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STARTING OF THE NAVAL DIESEL-ELECTRIC PROPULSION. THE VANDAL

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ABSTRACT

Until the advent of diesel engines, electric propulsion craft needed the energy stored in batteries (primary or secondary) fitted on board. That was the beginning of electric propulsion of ships. Their limitations were, like earlier today, the power and battery capacity restricting its usefulness as an energy source for propulsion of merchant ships. In the early twentieth century are starting to get on board diesel engines a technological revolution, but these first units were not reversible machines. Thus arises as a solution to this critical operational limitation, the first vessel with diesel-electric propulsion, the "Vandal", followed by another twin hull ship, the "Sarmart", also with diesel-electric propulsion, but with a different propulsion plant design.

This paper reviews the pioneering, yet little known, carried out in a river tanker early twentieth century history of the kind of widespread naval propulsion for large cruise ships of the early twenty-first century.

Keywords: Electric propulsion ship, reversibility, power sources, innovation.

INTRODUCTION

Until the nineteenth century, for ocean sailing, vessels are propelled by the wind pressure on the windward face of the sails, making it impossible to move against the wind. The course and speed depended on the direction and intensity of wind. The

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giant leap in large sailing guessed the appearance of steam. Its first experimental application was in 1707, where the French inventor Dennis Papin installed a small steam engine 1,5 hp on a paddle wheel boat. The first transatlantic voyage sailing only with steam was performed in 1837 by the ship "*Sirius*". Since the early years of the twentieth century gradually imposed Diesel propulsion. In 1914 there were just over 300 diesel-powered ships, 10 years later there were over 2000 ships and about 8000 in 1940. In that year, about 60% of ships coming out of the shipyards were diesel powered and virtually the rest with steam turbine or reciprocating engine.

The first practical diesel engines appeared from 1897, resulting from the work of its inventor Rudolf Diesel. These engines were very bulky and heavy, they developed an output of 17,8 hp (13,1 Kw) to 154 rpm and its consumption was 238g/hp·h (efficiency 26,2%) was a single cylinder engine, four stroke, with a bore and stroke of 250 mm and 400 mm respectively. The following were already two-cylinder, 70hp at 160 rpm, weighed 15,5 tons, giving a ratio of 221 kg/hp. In 1905 consumption had fallen to 185g/hp.h with fuel calorific value of 10.000 Kcal/kg.

The main drawback of these engines to be applied for naval propulsion was its non-reversibility. In 1904 the first diesel engine for propulsion was fitted at the vessel " Petit Pierre " , a small river vessel 38 m in length. It was the first ship diesel mechanics (conventionally powered) and also had a reversible-pitch propeller. Many sources say that the first ocean-going vessels with diesel propulsion were the "*Selandia*" (launched in 1912), a passenger/cargo ship, with 2 Burmeister & Wain of four stroke, 8 cylinders, 1250 hp, 140 rpm reversible, each moving its propeller and the "*Monte Penedo*" also in 1912, with two Sulzers of 625 Kw each, 160 rpm (it was the first ship powered by a two stroke Diesel).

As mentioned earlier, the first diesel engines were not reversible, and therefore could not be used as propellers in vessels as they lacked the necessary manoeuvrability. Another solution to this problem was proposed by Italian electrical engineer Cesidio del Proposto with his patent of 1903 .(Proposto, 1906)

The innovative proposals in naval propulsion are continuous, also from Spain (Llana, 2009)

YEAR 1900. STATE OF THE ART

The transition from steam power to diesel propulsion was justified by the lower fuel consumption (assumed to spend about 700-180 g/hp.h) that is to say, less fuel was needed to travel a great distance. It is also apparent that for a weight of fuel stored given, autonomy would be much higher. The boiler consumed coal, in front of, the liquid fuel of the diesel engine. Liquid fuel, unlike coal, could be stored in double bottom tanks or structural difficult for other uses, remaining free spaces for holds, cabins, cargo tanks,…but against was the cost per kg of fuel, much cheaper the coal than gasoline. An economic study done at the time for two identical vessels was a fuel cost for a vessel powered by diesel engine of the third part of the steam-powered machine.

In the late 20's of XX century, fuel consumptions, depending on the locomotive engine, was as show in the tables below (Ludwig, 1933)

Table 1: Fuel consumptions with steam machine.

Machine class	Power in HPI	Saturated steam g/HPI·h	Superheated steam g/HPI·h
Compund Machine small	50 - 200	1800 - 1400	
	With condensation	1300 - 1000	
Triple expansion Machine	400 - 1000	870 - 700	700 - 600
Triple expansion Machine	1500 - 3000	690 - 640	580 - 530
Quadruple expansion Machine	5000 - 10000	680 - 630	570 - 520
Installation of two steam engines and exhaust turbine in the central shaft	10000 - 50000	550 - 500	510 - 450
Triple expansion engine with exhaust turbine on the same central shaft	1000 - 5000	520 - 480	440 - 400

This data includes auxiliary machinery, and burning coal of 7800 cal/kg. Using liquid fuel of 9600 cal/kg, the consumption lowered by 25%.

Table 2: Fuel consumptions with steam turbine

Machine class	Power in HPI	Saturated steam g/HPI·h	Superheated steam g/HPI·h
Turbine working independent in each tree	3000 - 5000/shaft	750 - 700	
Turbine in serie working on several shafts	10000 - 75000	700 - 600	
Turbine with reduction gear	5000 - 20000/shaft	600 - 550	550 - 450

Equally including the auxiliary engines, and burning coal of 7800 cal/kg. Using liquid fuel of 9600 cal/kg, the consumption lowered by 25%.

Table 3: Fuel consumptions with engine diesel

Diesel engine Class	g/HPE·h
Four Stroke - Single effect	180- 185
Four Stroke - Double effect	182 - 188
Two stroke - Single effect	188 – 194
Two Stroke - Double effect	190 - 195

These dates considered that the injection compressors, water circulating pumps, oil pumps, and turbocharger are clouped to the engine.

In all cases the date refers to average values for marine equipment. The highest rates are for low power and lower to the higher powers. Today, early twenty-first century, the large marine diesel engines of two stroke have a consumption smaller than 170g/Kw·h (127g/hp·h). (Weisser, 2004)

Other disadvantages of steam propulsion, turbine or reciprocating machine, starting from initial state, is the enormous time for starting, whose remedy is also for port days, keeping the boiler continuously running, with the need permanent personnel for watching and operation and consuming fuel. Moreover, the embarrassment is great for this type of installations.

In front of the undeniable advantage of higher thermal efficiency, characteristics against diesel propulsion were:

1. Non-availability of large power per unit.
2. Non-directly reversible.
3. Difficult regulation
4. Special difficulty in working at low revolutions. Little torque available.

Let see each of the items listed.

1. In 1906 three years after of the launched of “ Vandal “, the maximum power per cylinder was 250 HP, which accounted for a four cylinder, four stroke and single effect, normally in this time the diesel engine was 1000 HP. The bore and stroke of these engines were respectively 700 and 770 mm, and 150 rpm speed.

One solution to increase the total power was fitting three propulsion engines, each one moving its tail shaft and propeller. A total of 3000 HP, power certainly not depreciated and sufficient for most merchant vessels. Although from the standpoint of power is a satisfactory solution, it has several disadvantages. The first, it is an expensive solution, three tail shafts with its propellers, and the two axial shafts with its propeller shaft stay, three stern bush,… Moreover, three sets of machines occupy much space in the engine room.

2. Non-reversible. The non-reversibility implies that it cannot be used as naval propulsion, and they are deprived of the necessary handling, essential not only in the mooring and unmooring.

Since 1899 patent arise to make it reversible. A first patent was based on a double camshaft. Its practical application was not satisfactory as some subsequently.

Solutions provided in these in these early years were the use of reversible-pitch propellers or mechanical clutches, but that served only to small powers (fishing, tugs, yachts)

3. Difficult regulation. When working out the condition of constant load torque, as is the case for example of navigation in bad weather, it is difficult to adjust the amount of fuel to be injected. Bosch injection does not appear until 1927.

4. Reduced torque at low revolutions.

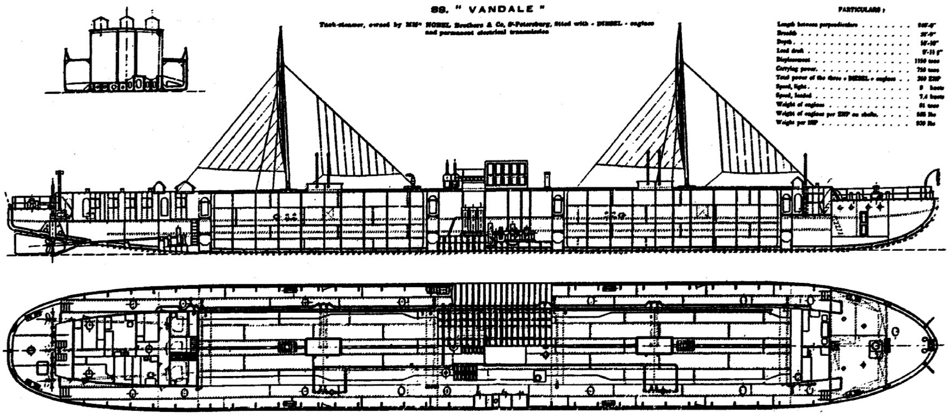

Figure 1. Vandal. General arrangement.

Diesel engines have a torque-speed characteristic with a very low torque at low revolutions, which prevents them for working at very low speed. Say another way, the torque available at very low speed is less than the resistive torque exerted by the propeller and therefore the engine would stop. Unable to work at very low revolutions, if necessary a low speed, we need to work cycles of start-stop-start either starting ahead-stop-astern.

Another drawback, although minor, it is that the engine room is very noisy.

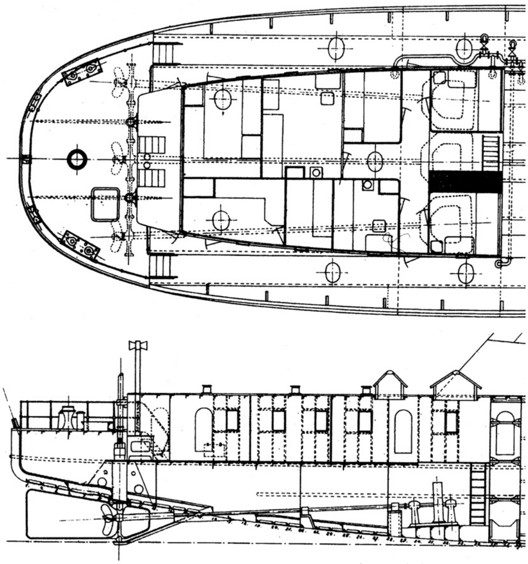

Figure 2. Stern of Vandal.

CHARACTERISTICS OF THE "*VANDAL*"

Length between perpendiculars: ...	75 m.	Deck cargo:	750 Tm.
Breadth:	9,70 m.	Power:	360 EHP
Depth:	3,33 m.	Speed:	8 Knots
Draught:	1,83	Load speed:	7,4 Knots
Displacement:	1150 Tm.	Machine weight:	81 Tm.

The "*Vandal*" ,tanquer vessel of 1150 tonnes of displacement, shallow draught, was built in the yards " Nobel Brothers Company " of San Petsburgo under the direction of Immanuel Nobel (son of Ludwing Nobel) and engineer Hagelin KW. (Koehler, 1998).

Designed to carry oil through for the Volga River and Caspian Sea was launched in 1903 and operated by the “ Nobel Brothers Petroleum Company “. Its first voyage was in the spring of that year, to get rid of winter ice. The Nobel brothers (Robert and Ludwing) drove the business and the oil industry in Azerbaijan. In 1903 the Baku region provided 50% of word oil production.

Figure 3 shows a bad photo, a model and a little faithful picture of the Vandal.

This vessel had three generators (diesel engine-dynamo) each diesel engine, three cylinders with bore/stroke 290/430 mm, 120 hp runnig to 240 rpm(another reference gives the date of 255 rpm), simple effect, moving a generator of 87 Kw and 500 V (figure 1). Each dynamo fed to its propulsor electric-motor, reversible, of 75 Kw directly coupled to the propeller shaft. Speed control of each propeller is made with a “controller” from the bridge which acts on the excitation current of the dynamo, current from a small exciter located within the same axis line of the main dynamo.

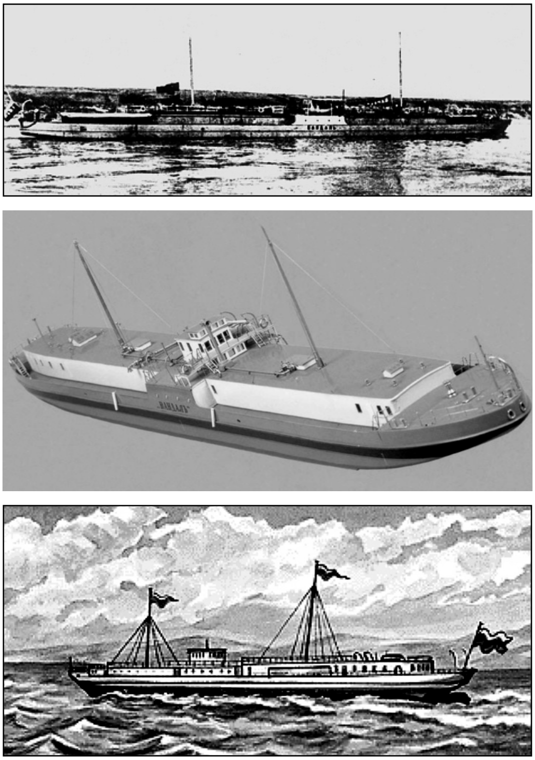

Figure 3. Photo, model and picture of Vandal.

This is achieved by controlling a large current (the induced main generator and propulsor motor) to adjust a small current (the excitation main generator), with a small rheostat. In this ship could move from ahead machine to astern machine all in under 10 seconds (between 8 and 12 according to another reference). The speed of the propellers could be adjusted between 30 and 300 rpm.

On the bridge is available for three controls (drum manoeuvre or “controller”) on which it acted by a handle outside, and therefore could independently regulate the speed of each propeller. Inside the “controller” has a cylindrical drum and turning some contacts opening and closing other, with several connections, suitable for any situation desired. The switching elements were supplied by ASEA (Sweden).

The figure 4 shows a combiner, but after these years. The signalling lamp H indicates that is now available to operate the propeller and the voltmeter V indicates the

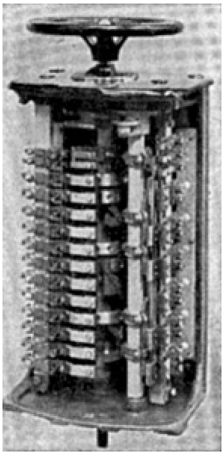

Figure 4. "Controller".

speed of the propeller as propulsion engines since it is independent of excitation voltage is (approximately) directly proportional to the rotation speed. The reversal of the progress achieved by reversing the current in the winding excitation of the main generator, which, by staying the same direction of rotation imposed by the diesel, it reverses the polarity of the voltage produced by the main generator for that in the propulsor motor, to keep the polarity of the field inductor , the rotation is reversing, by reversing the feed current of the inductor.

That is, both the combinators as the lamps H and the voltmeters V were located on the bridge, which is just where you could manoeuvre.

The electrical connection between the main generator and electric motor propulsor was direct and permanent, that is, without any interference of some element of manoeuvre or protection in this line. This design has certain advantages (simpler, cheaper, less faults, not interference..) but also some drawbacks (unable to feed from a generator to another engine than the yours, not being able a fault).

The machinery was distributed between the engine room, located half a length (Figure 1), where diesel engine were installed, aligned in the direction forward-aft, with output power by the forward end to the continuation of the flywheel that follows the coupling and the dynamo and exciter. That is: diesel engine – flywheel - bearing support – dynamo – bearing support exciter. And the whole multiplied by three, distributed in parallel: one in the center and the other at the line to both sides. Electric motor room was located in the aft. As in the main engine room, electric motors are fitted one in the center, and the other two to both bands. Each engine moving through the tailshaft , about 10 m in length, its propeller (fixed pitch) respectively. Tailshafts could not be shorter, seeing that, the electric motors, for its diameter, could no be located more aft. Therefore, the motor-side assemblies, tailshaft, propeller were slightly divergent alignment, as open in angle, of about 3° each. Between each two propellers were fitted two semicompensed rudders. As can be seen in cross section (figure 2), the tailshafts had a slight fall towards the aft (about 5 degrees). At the plan does not appearence drawn the three thrust bearings.

Table 4. Characteristics.

Diesel-Engine	Dynamo	Exciter	Electric-motor	Total Weight	Speed (knots)
N° cylinders 3	Power(Kw) 87,5	Power (Kw) 20	Power (Kw) 75	81(Tm)	Unload (8)
HPE 120	Tension (V) 500	Weight (Tm) 1,7	Weight (Tm) 4,2	—	Load (7,4)
Rpm 240 (255)	Weight (Tm) 4,5	—	—	—	—
Weight (Tm) 16	—	—	—	—	—

The simplified scheme of the propulsor system is as follows:

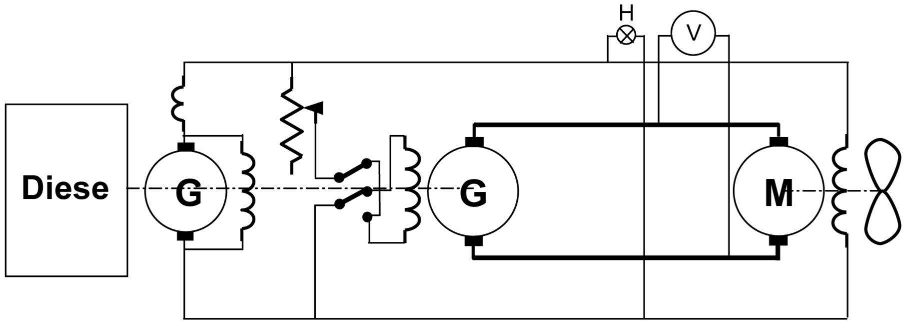

Figure 5. *"Vandal"* Electric scheme.

Diesel engines manufactured by the "Swedish manufacturer A.B. Diesel Engines" (later Atlas Diesel Company), had been delivered in the Autumn of 1902. Electrical machines were built by General Electric Company of Sweden (later A.S.E.A.).

Table 4 above are some characteristics relating to this ship.

The arrangement is as a Ward-Leonard system, where it replaces the alternating current motor fed from a three-phase network by diesel engine. It can be seen both in the cut of Figure 3 as in the photo of the centre in the annex, for the same power the size of the electrical machine is much smaller than the diesel engine.

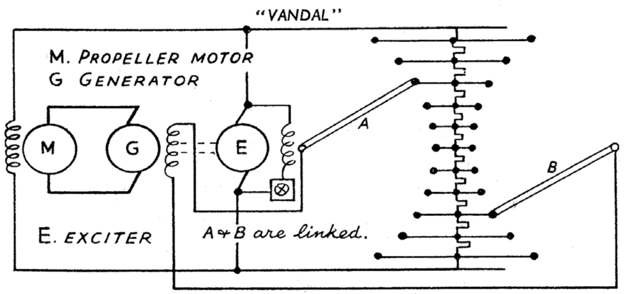

Figure 6. " *Vandal*" Alternative electrical scheme.

Another possible scheme of the electrical propulsion of this vessel can be seen in Figure 6, very similar to previously represented in figure 5; the inversion will be progressively achieved by acting on the double switch by means of the controller. (Horne, 1939)

As an example could be the following:

Initial position represented: " HALF AHEAD " (potential of "A" greater than "B").

Acting on the drive to the left, the cursor of the left side turns in the clockwise, and the right cursor in counter clockwise together. The electric potential difference between the two cursors decreases, the excitation current of the dynamo G decreases, the magnetic flux and the voltage generated by G lows, and the voltage applied to the armature M lows, without changing its magnetic flux, its speed lower proportionately. (M: Propulsor engine directly coupled to the propeller).

If you continue turning the slide and a position is reached, that in the figure corresponds to both cursors aligned, connected to two terminals at the same potential, and therefore without excitation current from the generator E, and without feeding the propulsor engine. Position "STOP".

If the drive continues turning to the left, now the cursor of the left is connected to a potential more negative (less positive) than the right. Therefore the current is reverses in the inductor of the generator G and the polarity of the brushes is reversed. In the propulsor motor the flux was not changed, thus to reversing the current in the armature, the torque will be reduced and it will rotate counter clockwise. It corresponds to the position "LITTLE ASTERN"

A drawback of this system and it is the argument that always is invoked against the electric propulsion, they are some loss of power at each processing of power and also that the propulsion plant is more expensive. In this vessel the output of the diesel engines amounted to 360 HP, instead the power transmitted to the propeller was 290 HP. That is, the loss was almost 20%.

