Empirical analysis of the implantation of an automatic mooring system in a commercial port. Application to the Port of Santander (Spain)

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Maritime Technology and Engineering 3 – Guedes Soares & Santos (Eds)

Empirical analysis of the implantation of an automatic mooring system in a commercial port. Application to the Port of Santander (Spain)

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ABSTRACT: Recent years have seen a great deal of innovation in all areas of the maritime sector including that of vessel mooring systems and since 1914, research has been carried out into the possibility of developing alternative mooring systems. This is an automatic vacuum-based mooring system. The feasibility of the implantation of the system in a given port depends on technical factors (winds, currents, type of vessel) and economic factors (investment, operating costs, traffic flows). The aim of this work is to determine the viability of the implantation of the system in a commercial port. The technical viability will be analyzed using a real-time maneuver simulator. The economic viability will be analyzed starting from the determination of the traffic threshold which would make the investment profitable and the traffic flows of the selected port. The aim is to establish a general procedure and then apply it to the Port of Santander.

1 INTRODUCTION

Recent years have seen a great deal of innovation in all areas of the maritime sector including that of vessel mooring systems, though on a smaller scale in this than in some other areas, the conventional system still being used today in most ports. However, since 1914, research has been carried out into the possibility of developing alternative mooring systems (Hadcroft & Montgomery 2005), using devices other than the conventional ones. The research carried out over the last 100 years has led to an automatic vacuum-based mooring system (Villa 2014) which has been implanted in more than 20 ports worldwide, and whose use seems to be on the rise. It is a hydraulic mooring system by suckers. The viability of the system to be implanted in a port has to be assessed taking into account both technical factors (prevailing winds, currents, types of vessel, etc.) and economic ones (investment, operating costs, traffic flows, etc.) (Díaz 2016). The aim of this work is to determine the viability of the implantation of the system in a commercial port. The technical viability will be analyzed using a real-time maneuver simulator, and thus can be applied to any port for which this information is available or whose activity can be reproduced in the simulator. The economic viability will be analyzed starting from the determination of the traffic threshold which would make the investment profitable and the traffic flows of the selected port. The aim is to establish a general procedure and then apply it to the Port of Santander.

2 AIMS AND HYPOTHESIS

As mentioned above, traditionally the conventional mooring system has been used to undertake the mooring maneuvers of merchant vessels, but new automatic mooring systems for all vessel types are now being developed and installed in many ports (Nakamura 2007). In this context, our overall aim is to analyze the impact of this innovation on the mooring systems used in commercial seaports. We hope to find out how much influence the innovation in mooring systems has had, to what degree these have been implanted and how profitable they have been. This analysis of both technical and economic aspects will be applied to the Port of Santander (Spain).

It is intended to reach this overall aim by means of the following specific aims:

1. Analysis of the technical viability of the implantation of the automatic mooring system in the port of Santander, using a real-time maneuver simulator. Two different system installation scenes are considered, denominated Scene I (Raos Quay 8) and Scene II (Raos Quay 9, under construction). These two terminals are used for the mooring of Ro-Ro vessels. The application of the automatic mooring system was simulated in the Port of Santander in the above scenes comparing three different wind speed situations, taking into account the reactions of the vessel as a function of these variables. The maneuvers were performed in extreme operating

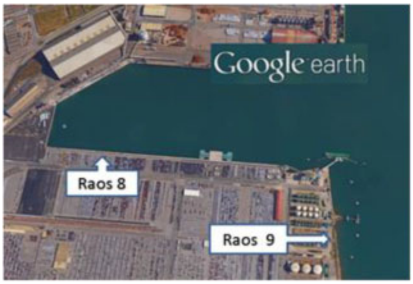

Figure 1. Situation of the selected moorings. Source: authors' own illustration, based on Google Earth.

conditions with the largest-sized Ro-Ro vessel that currently uses the mooring system.

2. Estimation of the profitability of the automatic mooring system in two possible situations (one terminal or both). This requires the estimations to be carried out in two different scenes: Scene I (installation of the automatic mooring system in Raos 8) and Scene III (installation of the system in the two quays selected: Raos 8 and Raos 9) (Fig. 1).

3 METHODOLOGY

In order to achieve the objectives of the technical viability study and the financial profitability analysis of the establishment of an automatic mooring system in the Port of Santander, three different methodologies were used in the selected scenes.

The technical viability analysis of the automatic mooring system is performed using the Maritime Constructions Recommendations Methodology ROM 3.1–99 (Ministerio de Fomento 2000), drawn up by the group of experts of the Coasts and Ports Authorities (currently National Ports Authority) in the year 2000. These recommendations are designed for studies undertaken with a real-time maneuver simulator. In the present case, a "Polaris" simulator, developed by "Kongsberg Norcontrol Simulations" (Norway), and located in the School of Nautical Studies of the University of Cantabria was used (Snellingen 2013).

