out for the ports of Vigo and Pasajes, and will appear in the above mentioned Guide for the Evaluation of the Economic Impact of Ports, which will be published shortly by the State Public Ports Authority.

We would not wish to end this section of the presentation of our methodological proposal without making it clear that against its advantages as regards the regionalisation of effects compared to other alternative proposals, the main disadvantage of this procedure is the need to have much more detailed direct information available, which differentiates, both regionally and sectorially, the supplier and client structure of the different agents included in the so-called port activity

4. SUMMARY AND MAIN CONCLUSIONS

In this article a review of the national and international literature dedicated to the study of the economic impact of ports has been carried out, and it has been seen that the applications which use the methodology based on Input-Output tables are those which enjoy greater popularity and application.

However, these applications are not free from either methodological or application difficulties, as their fundamental basis, the Input-Output tables, are not always available with the disaggregation and updating required by these types of studies of the macroeconomic impact of port activity.

Against these limitations, it is proposed that new Input-Output tables be used, which include both regional and sectorial disaggregation, and may be updated using indirect processes, and on which the classic analyses of the impact of port activity derived from the Input-Output methodology can be carried out, with the regional dimension being directly incorporated.

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EL IMPACTO MACROECONÓMICO DE LOS PUERTOS: REVISIÓN DE LA LITERATURA Y PROPUESTA ALTERNATIVA.

RESUMEN

En el presente artículo se realiza una revisión de las diferentes alternativas que han ido recogiendo en la literatura aplicada para el análisis del impacto económico de la actividad portuaria, detectándose las principales ventajas e inconvenientes de cada una de ellas y comprobándose que la aplicaciones basadas en tablas Input-Ouput son, con diferencia, las mas utilizadas tanto a nivel nacional como internacional.

A la luz de esta revisión realizada se propone un procedimiento alternativo que, recogiendo las principales ventajas de la metodología input-output, permita la aplicación sistemática a todas las regiones españolas y la ubicación regional de los diferentes impactos, tanto directos, como indirectos e inducidos.

Palabras clave: Tablas Input-Output, Impacto económico de los puertos, Regionalización.

RESUMEN Y CONCLUSIONES

En el presente articulo se ha realizado una revisión de la literatura, tanto nacional como internacional dedicada al estudio del impacto económico de los puertos, pudiendo comprobarse que las aplicaciones que utilizan la metodología basada en tablas Input-Output, son las que gozan de una mayor popularidad y aplicación.

No obstante dichas aplicaciones no están exentas de dificultades, tanto metodológicas como de aplicación, ya que su base fundamental, las Tablas Input-Output, no siempre están disponibles con la desagregación y actualización que precisan este tipo de estudios del impacto macroeconómico de la actividad portuaria.

Frente a estas limitaciones, se propone la utilización de unas nuevas Tablas Input-Output, que recojan una desagregación tanto regional como sectorial, que pueden ser actualizadas mediante procedimientos indirectos, y sobre las que elaborar los análisis clásicos de impacto de la actividad portuaria derivados de la metodología Input-Output e incorporando de forma directa la dimensión regional de los mismos.

De la revisión de todos estos estudios realizados, tanto nivel nacional como internacional, podemos deducir algunas líneas básicas que nos han servido para desarrollar nuestra propuesta alternativa para el análisis del impacto macroeconómico de los puertos y que podemos concretar en los siguientes puntos:

- La metodología basada en Tablas Input-Output, con todos los matices relativos a su escasa dinamicidad o los supuestos excesivamente simplistas con los que se abordan determinados aspectos del análisis parece ser la más adecuada para la realización de los estudios del impacto económico de los puertos.
- La mayoría de los estudios ponen de manifiesto la limitación temporal que supone el hecho de trabajar con unas herramientas, como son las Tablas Input-Output, que presentan, en general, un desfase temporal bastante significativo (lo más frecuente es disponer de una tabla Input-Output unos cinco años después de su periodo de referencia), por lo que, en la mayoría de las ocasiones es necesario realizar un proceso de actualización de dichas tablas para homologarlas temporalmente al periodo en el que se realiza la investigación o valoración directa de la actividad portuaria.
- En el mismo sentido, los diferentes estudios realizados ponen de relieve la problemática de la asignación espacial de los efectos inducidos por la actividad portuaria, siendo necesaria la construcción de Tablas Input-Output específicas del ámbito geográfico de referencia, en general regiones. Estas tablas regionales tienen la particularidad de diferenciar el sector interior, el propio de la región de referencia, del resto del territorio nacional, y del resto del mundo, por lo que el conjunto de efectos directos, indirectos e inducidos, pueden ubicarse, dentro de la propia región o en el resto del territorio nacional, entendido éste como un agregado total, sin que sea posible, en general diferenciar los efectos específicos en el resto de regiones.
- Igualmente, del análisis de los diferentes trabajos consultados parece deducirse un procedimiento de actuación, bastante compartido, que partiría de la necesidad de desagregar e identificar de forma específica la actividad portuaria dentro de la tabla I-O, que, en la mayoría de los casos, no se encuentra estrictamente contemplada, y para lo cuál se realiza un trabajo de campo específico que permite diferenciar los principales componentes de coste de las empresas vinculadas a la actividad portuaria (Columnas de la TIO), así como los principales clientes de dichas empresas o usuarios de los servicios vinculados a la actividad portuaria (Filas de la TIO).
- Adicionalmente, es importante considerar los denominados efectos inducidos o efectos de las rentas generadas como consecuencia de la actividad portuaria. En este sentido, si analizamos los diferentes cálculos realizados en los distintos estudios podremos comprobar que existen dos vías alternativas mediante las cuales la actividad portuaria termina afectando al conjunto del sistema económico, y que podríamos denominar, respectivamente como transacciones directas y transacciones inducidas. Dentro de las primeras incluiríamos las operaciones que se originan de forma directa en los agentes incluidos en el agregado de actividad portuaria e incluirían, tanto las compras de bienes y servicios corrientes, como las inversiones realizadas por dichos agentes y generarían lo que hemos denominado como efectos directos. Por el contrario, el segundo de tipo de transacciones serían las que generan como consecuencia de la distribución de rentas derivada de dicha actividad directa, y que responderían a lo que hemos denominado efectos inducidos.

A la vista de estos rasgos básicos identificados en los principales estudios consultados sobre el análisis del impacto macroeconómico de los puertos hemos diseñado nuestra propuesta alternativa para la determinación de dichos impactos y que se basa en la construcción y utilización de una Tabla Input-Output Multirregional Multisectorial (TIO-RS).

En efecto, y tal como se deduce de la revisión bibliográfica efectuada la realización de un adecuado análisis de impactos de la actividad portuaria pasa, necesariamente por la disponibilidad de una tabla Input-Output adecuada tanto al ámbito geográfico, como al momento temporal en el que se pretende realizar el análisis.

Sin embargo, consideramos una visión miope el establecer el análisis del comportamiento de la actividad portuaria, aún diferenciado en diferentes actividades, desde una perspectiva agregada espacialmente, máxime si se desea aplicar dicha metodología a estructuras portuarias concretas y localizadas regionalmente, que presentarán, previsiblemente, una estructura específica en cuanto a los diferentes servicios ofertados.

Es más, dicha estructura de la oferta de servicios estará condicionada no sólo por la composición sectorial de su economía regional, o por la evolución económica de la zona, (análisis que podría establecerse desarrollando, actualizando o generando la correspondiente TIO regional), sino que su mayor o menor nivel de especialización, de eficiencia, de calidad, etc., le infiere la posibilidad de captar nuevas cuotas de comercio interregional e internacional. Es decir, el crecimiento diferencial de un sector, sea cual fuere, en una región cualquiera puede y debe afectar a la actividad portuaria que en cada caso se esté analizando.

Precisamente es este segundo elemento el que invita a un novedoso planteamiento metodológico como el que proponemos, bajo el que se pretende generar una macro tabla Input-Output regional sectorizada, derivada de la última tabla nacional disponible, elaborada con información directa (1995), y que incorpora la información de la estructura productiva recogida en las distintas TIO regionales disponibles, congruente con la información de Contabilidad Regional y que recoge la estimación de los flujos de comercio entre las distintas regiones y sectores.

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