This vessel was operational until 1913, usually carrying lighting oil, although it could not operate during the long Russian winter, due to the ice.

The reason of such a short life period may be due to the fact that these first electrical machines, by the fact that they were working continuously, the maintenance was expensive and the fact that some of these operations of maintenance and repairing could not be carried out on board, with the consequent need for disassembly, transfer to the ground, unavailability... together with the resulting cost, it would have been to the ship-owners to choose another possibility.

In 1913 reversible diesel engines had already appeared , but the fact that the engine rooms were half a length, did not allow an easy transformation.

HANDLY AND SAFETY

The "*Vandal*", with its three lines of axes completely independent, it gave a great manoeuvrability, safety and reliability. Keep in mind that there is no delay from that, since each controller on the bridge, from the starting order in one direction until that the propeller is started, there is not conventional telegraph orders. Manoeuvres of go astern could be performed without difficulty.

The time to stop the vessel, as mentioned above, and the path overhauling would be very small, to be able to invert the rotation of the three propellers in a short time and also by the fact of the three propellers would be very effective.

The turning radius would be also reduced by the fact of having two rudders and, as has been said, of being able to work, for example, the starboard propeller " ALL AHEAD" and the port "ALL ASTERN".

As the rudders was not fitted on the aft of the propellers, it was a drawback from the standpoint of manoeuvrability, seeing that, with the vessel stopped or at very slow speed the rudder does not work. The advantage of the solution adopted was that the rudders were protected against impact, against the quay during the manoeuvres by the bulwarks of aft. Keep in mind that due to the small depth of the vessel, the surface of the rudder is based on the length, and as noted above the length of the tail was considerable.

Since the ship had two masts and four sails ready for sailing, they could be used if in that moment the wind blows "land" , by unmoored the vessel of the quay, or if the wind blows of the "sea" to bring it to the quay during the docking maneuver.

Regarding security, the fact of having three propulsor set independents, it is a safety because when a critical failure is produced in any of them (in the diesel, in the exciter, in the the dynamo or in the electromotor) the vessel could have continue working with the other two tailshafts. If the failure is on the central axis, the other two could continue working at full power. The consequence is that the speed will be now more reduced, but more than two thirds of which would be before the failure. If, however, that failure was one of the lateral axes (worst case), for example the starboard, we could navigate only with the central axe to full power, although the speed of the vessel will be smaller, or to increase the speed, with the center a full power, with the port a little less than full power, and to avoid falling to starboard, the rudders a little to port.

Keep in mind that the reliability of each propulsor set, being four machines, one thermic and three electrical, is less than each individually. In a chain of four links, if one fails, it fails the whole. And the repair of electrical engines, in many cases is not feasible on board with the consequences of the unavailability.

The use of the sails may be reserved only for cases with good weather navigation and wind very favourable. How curious, it is said that the stay and both masts instead to go to forward and aft, it goes in the direction of port bow- starboard.

CONCLUSIONS

In this paper was showed the first application of the Diesel electric propulsion in the naval field. But cannot say that it was the first step on the technology that was developed for ships propellant because it constitutes an experience that went unnoticed in the rest of the word, is enough to prove this check as the first monograph published in the UK and U.S., *The Electric Propulsion of Ships,* written by engineering H.M. Hobart in 1911, eight years after that the " *Vandal* " was launched, and discusses the possibilities and fields of applications of this technology, does not make mention of it. This engineer picks up, however, the first case of diesel electric propulsion in the United Kingdom, the " *Electric Arc* " a pleasure boat 50 feet, launched in Dumbarton in February 1911 (Times, 1911). The Diesel engine moved a three-phase alternator 800 rpm and the propeller was moved directly by a cage motor with two separate windings, one of four poles and the other six. (Hobart, 1911).

A paper published in 1918 by Civil Engineering A. Foillard appointment as first experiences in America to the vessels " *Frieda* " with propulsion turbo-electric, cargo of 5000 Tns, and the " *Tynemount* " (1913), electric diesel to navigate for the Great Lakes (in its first voyage in early 1914, carrying coal to Santander suffered a damage that the vessel was towed to port), the *"Jupiter"* a coal cargo, electrical-turbo of the Navy United States launched in April 1913. For Europe appointment as the first unit to *"Mjölner"* electrical-turbo, launched in December 1914.(Foillard,1918).

Finally, among others, a 1925 paper presented by A. Kennedy Frank Smith shows a propulsion type Ward-Leonard for two boats of Chicago fire, "*Joseph Medill*" and "*Graeme Stewart*", working in 1908.(Kennedy, 1925).

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INICIO DE LA PROPULSIÓN NAVAL DIESEL-ELÉCTRICA. EL VANDAL

RESUMEN

Hasta la aparición de los motores Diesel, la propulsión eléctrica en las embarcaciones precisaba de la energía almacenada en las baterías (primarias ó secundarias) montadas a bordo. Ese fue el principio de la propulsión eléctrica de buques. Sus limitaciones eran, antes igual que hoy en día, la potencia y la capacidad de las baterías que restringían grandemente su utilidad como fuente de energía para la propulsión de los buques mercantes. A principios del siglo XX se empiezan a montar a bordo los motores Diesel, una auténtica revolución tecnológica, pero estas primeras unidades eran máquinas no reversibles. Surge así, como solución a esta crucial limitación operativa, el primer buque con propulsión Diesel-eléctrica, el "Vandal", al que siguió otro buque con casco gemelo, el "Sarmat", también con propulsión Diesel-Eléctrica, pero con un distinto diseño de la planta propulsora.

Este artículo muestra la experiencia pionera, y sin embargo poco conocida, llevada a cabo en un petrolero fluvial a principios del siglo XX, antecedente del tipo de propulsión naval ampliamente extendido para los grandes cruceros de inicios del siglo XXI.

Palabras clave: Propulsión Eléctrica Naval. Reversibilidad. Fuentes de Energía. Innovación.

INTRODUCCIÓN

Hasta el siglo XIX, para las navegaciones oceánicas los buques se impulsaban gracias a la presión que el viento ejercía sobre la cara de barlovento del velamen, siendo imposible avanzar contra el viento. Rumbo y velocidad dependían entonces de la dirección e intensidad del viento. El paso de gigante en grandes navegaciones lo supuso la aparición del vapor. Su primera aplicación experimental data de 1707 donde el inventor francés Dennis Papin instaló una pequeña máquina de vapor de 1,5 hp en una embarcación de paletas. La primera travesía trasatlántica navegando sólo con vapor fue realizada en 1837 por el buque *Sirius*. Desde los primeros años del siglo XX se impuso progresivamente la propulsión Diesel. En el año 1914 había poco más de 300 buque propulsados por motores Diesel, 10 años más tarde había sobre 2.000 buques y en 1940 alrededor de 8.000. En ese año, alrededor del 60% de los buques que salían de los astilleros eran con propulsión Diesel y, prácticamente, el resto con vapor, turbinas ó máquina alternativa.

Los primeros motores Diesel con aplicación práctica aparecieron a partir del año 1897, fruto de los trabajos de su inventor Rudolf Diesel. Estos motores eran muy voluminosos y pesados, desarrollaban una potencia de 17,8 hp (13,1 kW) a 154 rpm y su consumo era de 238 g/hp·h. (rendimiento del 26,2%) Era un motor de un solo cilindro, cuatro tiempos, con un diámetro y carrera de 250 mm y 400 mm respectivamente. Los siguientes ya eran de dos cilindros y 70hp a 160 rpm, pesaba 15,5 Tm, lo que daba una relación de 221 kg/hp. En el año 1905 el consumo ya había bajado hasta 185 g/ hp.h con combustible de poder calorífico de 10.000 Kcal/kg.

El principal inconveniente de estos motores para poder ser aplicados para la propulsión naval era su no reversibilidad.

En el 1904 se monta el primer motor diesel para propulsión de un buque: el "*Petit Pierre*", un pequeño buque fluvial de 38 m de eslora. Fue el primer buque con propulsión diesel mecánica (propulsión convencional) y además disponía de una hélice de paso reversible. En muchas fuentes se dice que los primeros buques de navegación oceánica con propulsión Diesel fueron el *Selandia* (botado en 1912), un buque mixto de carga y pasaje, con 2 Burmeister & Wain de 4 tiempos, 8 cilindros, 1250 hp, 140 rpm, reversible; cada uno moviendo su hélice y el *Monte Penedo*, también de 1912, con dos Sulzer de 625 kW cada uno, 160 rpm (fue el primer buque propulsado por un Diesel de dos tiempos) . Otras fuentes, bien documentadas, dan como buques mercantes para navegación marítima, pioneros en la propulsión Diesel, al "Orion" (1907) -aunque con una propulsión híbrida-, una goleta de 26m ; al "Rapp" y al "Schnapp" (1908) cargueros de 350 DWT, ambos con motores de 120 BHP y 300 rpm.,el mecanismo de reversión con patente Hesselman. En los tres casos los Diesel eran A.B. Motorer.

El "Toiler", botado en 1911, un buque diseñado para navegar por los canales de los Grandes Lagos transportando mineral fue el primer buque con propulsión Diesel en atravesar el Atlántico. El "Petit Pierre" ,1903, fue el primer buque al que se le montó un diesel (un cilindro horizontal, dos pistones opuestos, 25 BHP, 360 rpm. Era un buque para navegar sólo en aguas interiores . Poseía una hélice de paso reversible. Del 1910 son los buques oceánicos "Romagna" y "Vulcanus"

Como se dijo antes, los primeros motores Diesel no eran reversibles y por tanto no podían ser utilizados como propulsores en los buques ya que carecían de la necesaria maniobrabilidad. Otra solución a este problema fue propuesta por el ingeniero eléctrico italiano Cesidio del Proposto con su patente de 1903 que se verá en un artículo posterior, y otra , de la que trata este artículo, la propulsión diesel-eléctrica.

Las propuestas innovadoras en propulsión naval son continuas, también desde España.(Llana, 2009).

CONCLUSIONES

En este artículo se mostró la primera aplicación de la propulsión Diesel eléctrica en el ámbito naval. No obstante no puede decirse que constituyó el primer peldaño sobre el que se desarrolló esta tecnología propulsiva para los buques porque constituyó una experiencia que pasó desapercibida en el resto del mundo, basta para demostrar lo anterior comprobar cómo el primer libro monográfico editado en Reino Unido y Estados Unidos, *The Electric Propulsion of Ships*, escrito por el ingeniero H. M. Hobart en 1911, ocho años después de haber sido botado el *Vandal*, y que trata sobre las posibilidades y campos de aplicación de esta tecnología, no hace ninguna mención del mismo. Si recoge, por el contrario, el primer caso de propulsión Diesel eléctrica en el Reino Unido, el *Electric Arc*, una embarcación de recreo de 50 pies botado en Dumbarton en Febrero de 1911. El motor diesel movía un alternador trifásico a 800 rpm y la hélice era movida directamente por un motor de jaula con dos devanados independientes, uno de cuatro polos y el otro de seis .

Un artículo publicado en 1918 por el Ingeniero Civil A. Foillard cita como primeras experiencias en América a los buques *Frieda* con propulsión turboeléctrica, carguero de 5000 Tm ; el *Tynmouth* (1913), Diesel eléctrico para navegar por los Grandes Lagos (en su viaje inaugural, principios de 1914, llevando carbón a Santander sufrió una avería que le obligó a ser remolcado a puerto) ; el *Jupiter,* un carbonero turboeléctrico de la marina de guerra de Estados Unidos botado en Abril de 1913 . Para Europa cita como primera unidad al *Mjölner*, turboeléctrico, botado en Diciembre de 1914.

Por último, entre otros, un artículo de 1925 presentado por A. Kennedy y Frank Smith señala propulsión Ward Leonard para dos embarcaciones de bomberos de Chicago, *Joseph Medill* y *Graeme Stewart*, puestas en servicio en 1908.

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BIOLOGICAL INVASION OF SEAS AND OCEANS

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ABSTRACT

Biological invasion is the entry of invasive species. Species are considered invasive when they become established in natural habitats, are agents of change, and threaten native biological diversity. Most invasive organisms from other ecosystems are transported around the world in the ballast water of ships.

In this paper for the Journal of Maritime Research, it will be explained to the audience which is the problem with these organisms transported in ballast water of ships, as well as prevent their invasion in other ecosystems and how to choose the right equipment to remove such species.

These invasive species densities are up to several thousand individuals per square meter, which can cause significant damage to hydraulic infrastructure such as hydropower centrals. Also in aquatic ecosystems can cause major disruptions in the food chain or food web dynamics, leading to displace native species. As is well known, the ballast is needed for many functions related to stability, manoeuvrability and propulsion of ships. The problem is that ballast water contains a soup of organisms. These organisms are composed of plankton (microscopic plants and animals), bacteria and viruses. This movement of organisms is now seen as one of the greatest threats to coastal ecosystems in the world. The ballast water organisms have a great environmental and economic impact. If ignored, a marine species could invade a new environment somewhere in the world every nine weeks. To combat this problem there are different solutions, each belonging to one of the largest companies in the marine sector. In the present circumstances of technological development, it is estimated that new generation of ballast water treatment systems, based on physical processes (such as in

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this paper presented) are the safest and most reliable to avoid transporting and unloading of organisms that ballast water contains.

This article concludes that a more suitable to fit onboard systems based on physical removal than those based on chemical, aggregations and storage of chlorine products and / or other chemicals where, if there is any leakage, may pose a risk to the safety of crew and vessel. Among the solutions discussed in this article for the Journal of Maritime Research, have been identified a number of disadvantages in each. The first is the unit cost and maintenance, in the case of using Ultra-Violet or inert gas is very high. The size and footprint are important determinants from the design point, and something that in practice all units showed. The simplicity of design, elimination of chemical additives, the small size and low maintenance costs are the parameters that should determine the adoption of a system or another.

Key words: Naval Engineering, Ballast Water, Biological Invasion.

STATE OF THE ART

One of the issues on the conservation of the marine environment, the most important being given in the naval world, is the elimination of the organisms found in ballast water of ships. Due to the volume of traffic and maritime trade, which has increased in recent decades, the need to assess the risks of invasive species has entered the scene. International data show that the proportion of invasions by biological agents is constantly increasing in a disturbing rate. This problem was first shown at the International Maritime Organization in 1988 and since then the Committees of Environmental Protection and Safety Committee of the International Maritime Organization, together with the technical sub-committees have been addressing this issue, focusing initially on standards and subsequently in developing the new Convention.

The first time that the scientific community recognized signs of introduction of species, was after the emergence of a mass of seaweed from Asia in the North Sea in 1903. It was not until the seventies when scientists began to revise the problem in detail. At the end of the eighties, Canada and Australia were among the first countries experiencing particular problems of unwanted species, bringing their problems to the attention of the Committee on Environmental Protection of the International Maritime Organization.

In 1991 the Committee for Environmental Protection, adopted Resolution 50, some rules to prevent the introduction of unwanted organisms and pathogens from the discharge of Ballast Water and Sediments, while the Conference on Environment and United Nations Development, held in Rio de Janeiro in 1992, recognized that the problem should be assessed as a major international concern.

In November 1993 the IMO Assembly adopted Resolution A.774 (rules to prevent the introduction of unwanted organisms and pathogens from the discharge of Ballast Water and Sediments) based on standards adopted in 1991. The Order enjoined Committees Environmental Protection and Maritime Security to maintain the standards under review with the intention of developing the international application of mandatory laws. In November 1997 the IMO Assembly adopted Resolution A.868, rules for the control and management of ballast water from ships to minimize the transfer of harmful aquatic organisms and pathogens.

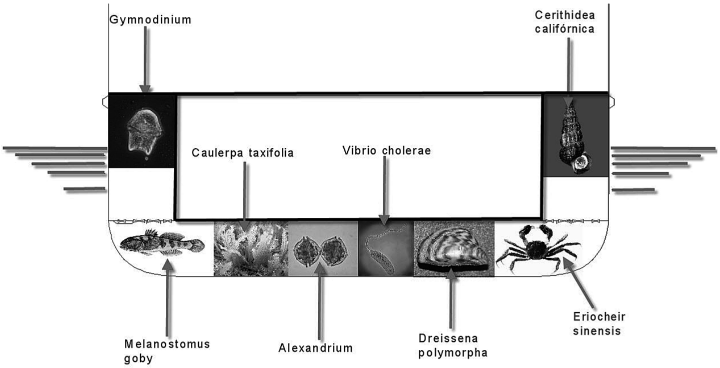

Figure 1: Example of biological organism that could be in ballast tanks.

When the international community was aware that he faced one of the greatest threats of seas and oceans of the world, since the introduction of invasive species into new ecosystems through ballast water had catastrophic effects on 13 February 2004 at the International Maritime Organization adopted the International Convention for the Control and Management of Ships "Ballast Water and Sediments, which requires all ships to implement a Management Plan" Ballast Water and Sediments, adopted by the Maritime Administration governments. The International Maritime Organization has defined in the Convention as follows:

• Ballast Water: water with suspended solids containing, loaded aboard a ship to control trim, list, draft, stability and stresses of the ship.

• Ballast Water Management: mechanical, physical, chemical or biological agents, whether used alone or in combination, to remove, or render harmless harmful aquatic organisms and pathogens present in the ballast water and sediments, or to prevent making or downloading them.

To combat this problem various solutions have emerged, splitting into three groups, depending on the mode chosen for the elimination of organisms:

• The first group would be the removal by mechanical means, to be included within the cyclonic separation and filtration.

• In a second group would be the physical media, such as ultrasound, cavitations, Ultra-Violet, heat, oxygenation and coagulation.

• The third group, chemical additions, electrolysis, ozone, chlorine and chlorine dioxide.

PROBLEMS CAUSED BY THE BALLAST WATER TRANSPORT

Studies in several countries show that many species of bacteria, plants and animals can survive in the ballast water and sediments carried in ships, even after journeys of several weeks. Subsequent discharge of ballast water or sediment into the waters of port States may result in the establishment of unwanted species which may seriously affect the existing ecological balance. If there have found other means of transferring organisms between geographically separated areas of the sea, the discharge of ballast water from ships appears to be one of the most important. Marine ecosystems are suffering from this phenomenon those results in the loss of biodiversity, caused mainly by organisms travelling in ballast water. The spread of disease can also result from the waters of port States receive large quantities of ballast water that contains viruses or bacteria, thus constituting a threat to the lives of human beings, animals and indigenous plants.

The problem with these unwanted elements in the ballast tanks has recently become a matter of considerable importance and, according to the International Maritime Organization is the fourth environmental problem that threatens the world's oceans, as the international traffic vessels has increased markedly in recent decades. And the trend continues.

Current studies estimate more than thirteen thousand million litres of ballast water being carried annually by merchant fleet worldwide, dragging rocks and sediment. Up to seven thousand different species, animals and vegetables, walk every day thousands of miles in the ballast water of ships and, with the unloading, reach a new destination for which will become a potential threat. This problem has already caused serious environmental and socioeconomic damage worldwide and therefore, this traffic has become a major vector for transferring marine organisms.

Unlike oil spill, the introduction of invasive species cannot be filtered or absorbed by the oceans. It could be said that, while in the first case, the impact of an oil spill decreases with time, in the second grows exponentially with it. After entering some species are virtually impossible to remove.

Shipping moves around eighty percent of goods transported annually and exchange three thousand to five billion tons of ballast water each year.

A ship can carry from a few hundred cubic meters to over a hundred thousand tons of ballast water, always depending on the size and type of vessel. This ballast water will be discharged by the vessel in or near the port of destination of the cargo, estimated at seven thousand the number of species transported across the ocean surface.

Most marine species carried in ballast water do not survive the journey: the loading and discharge of water and the atmosphere inside the tanks is generally hostile to the preservation of life of these species. Even for those species that survive the voyage and discharge, the chances of survival under the conditions of new marine environment, including the disappearance and competition with native species, are dramatically reduced.

The introduction of exotic species often result in most cases a dynamic impact on native marine populations and community structure where they are located. The main causes of such impacts are usually:

- Extermination of native species that have no defence system against such predators.
- Competition with other species occupying the same ecological niche and tend to be displaced.
- Alteration of habitat and consequent change in the structure of the communities where they settle.

Genetic pollution and reduction of marine biodiversity.