Among the methods or criteria most widely used to assess and select investment projects are the Net Present Value (NPV) and the return rate or Internal Rate of Return (IRR) (Suárez 2014). It is intended to estimate the profitability of the projects to be undertaken in the two scenes selected with these traditional methods of investment assessment. The practical application of these methods is of great simplicity as both functions can be estimated immediately using a spreadsheet.

4 SELECTION OF THE MODEL TO INSTALL IN THE PORT OF SANTANDER AND BUDGET

Taking into account the various automatic mooring systems found on the market and the fact that the only company that supplies them is Cavotec, they were contacted in order to provide information about the various models and to ask about the budget for the ideal model for the selected quays, Raos 8 and Raos 9, and the type of vessels that could use them.

Based on the experience accumulated over the years in the use of the MoorMaster™ technology, this company concluded that there were several benefits to be obtained in the Ro-Ro and Ferry terminals (Sakakibara & Kubo 2007). These benefits include the saving in response time; the reduction in infrastructure costs, the reduction in the maintenance costs for the port defenses; the increase in safety both on land and onboard due to the elimination of the ropes and the reduction in the labor costs both in the terminal and onboard for the mooring/rope-handling operations. All of these benefits indicate that the model MoorMaster™ 40015 (Cavotec 2015) would be suitable for the fast mooring of Ro-Ro vessels in the Port of Santander (Fig. 2).

Figure 2. Cavotec automatic mooring systems. Source: http://www.cavotec.com/

Table 1. No. of units to be installed as a function of vessels size and wind speed.

Vessel	Wind speed 15 m/s	20 m/s	25 m/s
City of Amsterdam	4	6	8
Parsifal	6	10	14

Source: Cavotec.

The number of units recommended for installation in the mooring quays Raos 8 and Raos 9, for vessels of the type "City of Amsterdam" and "Parsifal", are shown in Table 1.

The "City of Amsterdam" is a car-ferry under an Isle de Man flag, of 100 meters in length and 2,779 metric tons of deadweight. The other vessel on which this budget has been based is the "Parsifal" of the Wallenius Wilhelmsen Company with a total length of 265.0 m and a deadweight in summer of 43,878 metric tons.

Table 2 shows the budget (2015) for the total number of units or robots recommended as a function of wind speeds.

Table 2. Budget as a function of number of units and wind speed.

Wind speed max. m/s	Units	System Price €
15	6	3,000,000
20	10	4,900,000
25	14	6,700,000

5 DEFINITIONS OF CAPACITIES AND SYSTEM DETAILS

The capacity of the automatic mooring units (Shang, Zhen, & Ping Ren 2011) is conditioned not only by the vessel size, but also by the following factors: wind, tide, action of the waves, variation in height of tide and interaction of vessel with defenses. In our study, the wind and waves do not affect the quay of Raos 8.

The difference in height of the tide in the Port of Santander can reach up to 5 meters in spring tides, which means that mooring units will have to be capable of supporting the vertical movements of the variations in the tide, which implies that they will need two additional units more than in those ports that are not affected by the phenomenon of the tide.

The points of union between the mooring robot and the hull of the vessel must be resistant enough to withstand a force of 200 kN in vacuum on a surface of 1.9×1.4 m (size of the vacuum pad) and the hull of the vessel must be free of obstructions. The system to be installed is made up of robots composed of two pads each, which exercises a total force of 400 kN in vacuum per robot.

6 DESIGN AND RESULTS OF SIMULATION

6.1 *Determination of climatological variables on the simulation Scenes.*

The predominant winds in the Port of Santander in winter are those of the south, west and north-west. The south winds are the strongest (more than 55 knots). The big storms generally begin very strong in the south and then change to north-west, accompanied by showers.

In Raos 8, when the wind is over 50 knots, the use of tugboats is required to keep steady the moored vessels. The orientation of the mooring quay is 095°, so that the winds which have a south component, which are the ones that come in squalls, and those of the south-west, which are the strongest, are the ones which most affect the moored vessels. The west and north-west winds with speeds between 15 and 45 knots, without squalls, rock the vessel softly against the quay, without causing any problems during their mooring.

The orientation of Raos 9 is N-S, so that the winds which have the greatest effects in this quay are the west winds as these come in sideways. When the wind speed is over 50 knots, the use of tugboats is required in order to keep steady the moored vessels. It will also be affected, though to a lesser extent, by winds with a south-west component.