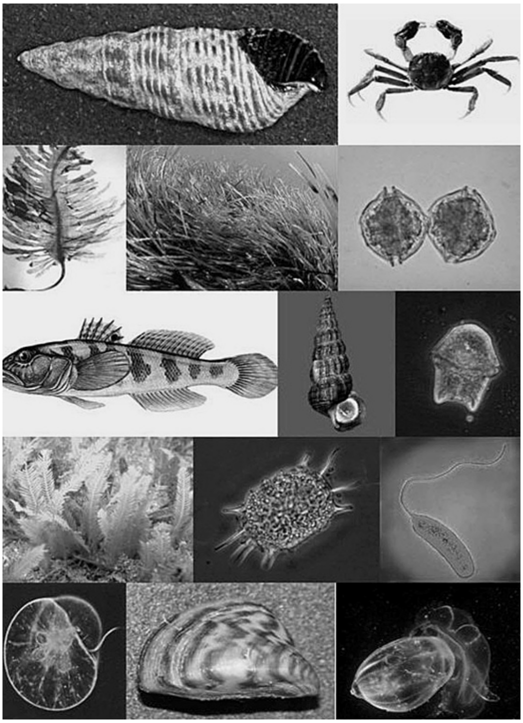

Figure 2: From left to right and from top to bottom: *Batillaria attramentarias*, *Eriocheir sinensis*, *Undaria pinnatífida*, *Poseidonia*, *Alexandrium*, *Melanostomus goby*, *Cerithidea califórnica*, *Gymnodinium*, *Caulerpa taxifolia*, *Odontella sinensis*, *Vibrio cholerae*, *Dinoflagelados*, *Dreissena polymorpha* and *Mnemiopsis* (Pérez and Vidal, 2010).

HOW TO SELECT A SUITABLE TREATMENT SYSTEM

It´s time to choose a treatment system. Several elements have to be analyzed. Assessing the vessel in question, it must be taken into account the following aspects that will be detailed below.

The requirements for ballast water treatment are directly related to the type of vessel. Those who are more dependent are the tankers (Mingorance *et al.*, 2009). For Suezmax, VLCC and ULCC where volume is the fifty-five thousand to ninety-five thousand cubic meters, the flow required will range from three thousand to six thousand cubic meters per hour. In a second step are the bulks, where Handy, Panamax and Capesize, will need to flow between 1300 and the three thousand cubic meters per hour.

The containers will have systems from two hundred fifty to eight hundred cubic meters per hour.

Passenger ships directly depend on the operating area, as its volume of ballast water is quite low.

It is necessary to know the salinity, temperature, concentration of water bodies in order to select the right system.

From the point of view of the treatment system, it could be made another classification. Currently available systems are divided into three groups.

The first would be the removal by mechanical means, to be included within the cyclonic separation and filtration. These methods may have problems of space if the volume of water to treat and / or the level of sediment are high.

In a second group would be the physical media, such as ultrasound, cavitations, Ultra-Violet, heat, oxygenation and coagulation.

The turbidity of water will be one of the parameters to take into account, as it directly affects the effectiveness and system performance.

The third group, chemical elements: electrolysis, ozone, chlorine and chlorine dioxide. Present the problem of disposing of the substances added and / or generated in various chemical reactions.

If the system uses filters, the pressure drop can go from one to four bars of pressure. Taking into account this data for new construction is not critical, but when it has to be adapted to a vessel in operation may lead to redesign pipes and pumps of the ballast system. The space required by these systems varies substantially for the same flow. We must also take into account the necessary piping. In many cases it may be a significant volume. If you are installing as a retrofit (means retrofit, upgrade mechanical equipment) on a vessel in operation shall be feasible for modular installation.

There are systems like the Ultra-Violet with very high fuel consumption, and if their operation is simultaneously to multiple systems of the ship, there may be power supply problems. It can become the main life-cycle cost of the system. Most of the systems will be handled with highly toxic elements. The system must have a safety manual, which will indicate how to properly store and use the additives.

It will be necessary to evaluate the cost of system acquisition, installation, and operational cost. These costs are difficult to assess and will depend on the type of ship and system. To evaluate correctly will be necessary to analyze:

- Power required.
- Cost of additives.
- Staff needed for the proper functioning of the system.
- Cost of maintenance.

RESULTS AND CONCLUSIONS

The globalization of transport (Schrooten *et al.*, 2009), a phenomenon which have raw materials or products manufactured anywhere in the world, involves the invasion of exotic, foreign or invasive species of invertebrates, algae, bacteria and viruses that are transported around the world ballast water of ships. Over a hundred thousand tons of ballast water is transported annually by ships from around the world. It spread species found in habitats that are not theirs. Some cause serious problems for ecosystems. Oceans of the world have begun to be biologically homogenized. The introduction of foreign organisms in ecosystems can lead to very significant losses of biodiversity. Once a species has been introduced, causing tremendous environmental damage, which leads to future spending millionaires to solve the problems that cause this kind. Commercial flow of goods into and out of access to the area of the bays is a vital part in the economies of the regions. However, the ships that bring these goods also discharge ballast water. The International Maritime Organization says that people can get sick or even die for marine pathogens introduced by ballast water. Since 1991 is working to create a mandatory regulation on the management of ballast water. Once the organisms are introduced into the ecosystem can be virtually impossible to eliminate in a short space of time can wreak havoc. The Conference on Environment and Development United Nations in Rio de Janeiro, acknowledged the situation and drive the need to assess appropriate measures, regulated in the discharge of ballast water to prevent the spread of organisms. Shipments of large volumes of sea water from one place to another, has been and is an international problem that has captured the attention of many countries and organizations like the United Nations, through the International Maritime Organization, devotes extensive efforts to control and mitigation of harmful effects they cause or origin in the marine environment where they are discharged. Following this, the technologies involved in the Ballast Water Treatment have received a boost in recent years which has resulted in a steady increase in the number of patents obtained.

When loading, it is necessary to ensure that only clean ballast water is taken, and minimize sediment loaded with water.

When selecting which procedures will be the discharge of ballast water and, therefore, sediments should be taken into account the following reasons:

- Monitoring of ballast water.
- Profitability.
- Safety of crew and vessel.
- Environmentalism.
- Possibility of operation.
- Activity.

Vessels should avoid taking ballast water in shallow areas, in areas where dredging to be conducted, and in areas that are affected by waterborne diseases ballast.

Since January of last year, according to the guidelines of the London Convention, ships of new construction shall comply with the rules of ballast water treatment.

As for water treatment systems for ballast, it must be noted that is considered most suitable for admission to board the next-generation systems than those supported by chemical means, with additions of chlorine products and other chemicals in causing which on a leak could endanger the crew and the ship itself. The simplicity of design, elimination of chemical additives, the small size and low maintenance costs are the parameters that should determine the adoption of a system or another. However, no system is suitable for all types of vessels. The requirements for ballast water treatment are directly related to the type of vessel. Those who are more dependent are the tankers. For Suezmax, VLCC and ULCC where volume is the fifty-five thousand to ninety-five thousand cubic meters, the flow required will range from three thousand to six thousand cubic meters per hour. In a second step are the bulks, where Handy, Panamax and Capesize, will need to flow between 1300 and the three thousand cubic meters per hour. The systems have sufficient container from two hundred fifty-eight hundred cubic meters per hour. Passenger ships directly depend on the operating area, as its volume of ballast water is quite low. Bulk carrier can then use any of the above systems, but from a dead weight greater than one hundred twenty thousand tons of systems using Ultra-Violet or chlorine will generate high volume and will be the hardest to adapt. It is the same in gas and chemical tankers, the limitation of space when the volumes of water to treat are high. And in the case of oil, the recommended system for all types of dead weight will be the addition of chemicals. This is similar to bulk carriers; from a dead weight over two hundred thousand tons of chlorine systems and Ultra-Violet will be too bulky. For container either system would be appropriate. It is necessary to know the salinity, temperature, concentration of water organisms in order to select the right system.

Then thus, in conclusion to this white paper for the Journal of Maritime Research, it is needed an intensive study of many conditions, and follow the development of policies to determine which system is right.

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INVASIÓN BIOLÓGICA DE LOS MARES Y OCÉANOS

ESTADO DEL ARTE

Uno de los temas sobre conservación del medio ambiente marino, a los que más relevancia se les está dando dentro del mundo naval, es el de la eliminación de los organismos que se encuentran en el agua de lastre de los buques.

Debido al volumen de tráfico y comercio marítimo, que se ha visto incrementado en las últimas décadas, la necesidad de evaluar los riesgos de las especias invasoras ha entrado en escena. Datos internacionales muestran que la proporción de invasiones por agentes biológicos está en continuo incremento en un porcentaje inquietante.

Este problema fue manifestado por primera vez ante la *Organización Marítima Internacional* en 1988, y desde entonces los *Comités de Protección al Medio Ambiente y de Seguridad Marítima* de la *Organización Marítima Internacional*, junto con los subcomités técnicos, han estado tratando este asunto, centrándose inicialmente en las normas y posteriormente en el desarrollo del nuevo *Convenio*.

La primera vez que la comunidad científica reconoció signos de introducción de especies extrañas, fue después de la aparición de una masa de Algas de origen asiático en el Mar del Norte en 1903. Pero no fue hasta los años setenta en que los científicos comenzaron a revisar el problema con detalle. Al final de los años ochenta, Canadá y Australia fueron de los primeros países que experimentaron problemas particulares por especies no deseadas, llevando su problemática a la atención del *Comité de Protección del Medio Ambiente* de la *Organización Marítima Internacional*.

En 1991 el *Comité de Protección del Medio Ambiente*, adoptó la *Resolución 50*, unas normas para prevenir la introducción de organismos no deseados y patógenos por la descarga del agua de lastre y sedimentos de los buques; mientras la *Conferencia sobre Medio Ambiente y Desarrollo de las Naciones Unidas*, llevada a cabo en Río de Janeiro en 1992, reconoció que el problema debía valorarse como una preocupación internacional mayor.

En noviembre de 1993, la *Asamblea* de la *Organización Marítima Internacional* adoptó la *Resolución A.774* (normas para prevenir la introducción de organismos no deseados y patógenos por la descarga del agua de lastre y sedimentos de los buques) basada en las normas adoptadas en 1991. La *Resolución* conminó a los *Comités de Protección del Medio Ambiente y Seguridad Marítima* a mantener las normas bajo revisión con la intención de desarrollar la aplicación internacional de las disposiciones legales obligatorias. En Noviembre de 1997, la *Asamblea* de la *Organización*

Marítima Internacional adoptó la *Resolución A.868*, normas para el control y manejo del agua de lastre de los buques para minimizar la transferencia de organismos acuáticos dañinos y patógenos.

Cuando la comunidad internacional fue consciente de que se enfrentaba a una de las amenazas más grandes de mares y océanos del mundo, ya que la introducción de especies invasoras en nuevos ecosistemas a través del agua de lastre tenia efectos catastróficos, el día 13 de Febrero del 2004 en la sede de la *Organización Marítima Internacional* se adoptó el *Convenio Internacional para el Control y Gestión del Agua de Lastre y Sedimentos de los Buques* que exige a todos los buques implantar un *Plan de Gestión de Agua de Lastre y Sedimentos* aprobado por la *Administración Marítima* de los *Gobiernos*. La *Organización Marítima Internacional* ha definido en la *Convención* los siguientes términos:

- Agua de lastre: el agua, con las materias en suspensión que contenga, cargada a bordo de un buque para controlar el asiento, la escora, el calado, la estabilidad y los esfuerzos del buque.
- Gestión del agua de lastre: procedimientos mecánicos, físicos, químicos o biológicos, ya sean utilizados individualmente o en combinación, cuyo fin será extraer, o neutralizar los organismos acuáticos perjudiciales y agentes patógenos existentes en el agua de lastre y los sedimentos, o a evitar la toma o la descarga de los mismos.

Para combatir este problema se han planteado diferentes soluciones, dividiéndose en tres grandes grupos, dependiendo del modo escogido para la eliminación de organismos.

- El primer grupo sería el de eliminación mediante medios mecánicos, dentro del que se incluiría la separación ciclónica y la filtración.
- En un segundo grupo estaría el de medios físicos, tales como *ultrasonidos*, cavitación, *Ultra-Violeta*, calor, desoxigenación y coagulación.
- Como tercer grupo, medios químicos: electrolisis, *Ozono*, cloración y dióxido de cloro.

RESULTADOS Y CONCLUSIONES

La globalización de los transportes, fenómeno por el cual se disponen de las materias primas o productos manufacturados en cualquier parte del planeta, conlleva la invasión de especies exóticas, extranjeras o invasoras de invertebrados, algas, bacterias, virus que son transportadas alrededor del mundo en el agua de lastre de los buques. Más de cien mil toneladas de agua de lastre son transportadas anualmente por los buques de todo el mundo. En ella se encuentran especies que se esparcen en hábitats que no son los suyos. Algunas causan problemas de gravedad para los ecosistemas. Los Océanos del mundo han comenzado a ser biológicamente homogeneizados. La introducción de organismos extraños en los ecosistemas que no les son propios puede conllevar pérdidas de biodiversidad muy significativas. Una vez que una especie se ha introducido, causa un tremendo perjuicio ambiental, lo cual deriva en futuros gastos millonarios para la solución de los problemas que aquella especie causa. El flujo comercial de mercancías dentro y fuera del acceso del área de las bahías es una parte vital en las economías de las regiones. Sin embargo, las naves que traen estas mercancías también descargan el agua de lastre. La *Organización Marítima Internacional* señala que la gente puede enfermar o incluso morir por patógenos marinos introducidos por las aguas de lastre. Desde 1991 está trabajando para crear una regulación obligatoria sobre la gerencia del agua de lastre. Una vez que los organismos estén introducidos en el ecosistema puede ser virtualmente imposible eliminarlos y en un corto espacio de tiempo pueden causar estragos. La *Conferencia sobre Medio Ambiente y Desarrollo de las Naciones Unidas*, en Rio de Janeiro, reconoció la situación e impulso la necesidad de evaluar medidas apropiadas, reglamentadas, en la descarga del agua del lastre para prevenir la extensión de organismos no autóctonos. Los traslados de grandes volúmenes de agua de mar de un lugar a otro, ha sido y es un problema que internacionalmente ha acaparado la atención de numerosos países y organismos como las *Naciones Unidas*, que a través de la *Organización Marítima Internacional*, dedica grandes esfuerzos a su control y mitigación de los efectos perjudiciales que éstas causan u originan en el medio marino donde son vertidas. Como consecuencia de lo anterior, las tecnologías involucradas en el *Tratamiento de Aguas de Lastre* han recibido un fuerte impulso en los últimos años, lo que se ha traducido en un constante incremento en el número de patentes obtenidas.

Al cargar el lastre se debe hacer todo lo posible para comprobar que sólo se toma agua de lastre limpia y reducir al mínimo los sedimentos embarcados con el agua.

A la hora de seleccionar cuales van a ser los procedimientos de descarga del agua de lastre y, por consiguiente, de los sedimentos, se deben tener en cuenta las razones siguientes:

- Vigilancia del agua de lastre.
- Rentabilidad.
- Seguridad de la tripulación y del buque.
- Ecologismo.
- Posibilidad de operación.
- Actividad.

Los buques deben tratar de no tomar agua de lastre en zonas de poco calado, en zonas donde se estén efectuando operaciones de dragado y en zonas que estén afectadas por enfermedades transmisibles por el agua de lastre.

Desde Enero del pasado año, según las *Directrices del Convenio de Londres*, los buques de nueva construcción deberán obedecer la normativa de tratamiento de agua de lastre.

En cuanto a los sistemas de tratamiento del agua de lastre, se tiene que destacar que se considera más apropiada la admisión a bordo de los sistemas de nueva generación, que aquellos sustentados en medios químicos, con aditamentos de productos clorados y otros causantes químicos en los que al producirse algún escape podrían poner en riesgo a la tripulación y al propio buque. La simplicidad de diseño, la eliminación de añadidos químicos, el tamaño reducido y los costes de mantenimiento bajos son los parámetros que deberían de determinar la adopción de un sistema u otro. Sin embargo, ningún sistema es adecuado para todos los tipos de buques. Los requerimientos de tratamiento de agua de lastre están directamente relacionados con el tipo de buque. Los que tienen una mayor dependencia serán los petroleros. Para los *Suezmax*, *VLCC* y *ULCC* donde el volumen va de los cincuenta y cinco mil a los noventa y cinco mil metros cúbicos, el caudal requerido irá de los tres mil a los seis mil metros cúbicos por hora. En un segundo escalón se encuentran los graneleros, donde los *Handy*, *Panamax* y *Capesize*, necesitaran caudales entre los mil trescientos y los tres mil metros cúbicos por hora. Los portacontenedores tendrán suficiente con sistemas entre doscientos cincuenta y ochocientos metros cúbicos por hora. Los buques de pasaje dependerán directamente de la zona que operen, ya que su volumen de agua de lastre es bastante bajo. Luego para graneleros se podrá utilizar cualquiera de los sistemas mencionados, pero a partir de un peso muerto mayor de ciento veinte mil toneladas los sistemas que utilicen *Ultra-Violeta* o generen cloro tendrán un volumen elevado, y serán los más difíciles de adaptar. Sucede lo mismo en gaseros y quimiqueros, la limitación de espacio cuando los volúmenes de agua a tratar son elevados. Y en el caso de petroleros, el sistema recomendado para todo tipo de peso muerto será el de adicción de químicos. Es una situación similar a los graneleros, a partir de un peso muerto mayor de doscientas mil toneladas los sistemas de cloro y *Ultra-Violeta* serán demasiado voluminosos. Para portacontenedores cualquiera de los sistemas sería apto. Es necesario conocer la salinidad, temperatura, concentración de organismos del agua para poder seleccionar el sistema adecuado.

Luego por tanto, como conclusión a este artículo técnico para el *Journal of Maritime Research*, es necesario un estudio intensivo de muchos condicionantes, y seguir la evolución de las directivas para poder determinar qué sistema es el adecuado.

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OPTIMIZATION OF OPERATIONS IN MARITIME CONTAINER TERMINALS

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ABSTRACT

The objective of this article is to present a general analysis of the various different elements that comprise the operating chain or process for working a container-carrier vessel, defining the operating ratios involved and the relationships between them; similarly, the parameters that influence the operational process are indicated. This paper includes an approach to the problem focused on a case-study: the Spanish terminals. We have carried out a quantitative analysis that allows comparative strategies to be established and applied to practical cases. The correct planning and execution of operations on a container-carrier vessel is a decisive element in the strategy of a Terminal. Numerous factors come into play and some of these, but only some, can be controlled. Experience and knowledge of the problems that can arise is fundamental when attempting to deal with these operations. We put aside, for the time being, the initiatives a terminal can take to optimize yard distribution, as well as reducing the impact of berthing problems. We consider the different measures of the various kinds of production, and the difficulties that could be encountered in trying to maximize productivity. Finally, we offer some suggestions regarding what is being done presently at the terminals to achieve their operating targets.

Key words: Container Terminal, Port management, Optimization, Spain.

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INTRODUCTION

Objectives

Determining the optimum way of working a container vessel in a terminal is an arduous task, in which numerous different factors need to be juggled. By optimum, we mean in such a way that maximum productivity, measured in movements per hour, is obtained, while the period of time that the vessel has to spend at the quayside in minimized, so that finally the desired costs per unit are achieved. The objective of this article is to present a general analysis of the various different elements that comprise the operating chain or process, defining the operating ratios involved and the relationships between them; similarly, the parameters that influence the operational process are indicated.

The diverse sub-systems that are intrinsically combined in this operational process are considered vitally important: the berthing subsystem and the prior planning of this phase; the subsystem of direct operations undertaken at the wharf; the dockyard operations; and finally the port operations, of considerable importance in export-import terminals. The subsystem that has probably been least studied is the one that directly concerns the operational process of the vessel at the quayside. We believe that the fundamental reason for this is the impossibility of mathematically modeling it, given the diversity of the circumstances that directly affect the good functioning or handling of the equipment utilized, the importance of the human factor, and the experience necessary for dealing with these operations. This paper sets out to analyze in more detail this particular subsystem.

Review of the scientific literature on the subject

The studies of Steenken (2004) and, more recently, of Stahlbock and Voß (2008) and Vis and Koster (2003) cover a wide range of experience with container terminals, including case studies, and serve to define the initial problem for us.

One specific problem that has received considerable study, because it is more suitable for mathematical modeling, is the berthing allocation problem. This concerns how best to plan the berthing of several different vessels at the wharves of the terminal, so that the fixed working periods and the number of hours of work agreed with the customers in their corresponding contracts (windows) are respected. The length of time that the vessel needs to spend at the wharf must be minimized and the fullest advantage must be taken of the handling facilities available. This is the case of the study by Jim Dai (2004) in which the static problem is differentiated from the dynamic problem, and the time factor and its implications in a set period are included in the latter.

In Brown et al. (1994) a practical optimization model, with various restrictions, is offered[1]. Lim (1998) proposes a heuristic method utilizing graphical representa-

[1] Of application in the various services of berthing and provisioning of the vessels of the US Navy; demonstrations of the utilization of the model were carried out at the US Norfolk Naval Base.

tion[2]. In another field, the study carried out by Dragovic (2006) deals with the mean time a vessel remains at berth and its dependence on the mean number of vessel arrivals at the port[3].

Traditionally, to evaluate the performance of a container terminal, the berthing and yard operations are optimized, either by analytical methods or by computational or algorithmic modeling techniques (Petering 2011; Fockert 2009; Günther 2006; Vis and Koster 2003; Dowd and Leschine 1990). Firstly, an index of occupation of the terminal or adequate yard density must be obtained. There appears to be an inverse statistical relationship between the density and the productivity. The operations in the yard are performed more slowly the greater the number of containers per unit of area; this is because the operating cycles of the machines (trucks, straddle carriers, etc.) needed to move the containers to and from the wharf are longer. More errors may be made and there may be more difficulties in locating the particular containers required, since they may be at lower levels in the stacks. There is a greater possibility of accidents occurring.

Different terminals may measure this ratio in different ways. Some terminals, where the containers are usually stacked to low levels or heights (straddle-carrier terminals, or chassis terminals, for example), can measure the occupation of the slot by unit of area, without much need to take into consideration the different heights to which the containers may be stacked (Longo 2010; Lau and Zhao 2008; Lee et al. 2007). Various studies have been made of the operational process in this type of terminal. Vis and de Koster (2003) have already demonstrated the difference existing between terminals of the ITS (Indirect Transfer System) type and those of the DTS (Direct Transfer System) type[4].

For a DTS type terminal the objective is to minimize the times of the operation to move the container between vessel and stack (and vice versa when loading); however, in the case of the ITS, it can be appreciated that there is an additional objective element or operation to minimize (Nam and Ha 2001). Kim et al. (2003a, 2003b, 2000, 1999a-e, 1998 and 1997), analyze the problem of space allocation in both types, in the case of export terminals.

Zhang et al. (2003) study storage space allocation for import, export and transshipment terminals in an ITS system. They break down the problem into two parts: the first is how to assign the stack for each sequence of work (that is, taking into con-

[2] This method, with special variants, is frequently utilized in terminals, and can be performed simply using common spread sheets.

[3] The study applies queuing theory models and an Erlang distribution (k phases) for the mean time for servicing the vessel (berth average) once tied up. Factors directly attributable to the operational process on the wharf in itself have an influence but, as seen in the study previously cited, the creation of queues of waiting vessels directly affects the vessel servicing time, independently of the quality of service that may be provided on the wharf.

[4] In the first, a fleet of machines or vehicles is used to transport the containers from the side of the vessel to the stacking area, where another type of machine (an RTG or Rubber-Tired Gantry) stacks them according to the storage criteria. In the DTS system, the machine (a Straddle Carrier) that picks up the container at the quayside takes it to the storage area and stacks it directly.

sideration the type of container, import, export, relay); and the second is how to minimize the distance from the stack to the vessel (that is, reducing the distance that the container-transporting vehicle, or shuttle, has to travel).

Presentation of the problem

The changes of destination of vessels that the shipping line may decide once the containers have already been stored in the yard, have a fundamental effect. A high percentage of renominations lowers the productivity drastically. It is not unusual for the situation to occur that the loading of a particular vessel on a particular wharf has been prepared for working the vessel in the optimum way, and then to find that it has been changed to another vessel that is or will be berthed on a different wharf. This often happens and, unless the change of plan can be renegotiated with the customer, it must be accepted by the terminal. The customer will normally be ready to accept an additional charge on its agreed cost per movement that, in function of the existing cost statistics, can be negotiated as a lump sum.

The movements that are made to tidy the loads in the yard and prepare the yard for the particular vessels that are going to be worked, or else for the optimum storage of containers and organization of the yard, are normally termed house keeping. The more there are of these container movements associated directly with the renominations, the more the smooth operation of loading or unloading a vessel is inevitably obstructed, when the yard has not been prepared in advance. The result is more non-essential movements, higher costs and lower productivity.

The objective of this article is to identify and analyze the problems that arise on the ground at the wharf, when working directly on vessel. The literature on this subsystem is extensive but does not cover the other subsystems, perhaps because other factors come into play, such as the specialization of the machinery (Robinson 2008), the problems of portainer crane planning and QC scheduling (Sammarra et al. 2007), the human factor (Legato and Monaco 2004), the various collective labor agreements and the legislation in this respect (López-Rueda 2005; Arroyo-Martínez 2009).

We will seek solutions or alternatives to the existing methods for optimizing the operations of container carrier vessels, from the perspective of the wharf, and aim to define the physical measurements that we use for making this assessment and its relationships.

Methodology

In this approach to the problem of optimizing operations in maritime container terminals, our starting point is professional experience in the field of port operations in the Bay of Algeciras (Southern Spain); this is the leading Spanish port for the movement of containers (Suárez de Vivero and Rodríguez-Mateos 2002). We also analyze the existing bibliography. On the basis of this, we have carried out a quantitative analysis that allows comparative strategies to be established and applied to practical cases; this has been done in the case of the Container Terminal of the Port of Barcelona. We start from a study made of large-capacity vessels with more than 900 operational movements, utilizing the Six-Sigma Lean methodology (Brook 2009). The socio-occupational context of this study is the Spanish national legislation applicable to the stevedore labor sector (Convenio 2008)(Blanco et al. 2010), but to a large extent, this is similar to the context in the rest of the European Union (Baird 2000).

OPTIMIZING THE OPERATIONAL PROCESS

The concept

In all productive processes, the optimization of the operational process consists essentially of obtaining the maximum output at the lowest possible cost while meeting the optimum quality standards for the customer and user of the product or service. In the context studied here, the operational process of a container terminal can be considered as a large productive process where the final element is not a tangible product but rather a specified service. The service to which we refer is the handling and storage of the containerized merchandise of a particular customer. Thus we are talking either of reception terminals (import and export) or of trans-shipment terminals, where container s are transferred from one vessel to another. This service needs to be delivered, i.e. performed, on the date agreed with the customer, and in accordance with the same conditions that the seller, exporter, loader (or any other legal entity considered to be the person putting the container at the disposition of the carrier) has contracted with the customer. The basic objective is to carry out the operations as rapidly as possible, to enable the vessel to spend the minimum time necessary in port and, consequently, to obtain maximum economic utilization of the high-value capital asset, the vessel (Onyemechi 2010).

As a general rule, in container terminals today, whether of the trans-shipment or export/import type, several days before the vessel berths, its container load layout is known; that is, how its load has been stowed, and which particular holds (or bays) will need to be worked, in which order. The terminal management must decide, based on the instructions received from the stowage coordinators, how to distribute the containers - by weight, final destination and the characteristics of each particular container (refrigerated, 40', 20', IMO, OOG (out-of-gauge), BBK (break-bulk), etc.

Once the containers have been distributed, the loading and unloading in the yard has been planned, and various movements of containers that may need to be carried out on board the vessel, the persons responsible should in theory have full knowledge of the prospective condition of the vessel on its departure after being worked (i.e. the conditions of stability, trim or seating, draught, ballast, etc.). Unless the First Officer or Captain of the vessel decides to make additional changes, the order of working the vessel is maintained during the entire course of the operational

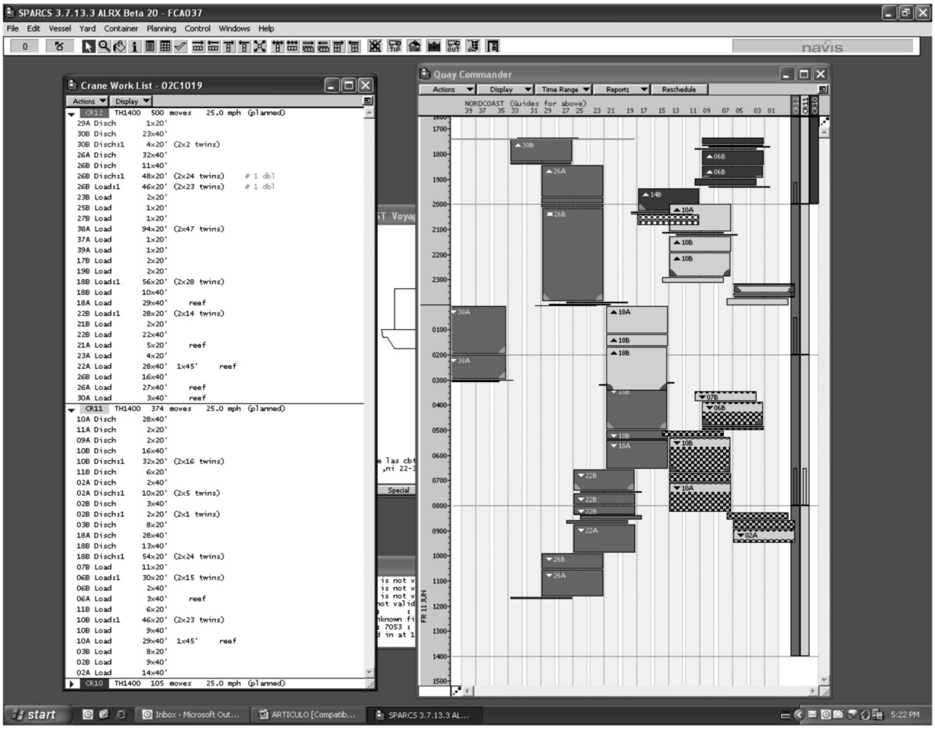

Table 1: Example of a work sequence according to the SPARCS system.

process. The order of working is a sequence of specified tasks, organized for that particular vessels, that can be presented in different forms, according to the terminal and the computer systems used for loading and unloading. It may be a simple sheet of paper on which the work to be done is described, or a plan where the tasks to be carried out are indicated consecutively.

The above example may serve as an order of work; either the chart on the left, defined and described or the figure on the right, where normally a color is assigned to each crane or item of handling equipment.

The team of stevedores that works a shift during any twenty four hour period is known as a gang. The gang generally corresponds to a group of employees who work with a particular crane performing a particular order of work with that crane in the bays corresponding to their work.

Case study: Large terminals in Spain.

In Spain a gang works a shift of six hours, but the personnel comprising each gang varies according to the terminal, the customary practices and the work load. This is stipulated in the various sectoral agreements negotiated for each port.

The stevedoring companies of the various ports and/or groupings of ports (*Agrupaciones Portuarias de Interés Económico*: APIEs) have the responsibility of supplying the various terminal operators with the specialized and specific personnel (stevedores) needed for the tasks or jobs that require them, in the numbers agreed. The ownership of these companies is usually comprised of personnel designated by the stevedoring companies, with the representation normally proportional to the demand, in terms of volume of work. In terms of finance and accounting, they are companies without any real assets, and the principal movements in their profit and loss account represent personnel costs.

The personnel employed are remunerated according to the piecework method: the more containers handled during the shift, the higher the remuneration obtained by the stevedore. In theory, under this system, the employees earn a fixed amount per shift on which they are nominated for work, independently of whether any work is done, for whatever reason. This fixed amount of remuneration is set in the collective labor agreements ruling in the sector. Apart from obtaining the negotiated basic income, for any additional container that is handled an agreed extra amount of remuneration is computed.

Obviously there are guarantees negotiated to protect the earnings of this group of employees - for example, if a vessel scheduled does not berth, or if it berths later than planned, or if a crane breaks down, etc. In the granting of these guarantees, the final decision is frequently up to the person with operational responsibility for the terminal at that time. It is therefore understandable that these decisions frequently involve discussion or negotiations that are or should separate from the specific tasks and jobs to be done, according to the various interpretations of the agreements, or as is commonly argued, according to the spirit of the law and not necessarily to the letter of the law or contract. The granting of a guarantee of this type when it is not really correct, often results in the operating personnel relaxing their efforts; and such a loss of concentration on the job in a gang has an adverse effect on productivity and, ultimately, on the achievement of the operating and financial objectives of the terminal.

It is interesting to note that there are three main types of gang: the complete gang, which includes among its members personnel responsible for the lashing and unlashing of containers; the simple gang, which does not do lashing, and is therefore considerably less costly; and thirdly, the specialist gang for lashing, generally composed of a foreman and team who do nothing but the attaching of containers on board to each other and to the structure of the vessel, on loading, and the reverse on unloading.

The particular use of simple gangs is justified by the fact that, apart from being more economical, there are some types of work on the vessel that do not need these specialist lashing activities to be performed: a full shift can be devoted to loading holds or on a vessel with systems of guides on its decks (Convenio 2008).

DISCUSSION BY OBJECTIVES

Presentation of operational objectives

The first objective is for the vessel to be tied up correctly to the wharf in the shortest time possible; that is, the operational process, from the time when the first line is made fast to the quayside until the berthing is completed, should be carried out as rapidly as possible. The time taken from when the vessel begins this operation until it is completed is usually referred to as the *berth time*. The total production or *berth productivity* is the total number of movements or individual tasks performed on the vessel (including all the concepts) divided by the total *berth time* (bmph).

The satisfactory organization of specific berthing windows or slots by the terminal operator, and commitment on the part of the customer to keep its vessel On Schedule and with the pre-defined movements, should minimize unproductive time drastically.

The customer or shipping line, for its part, should make every effort to keep to the date and time of arrival of its vessel to which it has committed itself (within the reasonable range of variation agreed previously with the terminal), so that the terminal operator may be able to work the vessel as planned, again within an equally reasonable range of possible variation from plan[5].

The second objective, intrinsically linked to the first (but this is not necessarily the order of priority), is for each gang, during its shift, to work the maximum number of containers per hour. This parameter, referred to as the production or productivity of the vessel, is measured in numbers of containers per hour. If no allowance is made for working time lost because of breakdowns of cranes or machinery needed for the operations, this is designated the *gross productivity* and if such allowance is made, then it is *net productivity*. For the purposes of this study, the *gross time*, or number of hours that the gang is theoretically working, will be considered. This is an objective of the operational process of the terminal: When each vessel is worked at a higher speed, the terminal is able to work a greater number of vessels. This results in a better *berth production*. In other words, this concerns the achievement of economies of scale, and lower cost per movement, by reducing the fixed costs of the terminal.

This minimum cost is the third objective, in this case of the terminal as a whole: it has an enormous impact on the tariffs or charges that the terminal can offer its customers. The unit cost has several components whose proportionate significance varies in function of the type of terminal and its particular characteristics. Generally the largest component of this cost is the remuneration of the work-force of stevedores, although equipment maintenance costs and depreciation of the capital cost of the machinery is

[5] The effects of the current world crisis are partially palliating the loss of productive time at the terminals, since it has obliged the shipping lines to cut fuel consumption by reducing cruising speeds and ensuring that the vessel reaches the pilot pick-up station at the correct time to start the maneuver of docking/berthing. For a large-capacity vessel this can take approximately one and a half hours. This means that, in theory and excepting circumstances of force majeure, the larger ships get into port in time, without delays.

not insignificant. The terminal's income is the result of the number of containers moved multiplied by the tariff applicable to each movement (Sala and Medal 2004).

The total costs, in general, are derived from the number of cranes and other machinery and equipment, plus the expenses of maintenance and depreciation. On the wharf the costs of the activity and the associated fixed costs include the fixed costs for the area of land occupied, the amortization of the loans for the purchase of the capital equipment, the maintenance of that equipment, and last but not least, the direct and indirect personnel costs.

Although, as mentioned, these are the general costs of the terminal, other costs must also be taken into account such as those for the repositioning, repair and replacement of the general machinery of the terminal due to wear-and-tear and obsolescence; other expenses include investment in new technologies and implementing them, research, development and innovation, and all the specific investment and expenditure that the terminals must incur in order to comply with and to update the security systems, given heightened awareness of possible terrorist attacks since 11 September 2001, and for risk prevention, health and safety and hygiene of the employees (Piniella 2009 and 2008).

In spite of all the expenditure, one of the more visible and worrying effects of the crisis being felt in this industry is the slow disinvestment that some terminals are making in items such as the preventive maintenance of machinery and safety, as described in the study conducted by Trelleborg Marine (Trelleborg 2010).

Quantitative analysis

If the cost per unit is defined as the quotient between the total costs and the total number of containers handled during a specified period of time; and taking, in turn, the total number of containers handled as the production of the terminal for the total length of time employed in the operations, the unit cost is, within certain limits, inversely proportional to the cited production.

$$\text{CPU} = \text{Total costs} / \text{N} \tag{1}$$

And therefore,

$$\text{CPU} = C_t / (\text{gpmh} \times T_t) \tag{2}$$

where CPU = Cost per unit

C_t = Total costs
N = Total number of containers moved
T_t = Total time employed in moving them
gmph = gross movements per hour, understood as the mean during a specified T_t (similarly designated production).

In productive processes there is a certain level of production that minimizes the unit cost. In container terminals the production of a particular service is measured (containers per hour), and each terminal knows what is its optimum level or rate of production. Higher rates of containers moved per hour imply a greater investment in resources, and this investment increases the cost in a non-linear way. It is a complicated process to determine the optimum production, from the analytical perspective. The operating statistics of the terminal itself serve to orientate the operator regarding this optimum.

The number of gangs that, on average, can support the vessel during all the shifts that are worked is known as the *crane intensity*; this parameter is nothing more than a weighted average of all the gangs with which the vessel is capable of working on each shift. This is a most important parameter for calculating the window or total time available for berthing and, therefore, for optimizing this window: it should be made as small (or short) as possible or in accordance with the contract signed with the customers.

The object of the terminal is to sub-divide the work on the vessel among several separate gangs, while also trying to ensure that the various gangs are as equal or balanced as possible. Given that theoretically the gang with the most work takes the longest and this, as we shall see, determines the overall length of time that the vessel has to remain in port, another aim is to organize the work so that all the gangs finish at the same time. This offers the possibility, reflected in the various working agreements, that the vessel may waive or forego certain gangs, termed passing; when this occurs, the passed gangs may continue working other vessels. This normally results in the recognition of certain financial guarantees for the stevedores, as already commented.

The *crane intensity*, an adimensional quantity, is easy to predict at the start of operations, according to the expression:

$$C_I = \sum M_i / M_{max} \tag{3}$$

where C_I = is the crane intensity and $\sum M_i$ is the sum of all the movements performed by the several M_i gangs, and M_{max} is the number of movements of the queue or the sum of movements by the gangs taking the longest times in the order of work (assuming continuous working from the start of operations up to their completion, except for breakdowns, with the same crane). The duration of the longest queue determines the *berth time*, and therefore the *berth productivity* is obtained as follows:

$$M_{max} = gmph \times bt \tag{4}$$

where bt is the berth time and the gpmh (gross movements per hour) is the assumed general production of the vessel (total number of movements made divided by the total number of hours employed); we have already defined the bmph previously, as follows:

$$\text{bmph} = \sum M_i / \text{bt} \quad (5)$$

It can easily be deduced that the *crane intensity* is:

$$C_I = \text{bmph} / \text{gmph} \quad (6)$$

This expression inevitably gives the number of cranes or gangs that have been utilized, on average, during the entire operational process of the vessel, the weight applied in number of gangs for each shift worked.

It is preferred, however, to differentiate between the two formulas, although both lead to the same result: The first is known from the start of operations on the vessel. On a container carrier vessel it is very unlikely that all the gangs work at the same rate or gpmh. The item obtained by equation (6) indicates, at the completion of the operations, how efficiently that entire operational process has been performed. We would like to designate this quotient as Crane density (C_δ), to differentiate it from the parameter given by equation (3), on the one gang, by the point in time when each parameter is useful to know, and on the other, because what is most likely is that they are different. This is because diverse factors come into play, which the terminal, as operators, must control heuristically. The shrewdness of the vessel's operator, and of the terminal, tends to be very similar: in any case the following will always apply:

$$C_I \geq C_\delta \quad (7)$$

From the same definition of C_I and C_δ it can be concluded that, once this quantity has been fixed, an increase in the gmph implies another proportional increase in the bmph. For any particular vessel, this indicates clearly that an optimization of the gmph reasonably implies a shorter stay of that vessel in port. Again we perceive the relationships between the three objectives, although the reality is normally otherwise.

The annual datum of the total production of each terminal varies considerably according to the type of terminal and its traffic, (*feeder* or *mainliner*), from one particular service to another, from one berthing to another, of the same vessel (in consequence of a different distribution of the containers in the terminal), from breakdowns, climatological conditions, and an endless list of other circumstances that in some cases are difficult to measure.

Nevertheless, for any particular vessel, during the course of a particular operation, the production of the vessel, in gmph, can be considered to be constant. The bmph should have the maximum possible value; this is the principal objective of the customer, in order to minimize the length of time of the stay. Without entering into specific considerations of the correct points to take as the start and finish of the operational process for the vessel, a bigger C_I will give a higher bmph. In other words, taking the gmph production as constant, it can now be understood that C_I is proportional to the bmph. The next step is to decide how this C_I can be increased, and the problems encountered in doing this.

The desired level of *crane intensity* cannot always be attained: The load should be sufficiently well-distributed among the different *bays* of the vessel to enable it to be worked with the maximum number of cranes, in the shortest time possible. It is very commonly observed that vessels requiring the operation of several gangs during several shifts have the movements concentrated in *bays* close to each other, where theoretically two gangs cannot work together because of the simple lack of physical space.

The reference here is to a specific linear distribution of the operational movements. Such a distribution would need to apply equally over the course of time. It could only be found on regular lines, in vessels of a certain capacity or dimension, with an agreed number of movements, with fixed ports of arrival, with itineraries also fixed, and where, of course, the volumes to be worked in each of these ports are constant over the course of that time (or where the variations are minimal). Hence, the planning from the initial port would be predictable: the *crane intensity* would remain practically unaltered.

Application to a practical case (the Port of Barcelona)

From the preceding analysis, we move on to its application to a practical case. For this the data in table 2 are utilized, corresponding to the Container Terminal of Barcelona (Muñoz 2008). The vessel to be worked is the Maersk Antares, with a total of 832 movements. An average of 26 movements per hour means 32 hours of real work and somewhat more than the work of five gangs (each working a six hour shift). If the vessel could be worked from the start with these five gangs, and the general operational process is as expected, perhaps with a couple of hours to finish off, the ship would be finished in eight hours. The bmph measure of production would thus be 104 movements per hour. The Crane density would be this production rate divided by the gross obtained, that is,

$C_\delta = 104 / 26 = 4$

This indicates that the vessel in general could be worked with an average of four gangs (it can be considered to have been worked for six hours with five gangs, and for two hours with one gang): the weighting of the average does not deceive us.

However, the way the movements are distributed should be examined. A total of 273 movements are concentrated on bays 37/39. In this case it has to be added that, due to the operational circumstances of the terminal, only a maximum of 3 cranes are available for this vessel. The third gang, the longest, imposes a minimum length of time for working the vessel of

$T_t = 401 / 26 = 15$ hours 25 minutes

Linea			MK			29/06/2010 21:38		MAERSK ANTARES									
Nº MANOS		ETA			BANDA DE ATRAQUE												
IZADAS TWIN		BAY	DESC	TAPAS	R/S	RF/OOG	CARGA	TAPAS	R/S	RF/OOG	TOTAL	OBSERVACIONES	MANOS				
desc.	carga										MOVS		1ª	2ª	3ª	4ª	5ª
		1 / 3	10				8				18						
		5 / 7	25	2				2	6		35						
		9 / 11															
		13 / 15															
		17 / 19	40	2	3		58	2			105						
		21 / 23															
		25 / 27															
		29 / 31															
		33 / 35															
		37 / 39	110	2	3		156	2			273						
		41 / 43															
		45 / 47															
		49 / 51															
		53 / 55	96	3	2		102	3			206						
		57 / 59															
		61 / 63															
		65 / 67	50	2			76	2			130						
		69 / 71	25	1			36	1	2		65						
		73 / 75															
		78															
			356	12	8		436	12	8		832		158	273	401		

Table 2: Planning sheet for gangs and movements, TCB Barcelona.

Operations on the vessel and their possible delays

In this part we will describe the circumstances that occur in the direct operational process of the vessel that may alter the rate of production of the vessel, measured in movements per hour or gmph; this latter parameter is the measure that is of interest to the stevedores since they are paid on a piecework basis.

There are several factors that have a direct and adverse impact on the rate of production of particular operational process on board a vessel. It should first be stated that the rate of production decreases in line with the various losses of working time incurred in the operational process in general.

In one of our recent studies of large capacity vessels, in which the operational process comprises more than 900 container movements, utilizing the Six-Sigma Lean methodology[6] carried out exclusively during the first hour of commencement of operations, it was observed that there are three main factors that most influence this loss of working time: (1) the unlashing of the containers; (2) the time spent waiting for the vessel; and (3) crane breakdowns.

With reference to the unlashing of containers, so that they can be unloaded together with those positioned below them in the stack, it can be seen from Table 3 that this work accounts for more than 40%, on average, of the time lost at the start of the operations: we consider that the scope of the study is sufficiently broad to allow these data to be extrapolated to other terminals and other types of vessel. It is therefore considered that a loss of up to 20 minutes can be incurred in unlashing tasks.

[6] A more detailed description of the applications of the system can be found in the study by Quentin Brook (2009), for example.

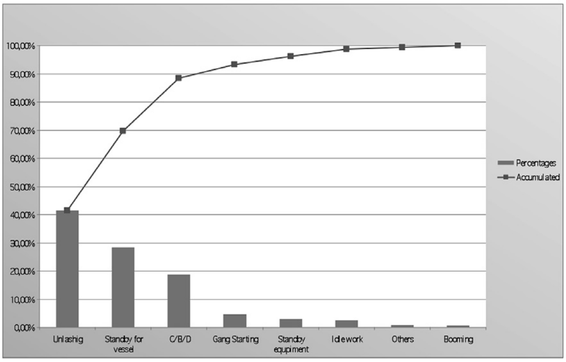

Table 3. Causes of the operating delays at the start of operations.

This is a considerable loss of time. Assuming that those 20 minutes could have been used productively at the same rate of operations, 50% more production would have been obtained in that hour. It is evident that the unlashing effect at the start of operations gradually diminishes as the work continues during the course of the shifts, and has practically disappeared by the time the operations on the vessel finish. We may be speaking of vessels which stay in port for 24 hours or more, but it should not be forgotten that each operational minute lost costs money.

Starting from a customary unlashing operation[7], the unlashing bars that are normally utilized allow the stevedore to pull the shank of the twistlock and open it, on stacks up to four containers high (five or six if the vessel has pedestal bays); in short, time needed to unlash one container depends on the configuration of the vessel. On the latest generation vessels, it is not unusual to see stacking heights of up to six, seven, eight and even nine containers in some cases. In that case it is advisable for the stevedore to work from inside a safety cage, utilizing long bars to release these twistlocks; terminals are now becoming increasingly strict in insisting that accident prevention measures are taken (Cooper 2000).

Figure 1. Detail of stevedore unlashing containers at height from a safety cage.

Apart from these alternatives, of technical character, there are others of different nature that, to date, have an extra collateral cost associated with them. Thus, if it is decided to berth the vessel ahead of the scheduled time, so that the unlashing work may be carried out before the effective operations are commenced, diverse problems can be encountered. In the event that it is the shipping line that wants this to be done, this would probably require an

7 Basically, the unlashing of containers high up in the stack consists of releasing the semi-automatic twistlocks (with shank) of the top-most row, so that the unloading of them from the vessel can begin while the unlashing stevedores proceed to unlash the containers in the first, second and third levels, releasing them from the bars. We are considering semi-automatic twistlocks, as the manual type, are now rarely used; however, when they are used they are rather more complicated to manipulate.

increase of cruising speed by the vessel in order to arrive sooner. We have commented already on the reluctance of ship-owners to incur higher fuel consumption.

It may be necessary to negotiate, in those ports where they do not exist, lashing/unlashing gangs independent of the rest, not in the operational sense (since these do in fact exist, as we have seen), but in the sense that these independent gangs may be nominated at the discretion of the terminal operator as and when needed. That is another complicated topic that requires negotiation and that would necessarily imply another type of counterparty on the part of the terminal[8].

The solutions are not easy, but any possible path must today be open to debate since important issues are at stake for all those involved.

In general, once the loading operations on the vessel are approaching completion, the lashing tasks do not represent much of an obstacle in the search for higher rates of production. The planner will now try to ensure that, if the vessel is finished loading, the various bays should have been lashed previously during the general loading operations (hold loaded, hold lashed). However, it is not unusual to find that the loading of the vessel is finished and that some lashing work is still needed, either because of general delays (inadequate planning), or because lashing personnel have not been designated (poor planning), or because of slacking by the specific gang responsible. Another possible reason, which sometimes occurs, is that the vessel does not give approval of the lashing that has been done (poor quality of work).

With respect to the item Stand by for vessel, it is not intended to enter into discussion of this, since it is understood that, except for specific causes like unexpected congestion of the wharf, this is a topic, decision or error that corresponds to the shipping line or customer.

The breakdowns of cranes (referring exclusively to the STS or gantry cranes) constitute a fundamental item in the reduced production of a vessel, not only for the time that the whole gang remains stopped, but also because, after the repair, it is complicated to re-start the operations with the same smoothness and coordination as before the breakdown.

From our study it can be stated that this is the second most important cause of lost time at the start of operations (this being the period when breakdowns are most frequent); it is observed that, according to these results, *crane breakdown* (CBD) is the third biggest cause of loss of time in operations (accounting for 18.72% of the total time lost).

If total crane breakdowns have accounted for the loss of X% of the total time of operations, and that production could have continued at the same rate during this period of time lost, the new production G would be

$$G = gmph\ (1 + X/100) \qquad (8)$$

[8] In Northern European ports, like Rotterdam or Zeebrugge, the lashing services are partially liberalized, and are provided under contract by external companies.

The loss of more than one point of production would be given in this case for percentages of breakdown such that:

$$X \geq 100 / gmph \qquad (9)$$

where X is the time of breakdowns, in percent. In other words, for an average terminal with a mean operational process of gpmh = 28, when crane breakdowns exceed 3.57% one point of production is lost (in this case, the production would have been 29.00 gmph). That is an extremely high cost on an annual basis. Hence it emphasizes the importance of optimum maintenance of the equipment, in the corrective, preventive and predictive aspects.

5. CONCLUSIONS

The correct planning and execution of operations on a container-carrier vessel is a decisive element in the strategy of a Terminal. Numerous factors come into play and some of these, but only some, can be controlled. Experience and knowledge of the problems that can arise is fundamental when attempting to deal with these operations. Especially important are the degree of professionalization specific to the sector and the weak relationships existing between all the various port professionals (including the stevedoring companies, the container terminals, etc.) and the rest of the sectors (in both directions).

As already stated, the operational process in the dockyard itself can be considered the heart of the terminal. It is there where the basic decisions are taken regarding the good working of the vessel in function of work planning and the consequent assignment of machinery (whether RTG's, Straddle-carriers or others). It is on the dockyard operations for the vessel that studies of the productivity of the terminal are normally focused. In short, it can be seen that there are many problems at crane level that can be improved, depending on the terminal.

From the calculations we have done, we can determine that, in any terminal, there are a series of basic rules for working these vessels that should enable this kind of work to be optimized or at least organized with greater efficacy, in the Spanish ports. Historical records need to be kept of how the service has been carried out in general and for the vessel in particular. Advance notice needs to be given urgently to the vessel regarding what needs to be prepared for the berthing – the scale has to be positioned before the operations start. The work on the vessel should be commenced in the holds, bays or decks where there are no lashings. The loading operations need to be finished (in the event of a cut-off, no containers are left on board). It should be made very clear to the stevedores what is the criterion for working each vessel - by rows, by tiers or some other. The sequence of work should be organized in such a way that two consecutive handlings are not obstructed by physical impossibility. The *break-bulks* should be planned with all the equipment and material prepared in such a way that the loading or unloading takes as little time as possible. *Twin* working should be adopted (two movements in one single lift) whenever possible. Physical interference by *ships' chandlers*, trucks collecting waste (MARPOL) and other companies external to the terminal during the operational process should be prevented (or such activities should be scheduled for periods when handling work is not being done).

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OPTIMIZACIÓN DE LAS OPERACIONES EN TERMINALES MARÍTIMAS DE CONTENEDORES: UNA APROXIMACIÓN A LA PROBLEMÁTICA EN TERMINALES ESPAÑOLAS

Resumen

Para trabajar con un buque contenedor en una terminal de forma correcta, de manera que alcancemos la máxima producción, medida en movimientos por hora, minimicemos la estancia del buque en muelle y finalmente obtengamos los niveles deseados de coste por unidad, resulta una tarea ardua en la que entran multitud de factores en juego. El objetivo de este artículo es analizar de forma general los distintos elementos que componen la cadena operativa, definiendo los ratios que entran en juego, así como las relaciones entre los mismos e intentando, de igual manera, señalar los parámetros que influyen en la operativa.

PLANTEAMIENTO DEL PROBLEMA

Los cambios de destino o de barcos que la línea puede dar, una vez los contenedores han sido ya almacenados en patio, son fundamentales. Un porcentaje elevado de "renominaciones" baja drásticamente la producción. No es raro encontrar la carga de un determinado buque en un sitio preparado para trabajar un barco de manera óptima y tener que ser cambiada a otro buque que se encuentra atracado o va a atracar en otro sitio diferente. Suele suceder y a menos que se logre negociar con el cliente, deberán ser asumidas por la terminal. El cliente normalmente podrá aceptar un cargo en su coste por movimiento adicional que, en función de las estadísticas anteriores, puede ser negociado como un *"Lump sum"*.

Los movimientos que, se realizan para "ordenar" la carga de patio y adecuarla a los buques en que van a ser trabajados, o bien para almacenar y organizar el buque de manera óptima, son denominados normalmente *"house keeping"*. Un mayor número de estos movimientos, relacionados directamente con las renominaciones implica un entorpecimiento de las operaciones de buque, cuando no una preparación previa del patio adicional. Tenemos pues más movimientos sin valor, más costes y menor producción.

El objetivo de este artículo es analizar cuáles son los problemas que nos encontramos "a pie de muelle", directamente operando sobre buque. La literatura existente para este subsistema, aunque siendo amplia, no alcanza la extensión de los demás subsistemas, quizá por entrar en juego otros factores, tales como la especialización de la maquinaria, el problema de la planificación de las grúas portainer ó QC *scheduling*, el factor humano, los diferentes convenios colectivos y la legislación al respecto.

Buscaremos soluciones o alternativas a las existentes para la optimización de las operaciones del buque portacontenedores desde la perspectiva del muelle, definiendo las medidas físicas que utilizamos para hacer tal valoración y sus relaciones.

METODOLOGÍA

Para llevar a cabo una aproximación al problema de la optimización de terminales marítimas de contenedores hemos partido de la experiencia profesional en el campo de la operativa portuaria en la Bahía de Algeciras (Sur de España), principal puerto de España en movimiento de contenedores y el análisis de la bibliografía existente hasta el momento. A partir de ello, hemos llevado a cabo un análisis cuantitativo que permita establecer estrategias comparativas a la hora de aplicarlas a casos prácticos, como así se ha realizado en un caso de la Terminal de Contenedores del Puerto de Barcelona. Partimos de un estudio realizado sobre buques de gran porte y con más de 900 movimientos de operativa, utilizando la metodología Six-Sigma Lean. Hemos de puntualizar que partimos del entorno socio-laboral de la legislación aplicable al sector de estibadores del Estado Español, extensible en gran medida al marco de la Unión Europea.

CONCLUSIONES

La correcta planificación y ejecución de las operaciones en un buque porta-contenedores es un elemento decisivo en la estrategia de una Terminal. Entran en juego multitud de factores, alguno de los cuales, sólo algunos, podremos controlar. La experiencia, el conocimiento de los problemas que pueden surgir es fundamental a la hora de abordar estos trabajos. De ahí la profesionalización tan específica del sector y la poca relación que hay entre profesionales portuarios (incluimos todos, las empresas estibadoras, las terminales de contenedores, etc.) y demás sectores (en ambos sentidos).

Como ya hemos mencionado, la operativa de patio (“*yard*”) puede ser considerado el corazón de la terminal, allí donde se toman las decisiones básicas a la hora de una buena producción del buque en función de una planificación del mismo y de una asignación de maquinaria consecuente (ya sean RTG’s, *Straddle-carrier* u otras), y que es donde normalmente están enfocados los estudios de productividad de la terminal. Vemos, en definitiva, que existen multitud de factores a “pié de grúa” que dependiendo de la terminal pueden ser mejorados.

De nuestros cálculos realizados podemos determinar que existen en una terminal una serie de reglas básicas a la hora de trabajar estos buques que permiten una mayor eficacia y una optimización, de acuerdo con la organización del trabajo en los puertos españoles: el histórico de producción del servicio y del buque en particular; avisar con premura al buque sobre qué debe tener preparado para el atraque –la escala tiene que estar posicionada antes del inicio de las operaciones-; comenzar a trabajar el buque "bays" en bodega o en cubierta donde no exista trinca, terminar la operativa cargando (en caso de corte no se quedan contenedores a bordo); dejar muy claro cuál es el criterio de trabajo en cada buque a los estibadores, si por andanas, por pozos u otro; hacer la orden de trabajo de manera que dos manos consecutivas no se estorben por imposibilidad física; planificar los "*break-bulks*" preparando todo el equipo y material de manera que su carga o descarga dure lo menos posible; trabajar a "*twin*" si existe posibilidad (dos movimientos en una izada); y evitar interferencias físicas de suministros navales, "*ship-chandlers*", camiones de recogida de residuos (MARPOL) u otras empresas externas a la terminal durante la operativa (o planificarla en espacios donde no haya mano trabajando).

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USE OF ROTATION MATRICES TO PLOT A CIRCLE OF EQUAL ALTITUDE

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ABSTRACT

A direct method for obtaining the points of a circle of equal altitude using the vector analysis as an alternative to the spherical trigonometry is presented, and a solution where celestial navigation and Global Navigation Satellite Systems are complementary and coexist is proposed.

Key words: Circle of Equal Altitude, Celestial Navigation, Vector Analysis, Rotation matrix, ECS.

INTRODUCTION

In celestial navigation, historically, due to the restrictions of the tools used for sailing, (paper nautical charts and their scale, sight reduction tables for solving the navigational triangle ...), only an approximation of the segment of the whole circle of position –*CoP*– near the fix is plotted. Today, electronic chart systems permit to plot the entire CoP on a nautical chart or a map in any projection. The following presents a vector method to implement this utility.

Variables and symbols

	Variable	Intervals
GHA	Greenwich Hour Angle	0 <= GHA <= 360º (W to E)
Dec	Declination	–90º (S) <= Dec <= +90º (N)
Ho	Observed altitude	0 <= Ho <= 90º
B	Latitude	–90º (S) <= B <= +90º (N)
L	Longitude	–180º (W) <= L <= +180º (E)

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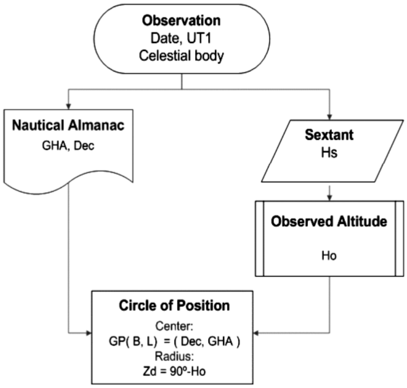

Figure 1. Circle of Equal Altitude parameters.

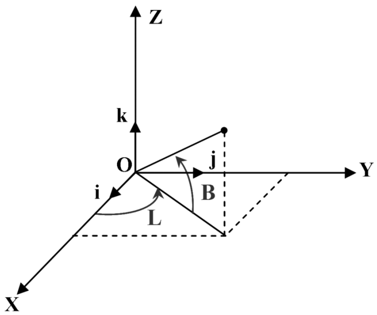

Figure 2. Coordinates and frame of reference.

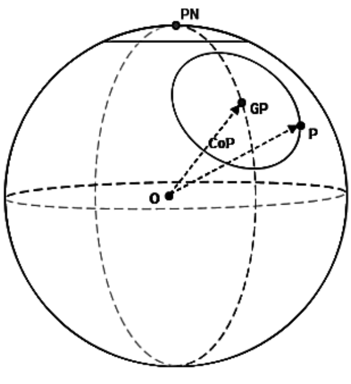

Figure 3. CoP with center at the GP, circle at the North Pole and vectors.

The Circle of Equal Altitude

Or circle of position in celestial navigation, is defined, Figure 1, by its geographical position –GP–, and the great circle distance from this point to the circle; the zenith distance of the body Zd (BOWDITCH, 1995. Ruiz, 2006 and 2008).

Coordinate Systems

To refer to the points on the surface of the Earth, a sphere of unit radius with its origin **O** in the centre of the Earth and a right-handed orthonormal basis $\{\vec{i}, \vec{j}, \vec{k}\}$ is defined as in Figure 2, constituting a ECEF –Earth Centered, Earth Fixed– reference frame. The axes of the defined Cartesian system of coordinates are:

- Z: from O to the North Pole.
- X: from O to the Greenwich meridian, included in the Earth's equatorial plane.
- Y: defined by $\vec{j} = \vec{k} \wedge \vec{i}$

The unit vector in Cartesian coordinates, (x,y,z), from the centre of the Earth to any point on the surface of the Earth with geographical coordinates (B, L,1), is:

$$\mathbf{OP} = \cos B \cos L \cdot \vec{i} + \cos B \sin L \cdot \vec{j} + \sin B \cdot \vec{k}$$

PLOTTING THE COP

For drawing a circle of position, the easy way is to place the circle with its center in the North Pole. In this fictitious position, all points of the circle has the coordinates (B,L) where B=Ho and L$\in$(-180,+180], Figure 3. Transforming these points to its true position on the spherical Earth, the coordinates of the points on the real CoP are obtained. *Note that only the real CoP satisfies the equation of the circle of equal altitude* (Ruiz, 2006):

$$\mathbf{OP} \bullet \mathbf{GP} = \cos(90^\circ - H_o)$$

Obtaining the points of the CoP

For each point on the Cop, its associated vector $\mathbf{OP}_\mathrm{i}$ is obtained doing:

$$B = \mathrm{Ho} \text{ and } L = (-180,+180]$$

The coordinates of the point are calculated by rotating this vector from its initial fictitious position to its real one using the equation:

$$\mathbf{OP} = \mathbf{R}_z(360^\circ - \mathrm{GHA})\mathbf{R}_\mathbf{y}(90^\circ - Dec)\,\mathbf{OP}_i$$

Where the rotation matrices are (Brossard ,1994):

$$\mathbf{R}_\mathbf{y}(\theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \qquad \mathbf{R}_\mathbf{z}(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

These matrices represent counterclockwise rotations of a vector relative to ECEF frame, by an angle of θ. $\mathbf{R}_\mathrm{y}$ rotates the z-axis towards the x-axis, and $\mathbf{R}_\mathrm{z}$ rotates the x axis towards the y axis.

Transforming the Cartesian coordinates of **OP** = (x,y,z) into geographical ones, the latitude and the longitude of the point will be obtained.

$$B = ATAN2(z, \sqrt{x^2 + y^2})$$
$$L = ATAN2(y, x)$$

The algorithm is shown in a flow chart in appendix A1.

Transformation of the center of the CoP

Of course, by the rotation of the vector defined by the fictitious center of the circle, –the North Pole (B=90º,L=0,R=1): $\mathbf{OP}_\mathrm{N}(0,0,1)$–, to the true one **OGP**, the geographical position is obtained.

CONCLUSIONS

A conceptually straightforward vector algorithm has been presented for plotting a celestial circle of position on an electronic chart. Is robust, fast and easy to implement, and the vector equation permits to map a circle of position into any projection (Mercator, gnomic, stereographic…).

Since the discovery of the line of position by Sumner (Ibáñez, et Al. 2004) in

1837, modern celestial navigation has been a valuable tool of the navigator, and now could be, or is (Kaplan, 1999), a reliable backup for a Global Navigation Satellite Systems (GNSS). An Electronic Chart Systems, ECS, including a celestial navigation module for sight reduction and running fix, with plotting capabilities like CoP and fix representation on an electronic nautical chart could be suitable for offshore navigation, a prototype is implemented with OpenCPN, appendix A3. In ship bridge design (Meck, et Al. 2009) celestial navigation could be another ingredient to take into account.

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APPENDIX

A1. Algorithm

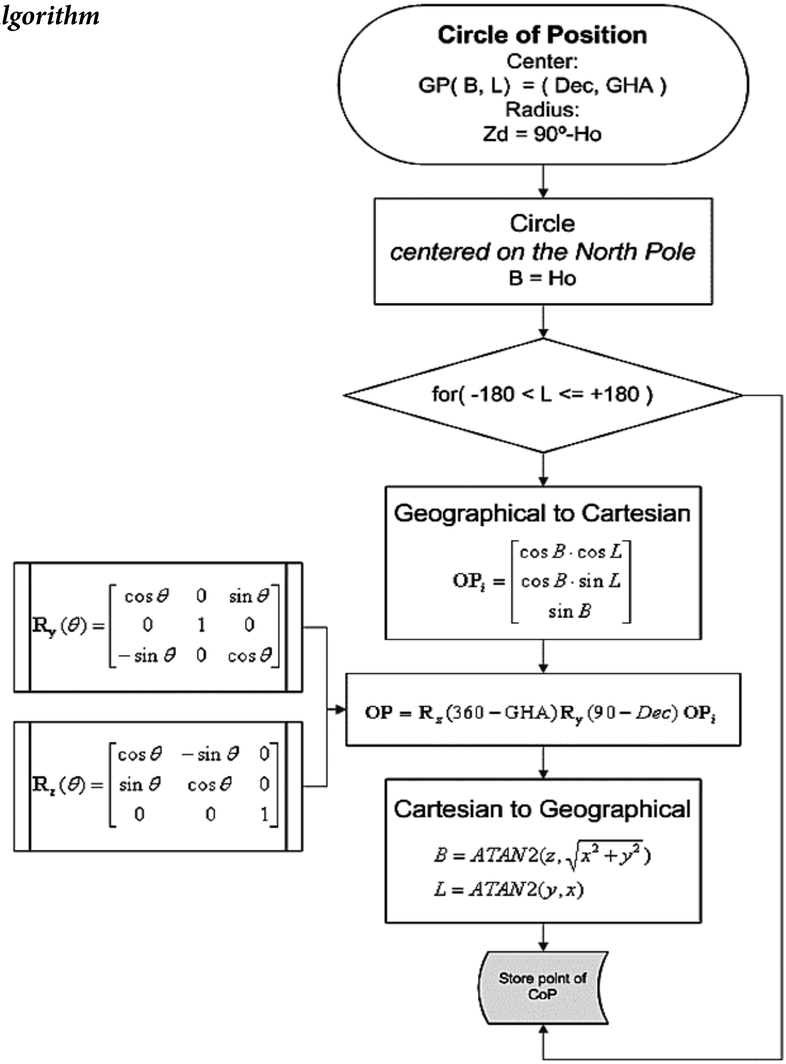

Figure 4. Points of a circle of equal altitude.

A2. Source code

Software and ANSI C source code for the algorithm is provided in an easy implementation, susceptible for being translated to other common programming languages. Available at the author's web site:

http://sites.google.com/site/navigationalalgorithms/

A3. Implementation in an ECS

This is an example of how celestial navigation serves to complement a GNSS: AstroNavigation.exe generates a *gpx* file as an input to OpenCPN.

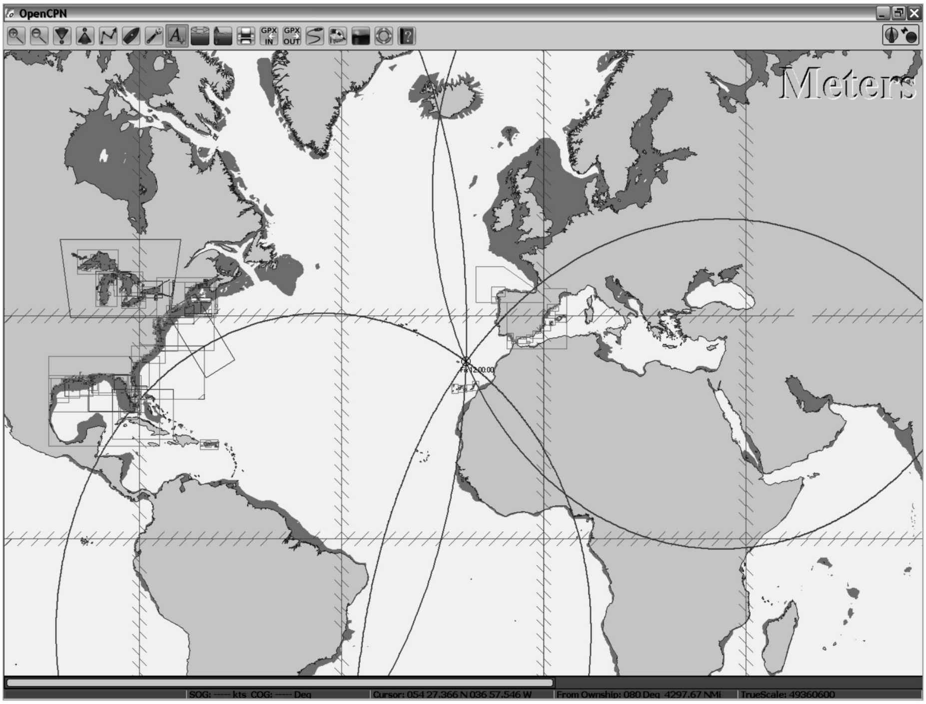

Figure 5. ECS and circles of equal altitude plotted on an electronic nautical chart. General scale.

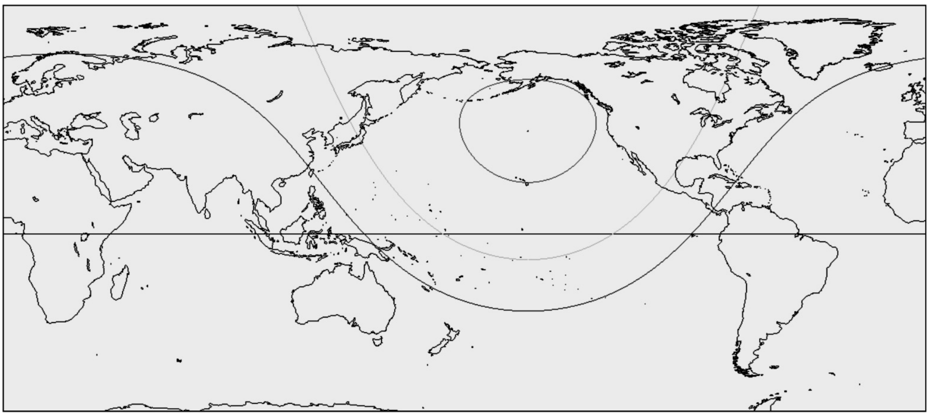

Figure 6 . Types of circles of equal altitude.

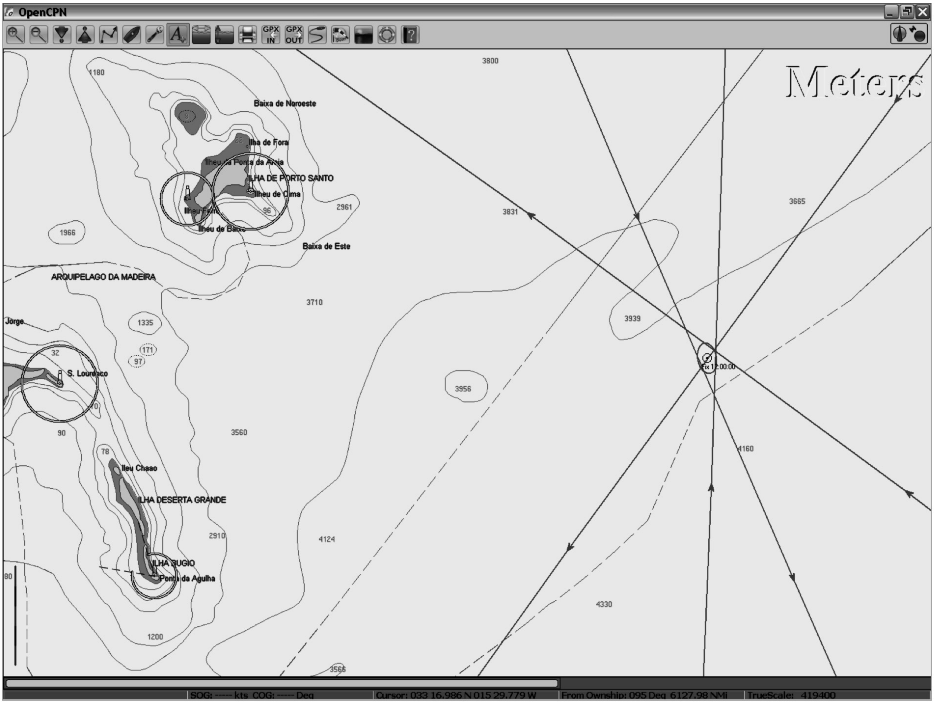

Figure 7 . ECS – Coastal scale: Fix and confidence ellipse.

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CURE KINETICS OF POLYURETHANE/SILICA SYSTEM TOPCOATS IN NAVAL APPLICATIONS

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ABSTRACT

The cure kinetics of polyurethane/silica system resins (used as topcoats in naval applications) are investigated by means of isothermal differential scanning calorimetry. The enthalpy isotherm generated during the sweep increases, while the residual enthalpy decreases. This is due to the increased mobility of the double bonds as the temperature rises, causing a reduction of the remaining and as yet unreacted double bonds, although the sum of $\Delta H_{iso} + \Delta H_{res}$ remains practically constant. By representing the Arrhenius equation in its logarithmic form, two slopes (Ea) are obtained for the same system which indicates that both mechanisms are involved in the curing reaction. The first mechanism may correspond to the crosslinking reaction of the urethane group, while the second may correspond to a secondary reaction due to the high temperatures at which the study is conducted.

Key words: cure kinetics, polyurethane resin, silica, DSC.

INTRODUCTION

This work focuses on curing polyurethane resins that are loaded for use as topcoats (two-component polyurethane) on the superstructures of light vessels, which pro-

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vide a high-gloss paint that is only able to maintain its brightness for a period of between two to four years.

During the curing of thermosetting materials a number of complex chemical and physical changes occur as the material turns from a viscous liquid to a highly crosslinked solid. All these changes, reflected in the cure kinetics and the chemical viscosity of each individual resin system, determine the optimum set of process parameters for the production of a material that will have the best morphological and structural properties for a given application. This is essential to prevent degradation of the coatings (R. García et al., 2010).

Several authors Díaz et al. (2008), Panagiotis et al.(2000) and Yousefi et al.(1997) have experimentally shown that the mechanism responsible for the curing process of a thermosetting resin may be studied through two methods:

Enthalpies residual method: samples are isothermally cured at Tc in a vacuum oven at different curing times, and then analyzed in the calorimeter. We obtain the dynamic DSC curve for each sample and determine the residual enthalpy of the sample.

Conventional isothermal method: by means of dynamic scans can obtain the temperature range at which the resin polymerizes, so we can determine the temperature at which we should perform isothermal sweeps. The next step is to study the kinetics of polymerization at a constant temperature.

Many researchers have proposed various methods to study the curing kinetics of polyurethane systems. Differential Scanning Calorimetry (DSC) is a useful method with which to study the exothermic curing reaction. Using DSC, kinetic analysis can be evaluated by isothermal and non-isothermal methods. By comparing the methods of kinetic analysis from isothermal and non-isothermal DSC measurements, it is evident that using the isothermal DSC experiment, the reaction rate as well as the curing process are simultaneously monitored throughout the course of the reaction. The kinetics parameters are calculated by applying a single method.

In the present study, the curing kinetics of polyurethane/silica were investigated by isothermal DSC. We have taken systems with a high proportion of silica load, cured at several temperatures. They are optimal temperatures for quick curing and for avoiding cracks and structural defects in the moulding production processes. This work will provide information that may be used to optimise the curing conditions of a high-silica loaded polyurethane system.

EXPERIMENTAL

Materials

The polyurethane resin used in this study results from a reaction of isocianathe and polyol. It was cured with a high loading of silica. The weight ratios of the isocianathe/ SiO_2/polyol/ pentadyone mixture were 100/365/80/0.37.

All the products were supplied by Ciba Specialty Chemicals. The chemicals were mechanically well mixed for 10 minutes at 30 °C to obtain a homogeneous mixture. After mixing the mixture was immediately stored in a refrigerator maintained at –20 °C to prevent any further reaction.

Techniques

Differential scanning calorimetry (DSC TA Instruments Q200) was employed in this study. The initial mixture was taken out of a refrigerator in a vial and left for around 15 minutes at room temperature until the condensed moisture on the surface had completely evaporated. Approximately 10 mg of the mixture was put into a DSC hermetic aluminium pan and then sealed by crimping. The sealed pan with the sample was isothermally cured in the calorimeter for 70 minutes at different cure temperatures. A nitrogen purge gas was used to avoid any oxidation of the samples during the experiments. The cure temperatures in this study were 20, 30, 40, 50, 60, 70, 80, 90, 100 and 110 °C.

RESULTS AND DICUSSION

Prior to the isothermal curing measurements, the sample was scanned from 0 to 200 °C at 5, 10, 15 °Cmin^{-1}. From these scans, we are able to determine the optimum range of curing, temperature of maximum effectiveness and global polymerization entalphy:

— Optimum range of curing: 20-110 °C
— Temperature of maximum effectiveness: 106.24 °C
— Total polimerization enthalphy: 80.02 J/g

The results of the isothermal experiments are shown in figure 1 for different curing temperatures, T_c. It can be seen that the cure rate of the systems increases with the reaction temperature.

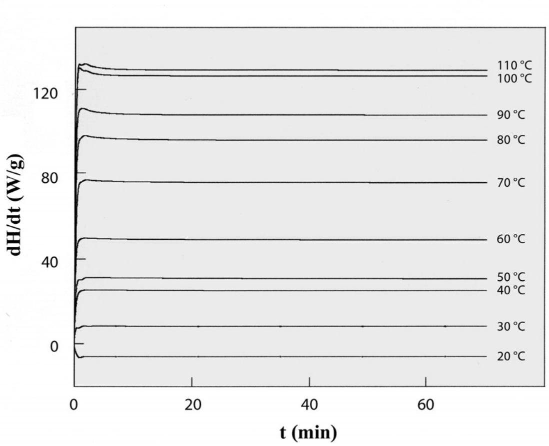

Figure 1. DSC curves from the polyurethane system cured for various temperatures.

All of the resin systems were subjected to dynamic runs at constant heating rates (10 °C/min) from –40 to 200 °C, in order to determine their conversion profiles and total reaction heat released during dynamic curing. From these scans, we are able to determine T_g and examine residual exothermic peaks by cure reactions to obtain the residual heat. In this study, T_g was taken as the inflection point of the step-transition. The values of the isothermal heat of curing (ΔH_{iso}), and residual heat of curing (ΔH_{res}) are shown in Table I, where we see that the enthalpy isotherm generated during the sweep increases, while the residual enthalpy decreases. This is due to the increased mobility of the double bonds with increasing temperature, causing a reduction of the double bonds remaining unreacted, but the sum of $\Delta H_{iso} + \Delta H_{res}$ remains practically constant see Ivankovic et al.; 2003

.

T (ºC)	H_{ISO} (J/g)	H_{RES} (J/g)	$H_{ISO}+H_{RES}$ (J/g)
20º	34.20	43.25	77.45
30º	46.36	38.62	84.98
40º	62.93	20.09	83.02
50º	75.18	7.098	82.27
60º	74.35	4.50	78.85
70º	78.00	1.06	79.06
80º	81.00	0	81.00
90º	82.00	0	82.00
100º	80.00	0	80.00
110º	80.27	0	80.27

Table I. Kinetic parameters for the polyurethane system.

However, certain characteristic aspects of isothermal curing heats should be highlighted. Other authors such as Mahfuz et al.(2004) and Saha et al., (2009) have observed that the reaction takes places very rapidly at the highest curing temperatures, the curing heat during the time required for temperature equilibration is not fully recorded in the DSC curve, which results in a decrease in the values ΔH_{iso}. In our case ΔH_{iso} has not decreased, which is because the reaction speed is slower because of the high silica loading of our systems. Similar behaviour that has already been observed in systems studied previously with other resins (Díaz et al.; 2008). The maximum values are observed in the interval of 80-110 ºC for these systems. In these temperature intervals, the values of ΔH_{iso} are very close to those measured non-isothermally at 10 ºCmin^{-1}: 80.02 J/g.

The following expression calculates the theoretical reaction rate, ($d\alpha/dt$), from the heat flux as a function of the curing time, $(dH/dt)_t$:

$$\frac{d\alpha}{dt} = \frac{\left(dH/dt\right)_t}{\Delta H_{din}} \quad (1)$$

where, total generated enthalpy is that obtained from dynamic scanning, ΔH_{din}. In Figure 2, we can see the curves thus obtained at different temperatures. In this figure we see that the time required to reach maximum speed torque becomes smaller as the temperature increases. This behavior is explained by the increased mobility of the double bonds with increasing temperature, as the residual enthalpy decreases.

From the enthalpy generated during the reaction, the evolution of the global conversion may also be calculated on the basis of the following theories:

— The density and heat capacity of the resin gradually changed in the liquid-solid transition phase within the temperature range in use.

— The reaction can be complete if the temperature is high enough for a sufficiently long period of time. The amount of heat generated during the curing reaction is directly proportional to the degree of cure of the sample at that time.

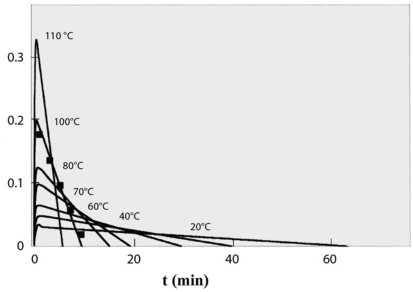

Figure 2. Times dependencies of the isothermal curing degree at 20, 40, 60, 70, 80, 100 and 110 °C.

The degree of cure, α, at any time t during the isothermal reaction can be obtained from:

$$\alpha = \frac{\Delta H_{din} - (\Delta H_{res})_t}{\Delta H_{din}} \qquad (2)$$

Where $(\Delta H_{res})_t$ is the residual enthalpy at each instant t, which is obtained by integrating the dynamic curve to perform a dynamic scan on the same sample that has undergone an isothermal scan at every instant t.

Figure 3 represents the evolution of the reaction rate versus time for the different temperatures in use. Note that the reaction rates increases as the temperature rises, which in turn increases the mobility of double bonds, as already discussed above. However, total conversion was not reached at any of study temperatures, such that the double bonds remain "trapped" in the microgel structure, as observed by Catherine et al. (2000) and Um et al.(2002).

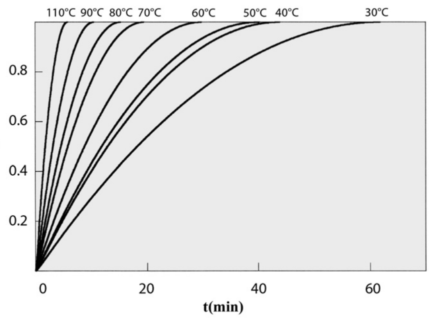

Figure 3. Time dependencies of the isothermal curing degree for polyurethane system.

Once we know the reaction rates and fractional conversions they can be represented as dα/dt vs α with the different temperatures in use (figure 4). It observed that the maximum speed is reached at times near the gel time, suggesting that the decline in the reaction rate is related to the sharp increase in viscosity that occurs during gelation.

On the other hand, differential scanning calorimetry has been used to determine the activation energy of the process. The rela-

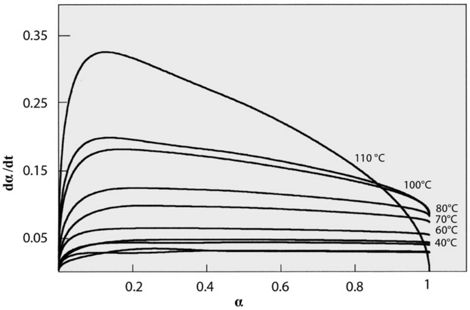

Figure 4. The isothermal reaction rate as a function of curing degree at 40, 60, 80, 90, 100 and 110 °C.

tionship between the activation energy, the heating rate and temperature which produces the maximum exothermic peak is based on the work of Malucelli et al.; 2005. It was observed that the extent of the reaction at the maximum exothermic peak is constant and independent of the heating rate. Based on this fact, the relationship between heating rate and the temperature at which the maximum, Tm, appears is given by the expression:

$$\frac{d(\ln v)}{d\left(\frac{1}{Tm}\right)} = -\frac{Ea}{R} - 2Tm \qquad 3$$

As *v* represents a function of 1/Tm (Figure 5), we can obtain a straight line the slope of which may be used to calculate the activation energy, that has a value of 55.026 kJ/mol.

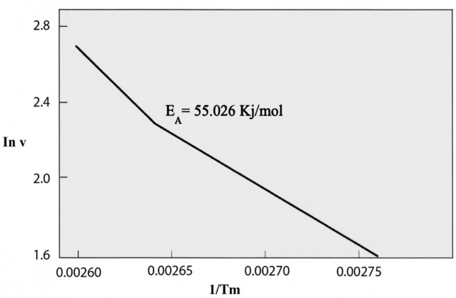

Figure 5. The ln v versus 1/Tm for polyurethane samples.

A study by DSC is very useful for the determination of the kinetics of curing of these resins. The data obtained by this technique can be used for the kinetic study of the isothermal curing reaction. Its simplest model corresponds to the expression of order n:

$$\frac{d\alpha}{dt} = k.(1-\alpha)^n \qquad 4$$

where, dα/dt is the reaction rate, α, is the degree of conversion (degree of cure), n is the reaction order and k is the rate constant, which depends on temperature and is given by the Arrhenius equation:

$$k = A\exp(-Ea/RT) \qquad 5$$

where, Ea is the activation energy of the reaction, A is the pre-exponential factor, R the universal gas constant and T the absolute temperature isothermal. For an isothermal test, equation (2) predicts the maximum reaction rate at time 0, so if an isothermal process is characterized by a thermogram showing its maximum velocity at a point other than the initial one, the so-called autocatalytic model is used by Silva et al.(2010) and Malucelli et al. (2005) expressed in the following form:

$$\frac{d\alpha}{dt} = K \cdot \alpha^m \cdot (1-\alpha)^n \qquad 6$$

where, $d\alpha$ / dt = reaction rate, α= degree of conversion and k, m and n= kinetic parameters of the model.

Up until now, it had been considered that total conversion was reached at the end of the curing process, however a linear dependence must exist between the final degree of conversion and the study temperature (test Panagiotis et al.; 2000). This behavior leads to reconsider the kinetic equations, in such a way that the reaction rate is considered to be 0 when it reaches the maximum degree of cure. Thus, the expression for the autocatalytic model is given by the following expression:

$$\frac{d\alpha}{dt} = k.\alpha^m.(\alpha_m - \alpha)^n \qquad 7$$

where, α_m is the degree of conversion reached at the maximum test temperature. The parameters k, m and n for each temperature are obtained by the linear regression multiple. For a first approximation of the value of n, the expression is written in logarithmic form in the autocatalytic model see Silva et al.; 2010:

$$\ln\left(\frac{d\alpha}{dt}\right) = \ln(k.\alpha_m) + n.\ln(\alpha_m - \alpha) \qquad 8$$

A representation of ln($d\alpha$ / dt) versus ln(1- α) gives a straight line whose slope yields the value of n, as shown in Figure 6. Both m and k may be rearranged as follows to obtain the value of the above equation:

$$\ln\left(\frac{d\alpha/dt}{(\alpha_m - \alpha)^n}\right) = \ln k + m.\ln \alpha \qquad 9$$

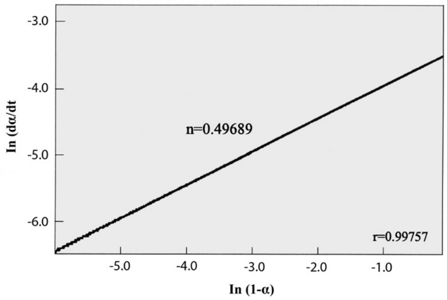

Figure 6. The ln (d_α /dt) vs ln (1– α) for polyurethane samples.

Representation of the first term of the equation, using the value of n obtained above, as a function of ln α, which results in a straight line that is used to calculate the value of m of the slope and the value of k from the intercept of the origin (Figure 7).

Applying the above process gives a first approximation, and more precise values for an iterative procedure are then applied. The new value of n is obtained from the equation that is rearranged as follows:

$$\ln\left(\frac{d\alpha/dt}{k\alpha^{m}}\right) = n.\ln(\alpha_m - \alpha) \qquad 10$$

The first term of the equation is calculated from the m and k values obtained and plotted against ln (α_m – α), obtaining a straight line the slope of which is the new value of n. With this value of n, the new values of m, k, are obtained through the process described above. The values obtained in this way were very similar to those calculated in the first calculation (Xie et al., 1993).

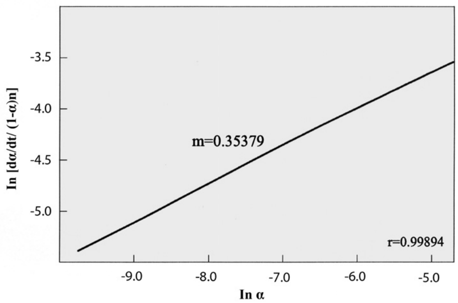

Figure 7. The Ln (dα/dt (1-α)n) versus ln α.

In Table II, we can see the kinetic parameters, where m and n are orders of reaction of the system and k is the reaction rate constant. In the range of polymerization from 20 to 110 °C, the reaction order to monomer undergoes a slight increase that can be attributed to a change in the reaction mechanism, but which is not considered a representative variation and is therefore not taken into account. Thus, the average value has been assigned 1. Under analysis, the observed rate of polymerization increases with increasing temperature.

Given this dependence on temperature, the Arrhenius equation is satisfied, which expressed in its logarithmic form is:

$$\ln k = \ln A - Ea/RT \qquad 11$$

T (ºC)	n	m	n + m	K (min - 1)
20	0.49761	0.35377	0.85138	0.024
30	0.50134	0.31896	0.82030	0.050
40	0.49717	0.37823	0.87540	0.052
50	0.49889	0.35553	0.85442	0.049
60	0.50201	0.34512	0.84713	0.063
70	0.50309	0.35849	0.86158	0.093
80	0.50303	0.35894	0.86197	0.108
90	0.50652	0.35650	0.86302	0.144
100	0.50650	0.35037	0.85687	0.133
110	0.50700	0.35870	0.86570	0.271

Table II. Kinetic parameters for the autocatalytic model.

By representing 1/RT vs lnk, we can determine the slope of the line to obtain the activation energy of the system. One can see from Figure 8 that this system has 2 pending, which indicates that two mechanisms are involved. The first mechanism may correspond to the crosslinking reaction of the urethane group, while the second may correspond to a secondary reaction due to high temperatures at which the study is conducted (Malucelli et al.; 2005).

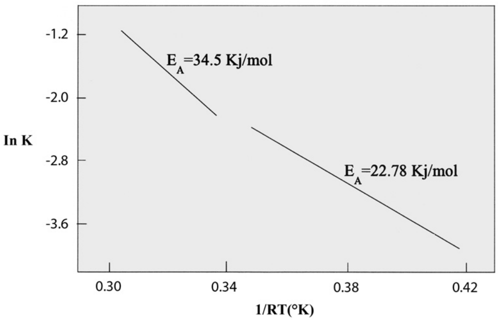

Figure 8. Representation of the Arrhenius law for polyurethane samples.

The values of activation energy obtained are:

E_{A1} = 34.50 kJ/mol
E_{A2} = 22.78 kJ/mol
E_{Total} = 57.28 kJ/mol

This energy is very similar to that obtained experimentally in Figure 5 (55.026 kJ/mol), which suggests that the autocatalytic model is reliable.

CONCLUSIONS

In the present study, the curing kinetics of polyurethane/silica have been investigated by isothermal DSC. We have examined systems with a high proportion of silica load, cured at several temperatures. The conventional isothermal method allows us to obtain very similar values of the enthalpies of polymerization using both dynamic and isothermal sweeps. By representing the equation in its logarithmic form, the Arrhenius equation gives us two slopes (Ea) for the same system which points to the presence of two curing reaction mechanisms. The first mechanism may correspond to the crosslinking reaction of the urethane group, while the second may correspond to a secondary reaction due to the high temperatures at which the study was conducted. Furthermore, the value of the activation energy is similar to that obtained by other methods which points to the reliability of the autocatalytic model.

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CINÉTICA DE CURADO DE PINTURAS DE ACABADO, PARA APLICACIONES NAVALES, COMPUESTAS POR POLIURETANO Y SÍLICE

RESUMEN

En este trabajo hemos estudiado, mediante calorimetría diferencial de barrido (DSC), la cinética de curado de resinas de poliuretano cargadas con sílice, utilizadas como pinturas de acabado en aplicaciones navales. Hemos observado que la entalpía generada en los barridos isotermos realizados aumenta mientras que la entalpía residual de la muestra disminuye. Este comportamiento se debe a la mayor movilidad de los dobles enlaces a medida que aumenta la temperatura, aunque la suma de ΔH_{iso} + ΔH_{res} se mantiene prácticamente constante. Cuando representamos la ecuación de Arrhenius en su forma logarítmica, obtenemos dos rectas con pendientes diferentes lo cual indica la existencia de dos mecanismos en la reacción de curado en estas pinturas. El primer mecanismo puede corresponder a la reacción de reticulación del grupo uretano, mientras que el segundo sería el responsable de una reacción secundaria, consecuencia de las altas temperaturas a las que se lleva a cabo el estudio.

METODOLOGÍA

En el presente estudio hemos realizado un exhaustivo estudio de todos los parámetros implicados en el proceso de curado del sistema poliuretano/sílice, utilizado como pintura de acabado en aplicaciones navales.

Materiales

La resina utilizada en este estudio resulta de una reacción de polimerización entre el isocianato y el poliol con una alta concentración de sílice. La composición de la mezcla fue de 100/365/80/0.37 para un sistema isocianato/sílice/poliol/pentadiona.

Técnicas

La técnica experimental utilizada en este estudio ha sido la calorimetría diferencial de barrido (DSC TA Instruments Q200). Las muestras utilizadas no superaron los 10 mg de masa, una vez sellado el crisol, éste es introducido en el horno calorimétrico, donde se realizaron los correspondientes barridos isotermos y dinámicos. Las temperaturas de curado utilizadas fueron were 20, 30, 40, 50, 60, 70, 80, 90, 100 and 110 ºC.

Método

Diversos autores han demostrado experimentalmente que el mecanismo seguido por las resinas termoestables en su proceso de curado se puede estudiar a través de dos métodos:

— *Método de las entalpías residuales:* aquí las muestras son curadas isotérmicamente a una T_c en una estufa de vacío a distintos tiempos de curado t_c, y posteriormente se analizan en el calorímetro. Para cada muestra se obtiene la curva DSC dinámica y se determina la entalpía residual de la muestra.

— *Método isotérmico convencional:* por medio de los barridos dinámicos podemos obtener el intervalo de temperatura a la que polimeriza la resina, de esta forma podemos determinar la temperatura a la que realizaremos los barridos isotérmicos. El siguiente paso consiste en estudiar la cinética de polimerización a temperatura constante.

En nuestro caso hemos empleado en primera instancia el método isotérmico convencional y luego una vez determinado los parámetros de intervalo de curado, temperatura óptima y ental- pía de polimerización hemos empleado el método de las entalpías residuales. Este método nos ha permitido determinar el resto de los parámetros cinéticos del sistema como son: constante de velocidad, orden de reacción, grado de conversión, energía de activación, etc.

CONCLUSIONES

El método isotérmico convencional nos permite obtener valores muy similares de las entalpías de curado o polimerización obtenidas por los barridos dinámicos. Si representamos la ecuación de Arrhenius, en su forma logarítmica, obtenemos dos rectas con pendientes diferentes (Ea) correspondientes a los dos mecanismos de curado que presenta el sistema. Además el valor de la energía de activación así obtenido es similar al obtenido por otros autores y métodos lo cual nos indica la fiabilidad del modelo autocatalítico elegido en este estudio.

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3D MODELING FOR COMPETENCES DEVELOPMENT OF NEW DEGREES WITHIN THE FIELD OF MARITIME

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ABSTRACT

This paper describes a pilot study involving a 3D modeling workshop as an educational innovation tool intended for development of spatial vision which is a competence that should be acquired according to curriculum of European space for higher education in the new bachelor's degrees within the field of Maritime, Nautical and Marine Engineering. The study has been performed with students in Marine Engineering, Nautical Engineering and Maritime Transport and Engineering Radio-electronics degrees at the University of La Laguna (Spain) during the 2010-2011 academic year. Software chosen for this workshop was the free version of Google Sketchup 8. For measuring its influence on student's spatial vision, MRT and DAT5-SR tests are used. After completing the workshop students fill a satisfaction survey. Format and structure of this workshop allow its implementation on virtual learning environments (virtual classroom).

Key words: 3D modeling, educational innovation, new technologies, spatial vision, competence, European space for higher education.

INTRODUCTION

In the framework of European Space for Higher Education, main aim of teaching-learning process is not only acquisition of knowledge by students but also develop-

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ment of several competences (skills and abilities) according to academic and professional profiles. Competences are understood as those knowledge related to professional duties as a result of learning.

One competence contemplated in the field of Maritime, Nautical and Marine engineering is spatial vision ability. This competence is also considered by several authors as fundamental for performing engineering duties (Adánez y Velasco, 2002;) (Ferguson, 1992).

However in courses of study for these new degrees there are no explicit activities focused on spatial vision improvement. It's understood than taking subjects related to drawings, diagrams and part's models that skill is developed although its effects are not measured.

Having this in mind, we propose a 3D modeling workshop focused on improvement of spatial vision measuring effects on that skill. Workshop's contents have been developed through a virtual classroom on Moodle teaching platform. So, it allows its easy implementation in any faculty or school which uses any similar platform in their virtual campus.

In this paper we will describe the experience of training for improvement of spatial skills. First, we will define spatial ability concept as well as tests used for measuring it. Workshop contents details are below together with results obtained through statistical analysis. Finally, conclusions obtained from this experience as well as future works proposal which staring from this workshop's model may develop competences related with design and interpretation of *drawings*, *sketches,* sections and *views from ship components*.

BACKGROUND

On January 21st 2009 the seven Technical Colleges and Nautical Faculties of the Spanish Universities and the official school of the Merchant Marine seeking an agreement on academic competences that may be acquired taking the decision of including spatial vision ability alongside representation, standardization, computer assisted design and industrial design fundamentals techniques as basic formation competences for the new degrees.

Science and Innovation Ministry published in the official State Bulletin (BOE 18th, 19th and 20th February 2009) a Ministerial order for each bachelor's degree with their acquirable competences for qualifying students in the exercise of their professions. One competence that should be acquired is 'Spatial vision ability and graphic representation techniques knowledge through traditional descriptive and metric geometry methods as well as computer assisted design applications'.

So, spatial vision ability is present as an acquirable competence in the curriculum for new bachelor's degrees of Marine Engineering degree, Naval Radio Electronic Engineering degree, Nautical Engineering & Maritime Transport degree, Naval architecture degree, Marine Engineering degree, Naval Systems and Technology Engineering degree and Marine propulsion and services Engineering degree.

It's remarkable that some curriculums refer to it as spatial conception, meanwhile others designate it as spatial vision. Both terms refer to ability for mental manipulation of objects and their parts in 2D and 3D environments. (Martín, 2009).

Indeed, in this curriculums knowledge of objects' dimensions in space as well as possible interaction between them through geometric projection use, CAD introduction and abilities acquisition for assembly drawings and mechanics dismantling appear as learning results.

That's why in university education, spatial ability reveals as a necessary skill for successful addressing of educational contents by students. Several authors relate high level of these skills with success in technical careers: spatial thinking is essential for scientific thought and it's used for information representation and handling while learning as well as for problems resolution. (Smith, 1964; McGee, 1979; Clements y Battista (1992).

In the maritime field this spatial vision ability intervenes in installations plan representation during visualization of its different components in both 2D and 3D as well as during parts setup and mechanizing on 3D environments for naming but a few.

In formation of future seamen, STCW code establishes simulator use as obligatory (Gorgoulis, 2010) where spatial vision does also intervene. When handling propulsion and auxiliary ship system simulators, available 2D information needs 3D visualization easing maintenance and operation tasks providing several improvements in ergonomic parameters. Many authors use simulators in the design of ship parts (Lamas, Rodríguez, Rodríguez & González, 2010) and for educational applications (Eguía, Trueba & Milad, 2008)

Many studies show that spatial skills may be developed through training if appropriate materials are provided (Cohen, Hegarty, Keehner, & Montello, 2003), (Kinsey, 2003), (Newcomer, Raudebaugh, McKel, & Kelley, 1999), (Potter & Van der Merwe, 2003) and there is common agreement that spatial ability can be improved through training (Sorby, Wyssocky, & Baartmans, 2003).

In this paper we will describe experience from training to improve spatial skills through a 3D modeling workshop.

SPATIAL SKILLS AND ITS MEASUREMENT

Spatial capacity is accepted by various authors throughout history as a component of intelligence. Some people have greater degrees of innate aptitude, but the vast majority can train this skill through practice (Sorby, Wyssocky, Baartmans, 2003). In this work we use the term spatial ability referring to the part of the spatial capacities that we can practice through training.

While studying components of spatial ability we found different approaches for establishing its classification and at the same time, several tools for finding out quantitative results through testing.

In recent years, a large number of authors classify the components of spatial ability using two categories: (Linn Petersen, 1985 ;) (Olkun, 2003):

— Spatial Relations (or Mental Rotation): ability for rotating 2D or 3D figures quickly and accurately in our imagination.
— Spatial Visualization: ability for recognizing 3D parts through folding and unfolding of their faces.

Some researchers (Maier, 2004, Mafalda, 2010) include spatial orientation as one of the components, defined as the ability for orienting themselves relating to the environment and location self-awareness. In the case of three-dimensional objects modeling we opted for the two categories classification: Spatial Relations and Spatial Visualization.

Around this classification there is a lot of testing in order to measure each of the components. In our research we use two of them which have been validated by fieldwork and use in other studies similar to ours (Devon, Engle, Foster, Sathianathan, & Turner, 1994; Sorby & Baartmans, 2000, Gerson, Sorby, Wisocki & Baartmans, 2001, Martin-Dorta, Saorin and Contreras, 2008):

— Mental Rotation Test (MRT) for measuring spatial relations (Albaret and Aubert, 1996; Vanderberg & Kuse, 1978).Highest score possible in this test is 40 points.
— Differential Aptitude Test 5- Spatial Relations Subset (DAT5-SR) for spatial visualization. (Bennett, Seashore y Wesman, 2002). Highest score possible in this test is 50 points.

PILOT TEST: 3D MODELING WORKSHOP

Description

This workshop proposes a strategy for improvement of spatial skills with a 3D modeling workshop combining handling of real parts and three-dimensional computer images.

This strategy has been validated separately by other researchers: some have worked with real pieces (Alias, Black & Gray, 2002, Ben-Chaim, Lappan & Hougang, 1998; Duesbury & O'Neil, 1996) and others conclude than manipulating the image of an object by computer is enough for improving spatial skills (Wiley 1990, Sorby, 1999).

Participants

Participants in our 3D modeling workshop includes undergraduate students in Marine Engineering, Nautical Engineering and Maritime Transport and Radio Electronics engineering of the University of La Laguna during the academic year 2010-2011. From a total of 72 students, 26 volunteers (20 men and 6 women) with an average age of 21 years.

Hardware and software

Pentium IV computers with 512 Mb RAM and the Windows XP operating system were used.

There are different commercial programs like Pro/Engineer, AutoCAD Inventor, Solid Works and others which are able to generate 3D models. Software chosen for our study is the Google SketchUp8, a multimedia application with free access and download that, although cannot compare in features and possibilities to commercial programs, it still offers the possibility for introducing us in 3D modeling with few technical knowledge and in a very short time. It has a friendly interface with few but intuitive commands which combined with easy use encourage quick learning. The fact that it's free eases its implementation at any centre, avoiding the problem of the software licenses acquisition cost.

Measurements

For measuring spatial ability: each participant performed both tests (MRT and DAT5-SR) prior to the experiment and after its completion for evaluating results.

For measuring user satisfaction (likability) each participant fills a survey upon workshop completion. Questions were asked according Likert's scale where numeric values are assigned to each question showing level of agreement or disagreement in a 5 points scale.

Survey has 56 questions organized according to three variables: the first refers to structure, presentation, design and materials of the workshop, meanwhile second refers to the contents and, finally, the last one to user satisfaction and motivation.

Instruction

Workshop consists of two phases: introduction and improvement. There are also three difficulty levels obtained from incorporation of inclined and curved faces. At the same time, figures are drawn in a three-dimensional grid which complexity increases with each level, containing 24 figures, where participants are asked to solve at least a minimum of six (Table 1).

The design of this workshop has been validated by Dehaes research group (Skill Development Space: http://www.degarin.com/dehaes/) at the University of La Laguna for the 2010-2011 academic year, verifying quantitatively the adequate distribution of learning stages and difficulty levels. Average times for solving exercises have been 3 minutes for the introduction phase and 8 minutes for development phase.

Table 1: Workshop structure.

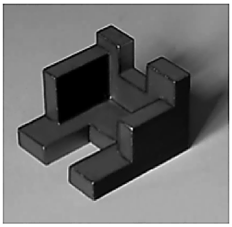
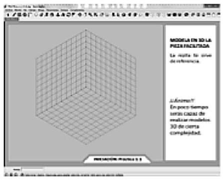
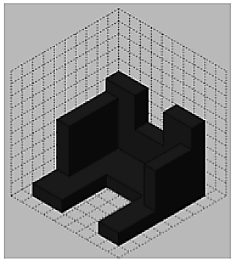
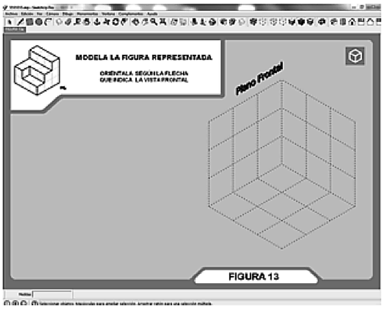
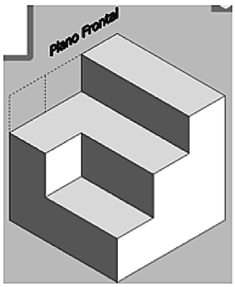
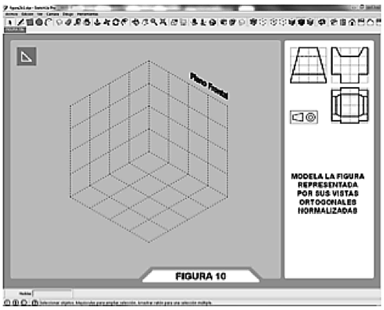
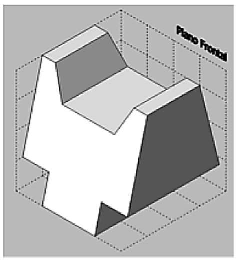
PHASE	PRACTICES/LEVEL		LOGO	DESCRIPTION
INTRODUCTION PHASE	PRACTICE 1.1			Creation of 3D models from real aluminum pieces
	PRACTICE 1.2 Creation of 3D models from isometric perspectives figures	LEVEL A		24 figures entered in a 3x3x3 grid with their faces parallel to coordinate planes
		LEVEL B		24 figures entered in a 4x4x4 grid including inclined faces
		LEVEL C		24 figures entered in a 5x5x5 grid including curved faces
IMPROVEMENT PHASE	PRACTICE 2.1 Creation of 3D models from standard view figures	LEVEL A		24 figures entered in a 3x3x3 grid with parallel faces to coordinate planes
		LEVEL B		24 figures entered in a 4x4x4 grid including inclined faces
		LEVEL C		24 figures entered in a 5x5x5 grid including curved faces

At introduction phase, following instructions included in the video tutorial, student takes basic training in use of SketchUp software. Students learnt most important functions of the program, such as line and polygon drawing in 3D space as well as making extrusions model as a basic operation.

Once they get used to the program they perform practice 1.1 creating 3D models from real pieces of aluminum. For this phase have been used five sets of case M14 (lote14A) Maditeg Company (Maditeg, 1997) consisting of 30 aluminum machined parts. Afterwards student proceeds to practice 1.2 creating 3D models from isometric perspectives figures in three difficulty levels.

At the improvement phase students carried out practice 2.1 creating 3D models from standard orthogonal figures views. In this phase students receive theoretical indications about representation basics and fundamentals, focusing on the European System of Standardized views for being able to perform this level. Like in practice 1.2, this phase is also structured into three levels A, B and C in increasing difficulty levels. (Table 2)

Table 2: Workshop description.

ACTIVITY AND MATERIALS	FORMAT STATEMENT	WORKSPACE	RESULT FORMAT
1.1 Creation of 3D models from real aluminium pieces. **Statement:** Aluminium pieces **Support:** SketchUp file in custom template.	 Statement	 Custom Template	
1.2 Creating 3D models from a isometric perspective. (Level A, B y C) **Statement and Support:** SketchUp file in custom template.	 Statement and workspace		
2.1 Creating 3D models from standard orthogonal figures views (Level A, B y C) **Statement and Support:** SketchUp file in custom template.	 Statement and workspace		

Meanwhile, workshop time distribution is found on table 3:

Table 3: Time distribution.

		Duration (minutes)	Number of pieces to be taken
Introduction Phase	Basic Training	30	—
	Real Parts	30	1
	Level A	30	6
	Level B	30	6
	Level C	45	6
Improvement Phase	Level A	45	6
	Level B	60	6
	Level C	60	6

Workshop contents are implemented within a virtual classroom as this format allows immediate incorporation in any center. Besides, work performed by students in digital format can be received, stored and properly evaluated in a virtual classroom structure.

Thanks to the modulation of the workshop it can be implemented in formal teaching by adapting the number of exercises to be developed depending on student's level and number of hours available for that subject, proposing more or less figures to work with at each level.

Work hypothesis

Work hypothesis set is the following:

— A 3D modeling workshop is a valid tool for the aim of spatial abilities improvement.

— Use of new technological tools for learning improves student motivation.

For validating hypothesis 1 a null hypothesis (H0) is set so assumption will be validated or not through statistical inference methods. For hypothesis 2 all data from satisfaction surveys completed by participants at the end of the workshop are added.

DATA ANALYSIS

Spatial skills

The workshop took place during the first weeks of the semester, for avoiding possible influence from contents covered by other subjects, such as Graphic Drawing thus preventing other factors which may interfere with the test measuring spatial skills.

Table 4 shows the scores mean obtained by students prior to (pre) workshop and after it (post) as well as average gains for MRT and DAT5-SR tests.

Table 4: Mean pre and post test scores and overall score gains.

		MRT			DAT5-SR		
Course 2010-11	Total N=26	Pre (s.d.)	Post (s.d.)	Gain (s.d.)	Pre (s.d.)	Post (s.d.)	Gain (s.d.)
		16.60 (7.64)	22.80 (7.23)	6.30 (5.03)	24.90 (6.95)	35.60 (7.88)	11.20 (5.91)

s.d. standard deviation

For statistical analysis we use the t-student variable (Student`s *t*-test), starting from null hypothesis (H0): mean values of spatial abilities have not changed after training. *t*-Student test is applied for paired series getting the *p*-values representing probability that this hypothesis is true (Table 5).

Table 5: Significance level for Google SketchUp course.

	MRT	DAT5-SR
Course 2010-11	P=0.0000030808 < 0.001	P=0.0000000020 < 0.001

It is shown that significance level never reaches 1‰ , so null hypothesis is rejected in all cases and we can state, with a significance level above 99.9% that average variation of studied group has increased. So, workshop has a clear effect on the average value of the spatial abilities measured from those who underwent training through the 3D modeling workshop.

From statistical analysis we may conclude that spatial skills experience a significant average increase of 6 points for the MRT test and 11 points in the case of DAT5-SR.

Satisfaction survey

Satisfaction survey provides some relevant data about studied variables:

Variable 1 (workshop structure, presentation, design and materials): A 95.6% of students consider that workshop structure, phases and levels are appropriate or very appropriate. 87% preferred this format based on digital and virtual classroom materials rather than the traditional paper format.

Variable 2 (contents): 87% agree or strongly agree on the workshop contents clarity. Thus, 82.6 per cent considered that these contents have allowed them better understanding of standard views.

Variable 3 (user's satisfaction and motivation): 91% of participants believe that workshop improved their attention and motivation for studying matters related to analysis, design and interpretation of forms. 100% of the students who took the survey answered affirmatively when asked if they would be interested in 3D modeling courses which work with the design and interpretation of drawings, sketches, views and sections of ship components.

CONCLUSIONS AND FUTURE WORK

From this experience with implementation of the 3D modeling workshop we may conclude about hypothesis raised:

— Hypothesis 1: The skills can be developed through training. 3D Modeling Workshop using Google SketchUp has proved to be a good choice for this purpose: it has significantly increased the space capacity of the participants with an average gain of 6.30 points (5.03 s.d.) and 11.20 points (5.91 s.d.) in the MRT and DAT test SR-5 respectively.

— Hypothesis 2: use of new technological tools for learning improves the motivation of the student: 91% of the students agree with this.

About future works:

— It would be interesting adapting contents of this workshop to the new portable media devices such as digital tablets of recent appearance for example.

— According to survey results, we propose developing digital material that combines two and three dimensions for performing exercises from auxiliary vessel elements, incorporating Augmented Reality technology.

The implementation of these workshops in a virtual classroom provides the possibility for immediate incorporation to any other Center as well integration into formal teaching. So, we could exchange experiences between different Nautical technical colleges establishing benchmarks.

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MODELADO TRIDIMENSIONAL EN EL DESARROLLO DE COMPETENCIAS DE LOS NUEVOS GRADOS EN EL ÁMBITO DE LAS INGENIERÍAS MARÍTIMA, NÁUTICA Y MARINA

Resumen

En este artículo se describe un estudio piloto consistente en el diseño de un Taller de Modelado 3D como Herramienta de Innovación Educativa que desarrolla la capacidad de visión espacial. Dicha capacidad es una de las competencias a adquirir en los planes de estudio del Espacio Europeo de Educación Superior para las nuevas titulaciones de Grado en el ámbito de las Ingenierías Marítima, Náutica y Marina. El estudio ha sido realizado con estudiantes de Grado en Ingeniería Marina, Ingeniería Náutica y Transporte Marítimo e Ingeniería Radioelctrónica de la Universidad de La Laguna durante el curso académico 2010-2011. El software elegido para el Taller ha sido Google Sketchup 8, en su versión gratuita. Para medir la la influencia que ha tenido la realización del mismo sobre la visión espacial de los alumnos se emplean los test MRT y DAT5-SR. A la finalización del Taller los alumnos cumplimentan una encuesta de satisfacción. El formato y estructura del Taller permite su implantación en entornos virtuales de aprendizaje (aula virtual).

INTRODUCCIÓN

En el marco del Espacio Europeo de Educación Superior, el objetivo principal del proceso de enseñanza-aprendizaje consiste no solo en la adquisición de conocimientos por parte del alumno, sino en el desarrollo de una serie de competencias en función de los perfiles académicos y profesionales. Se entienden por competencias a aquellos conocimientos relativos a la actividad profesional que son resultado del aprendizaje. Una de las competencias contempladas en los planes de estudio de las titulaciones de Grado en el ámbito de las Ingenierías Marítima, Náutica y Marina es la capacidad de visión espacial. En este sentido, proponemos un Taller de Modelado 3D dirigido a la mejora de la visión espacial, midiendo el efecto sobre dicha capacidad.

Los componentes de esta capacidad se clasifican en dos categorías (Linn & Petersen, 1985; Olkun, 2003).

— Relaciones Espaciales o Rotación Mental: habilidad de rotar en nuestra imaginación, rápida y acertadamente figuras de dos o tres dimensiones.
— Visión Espacial: habilidad de reconocer piezas tridimensionales mediante plegado y desplegado de sus caras.

Para medir la mejora de la visión espacial cada participante realiza dos test antes y después de llevar a cabo el experimento: Mental Rotation Test (MRT) para medir la componente de Relaciones espaciales (Albaret and Aubert, 1996; Vanderberg & Kuse, 1978) y Differencial Aptitude Test 5– Spatial Relations Subset (DAT5-SR), para medir la componente de visión espacial (Bennett, Seashore y Wesman, 2002).

En el Taller de Modelado 3D han participado estudiantes de Grado en Ingeniería Marina, Ingeniería Náutica y Transporte marítimo e Ingeniería Radioelectrónica de la Universidad de La Laguna durante el curso académico 2010-2011. De un total de 72 alumnos, han participado 26 voluntarios. El software elegido para nuestro estudio es el Google SketchUp8, una aplicación multimedia de libre acceso y descarga gratuita.

El Taller consta de dos fases: Iniciación y Perfeccionamiento. Existen a su vez tres niveles de dificultad que se consiguen con la incorporación de caras inclinadas y caras curvas. A su vez, las figuras están dibujadas en una rejilla tridimensional que aumenta su complejidad con el nivel. Cada nivel contiene 24 figuras, de las cuales se les solicitó a los participantes que resolvieran un mínimo de seis de ellas. El diseño de este Taller ha sido validado por el Grupo de Investigación DEHAES (Desarrollo de Habilidades Espaciales: http://www.degarin.com/dehaes/) de la Universidad de La Laguna durante el curso 2010-2011, comprobando cuantitativamente la adecuada distribución en fases de aprendizaje y niveles de dificultad: se han obtenido unos tiempos medios de resolución de ejercicios por fases y niveles de 3 minutos para la fase de iniciación y de 8 minutos para la fase de perfeccionamiento.

En la fase de Iniciación, el alumno realiza un entrenamiento básico del manejo del software SketchUp. Una vez familiarizados con el programa realizan la práctica 1.1, consistente en crear modelos 3D a partir de piezas reales de aluminio. Posteriormente, el alumno accede a la práctica 1.2, en la que ha de crear modelos 3D a partir de perspectivas isométricas de figuras, con tres grados de dificultad creciente. En la fase de perfeccionamiento el alumno realiza la práctica 2.1, consistente en crear modelos 3D a partir de vistas ortogonales normalizadas de figuras. Como en la práctica 1.2, esta fase está también estructurada en tres niveles A,B y C en grado creciente de dificultad.

Los contenidos de este Taller se han desarrollado dentro de un aula virtual en la plataforma educativa Moodle. Gracias a la modularidad del Taller se puede implementar en la docencia reglada adaptando el número de ejercicios a desarrollar en función del nivel del alumno y del número de horas de que disponga la asignatura, proponiendo trabajar, en cada nivel, con más o menos figuras.

Hipótesis de Trabajo

Las hipótesis de trabajo de las que partimos son las siguientes:

1. Un Taller de Modelado 3D es una herramienta válida para el objetivo de mejorar las habilidades espaciales.
2. El empleo de nuevas herramientas tecnológicas de aprendizaje mejora la motivación del alumno.

Para poder validar la hipótesis 1 se fijará una hipótesis nula (H0) y se validará o no la suposición a través de métodos de inferencia estadística, a partir de los resultados obtenidos en los test. Para la hipótesis 2 se aportan datos de encuestas de satisfacción cumplimentadas por los participantes al finalizar el Taller. Las preguntas de la encuesta están formuladas en una escala tipo Likert y consta de 56 preguntas organizadas de acuerdo a 3 variables: estructura, presentación, diseño y materiales del Taller; contenidos y, finalmente, satisfacción y motivación del usuario.

CONCLUSIONES Y FUTUROS TRABAJOS

De la experiencia obtenida en la realización del Taller de Modelado 3D podemos concluir, respecto de las hipótesis planteadas:

— Hipótesis 1: Las habilidades se pueden desarrollar mediante entrenamiento. El Taller de Modelado 3D utilizando Google SketchUp se ha mostrado como una buena opción para este propósito: ha aumentado significativamente la capacidad espacial de los participantes con una ganancia media de 6,30 puntos (5.03 s.d.) y 11,20 puntos (5,91 s.d.) en los test MRT y DAT SR-5 respectivamente.

— Hipótesis 2: El empleo de nuevas herramientas tecnológicas de aprendizaje mejora la motivación del alumno: un 91% de los alumnos así lo consideran.

En la línea de futuros trabajos sería interesante adaptar los contenidos de este Taller a los nuevos soportes móviles como por ejemplo las Tabletas Digitales de reciente aparición, combinando 2D y 3D para la realización de ejercicios de elementos auxiliares del buque en un entorno de Realidad Aumentada.

La implementación de estos Talleres dentro de un aula virtual ofrece la posibilidad de incorporarlos de manera inmediata en cualquier otro Centro e integrarlos en la docencia reglada. De este modo, se podrían intercambiar experiencias entre las distintas Escuelas Técnicas Superiores de Náutica, estableciendo parámetros comparativos.

INSTRUCTIONS FOR AUTHORS

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- ☐ Notes, when necessary, are to be placed at the end of the paper and numbered in their order of appearance in the text. Mathematical derivations should not be included in these endnotes.

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- Conclusions
- Endnotes
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References

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- Several authors: Goodwin and Kemp (1979); Ihere, Gorton y Sandevar (1984); Ihere et al.(1984); (Ihere et al., 1984)

The *bibliographic references* are to be arranged in alphabetical order (and chronologically in the case of several works by the same author), as is indicated in the following examples:

Books

Farthing, B. (1987) *International Shipping.* London: Lloyd´s of London Press Ltd.

Chapters of books

Bantz, C.R. (1995): Social dimensions of software development. In: Anderson, J.A. ed. *Annual review of software management and development*. Newbury Park, CA: Sage, 502-510.

Journal articles

Srivastava, S. K. and Ganapathy, C. (1997) Experimental investigations on loop-manoeuvre of underwater towed cable-array system. *Ocean Engineering* 25 (1), 85-102.

Conference papers and communications

Kroneberg, A. (1999) Preparing for the future by the use of scenarios: innovation shortsea shipping, *Proceedings of the 1st International Congress on Maritime Technological Innovations and Research,* 21-23 April, Barcelona, Spain, pp. 745-754.

Technical Reports

American Trucking Association (2000) *Motor Carrier Annual Report*. Alexandria, VA.

Doctoral theses

Aguter, A. (1995) *The linguistic significance of current British slang*. Thesis (PhD).Edinburgh University.

Patents

Philip Morris Inc., (1981). *Optical perforating apparatus and system*. European patent application 0021165 A1. 1981-01-07.

Web pages and electronic books

Holland, M. (2003). *Guide to citing Internet sources* [online]. Poole,
Bournemouth University. Available from:
http://www.bournemouth.ac.uk/library/using/guide_to_citing_internet_sourc.html
[Accessed 1 November 2003]

Electronic journals

Storchmann, K.H. (2001) The impact of fuel taxes on public transport — an empirical assessment for Germany. *Transport Policy* [online], 8 (1), pp. 19-28 . Available from:
http://www.sciencedirect.com/science/journal/0967070X
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