Taking into account all of the above and the calculations made to verify the most harmful wind directions for the vessel selected, the maneuvering simulations are performed using the following conditions: SW with speeds of 35, 45 and 50 knots, S with speeds of 45, 50 and 60 with gusts of more or less 10 knots and W with speeds of 35, 45 and 50 knots.

The movements of the vessel will be monitored for the different conditions.

Movements:

1. Vertical up and down movement: Heave.
2. Lateral movement on both sides: Sway.
3. Lengthwise movement forwards or backwards: Surge.

Rotations:

1. Along the vertical axis 'Z': Yaw.
2. Along the horizontal axis 'Y': Pitch.
3. Along the longitudinal axis 'X': Roll.

For the study (Thoresen 2014; Yamase & Ueda 2007) of the technical viability of the implantation of the automatic mooring system in the two scenes, it was decided that the maneuvers should start with the vessel moored in three different situations with different meteorological conditions; that is, with different wind directions and speeds.

Starting from these wind conditions, the following situations were proposed in the two scenes, Raos 8 and Raos 9.

Situation 1: Vessel moored without any rope made fast to land and applying the various alternatives or wind conditions. With these maneuvers, it is demonstrated that the wind really does affect and shift the vessel in different directions and speeds depending on the wind direction and speed. In this way, the simulator will be tested for each wind condition.

Situation 2: Vessel moored with ropes. With the vessel moored, the movements of the vessels are observed when subjected to the various alternatives or wind conditions. These maneuvers have made it possible to observe the extreme wind conditions after which it is necessary to reinforce the ropes or to keep tugboats pushing throughout the whole maneuver.

In fact, the number of ropes commonly used are $2+4$ fore and aft in summer and $2+2+3$ fore and aft in winter. The winter conditions are the ones that will be recreated so a total of 14 mooring ropes will be used of 392 kN each -which is the model used by the simulator- with a total of 5493 kN of retention. The tensions of the ropes and their working direction have been monitored in order to control not to pass the global retention limit. The lengths of the mooring ropes have also been defined so that the vessel is always moored in the same position.

Situation 3: Vessel moored with the automatic mooring system. With these maneuvers, we will try to demonstrate that the movements of the vessel moored with this system are reduced to the minimum and that it will not be necessary to use ropes or tugboats in order to keep steady the moored vessel in any extreme wind condition. In the maneuvers that have been performed simulating 14 robots with a retention capacity of 400 kN each, making a total of 5600 kN of retention – more or less the same as that achieved with the mooring ropes- we have used 10 pushing tugboats of 560 kN each positioned all along the length of the vessel.

In the maneuvers performed with the automatic systems, the tension of the robots is always kept constant in order to see if there is any change in the position of the vessel.

Cavotec has set the dimensions at 14 robots for winds up to 25 m/s, or around 48 knots.

For each situation, (1, 2, and 3) three "options" of wind direction are proposed: A = SW, B = S, C = W; and each wind option has three associated "alternatives" or wind speeds: a = 35 knots, b = 45 knots, c = 50 knots.

During the undertaking of the maneuvers, the same data has been recorded for each situation: time, heading, bow direction, location, wind speed, wind direction, sway, surge and roll. The vessel with which the maneuvers are performed in the simulator is the container ship converted to a Ro-Ro vessel "Barber Texas", which is a reproduction of the real vessel "Texas" of the Wallenius Wilhelmsen Company, a vessel which frequently makes calls in Santander. It is 261.5 meters in length, 32 meters in beam and has a total dead-work of 40 meters.

The recommended values of movement for the moored vessel are: surge 0.3 meters, heave 1.0 meters, yaw 0.5 meters, pitch 0.6°, roll 0.8° and sway 0.6 meters (Ministerio de Fomento 2011).

6.2 *Results of simulation of maneuvers in the different situations*

This work only presents the results of the simulation in the two scenes for the three situations, and only for the most harmful wind conditions (SW in Scene I and W in Scene II) and for wind speed of 35 knots. The illustrations are the graphic output of the simulator, representing the movements of sway and roll.

In the simulations without ropes of the vessel moored in Raos 8, it has been observed that the vessel:

- Maneuver n° 1: with a SW wind of 35 knots the vessel is displaced 190 metros, in a NE direction in three minutes (Fig. 3).
- Maneuver n° 4: with winds of 45 knots, the vessel is displaced 200 meters. Direction NE.
- Maneuver n° 7: with winds of 50 knots, the vessel is displaced around 225 meters. Direction NE.

Analyzing the simulations and the data obtained, we concluded that with SW winds of over 35 knots, the capacity of retention of the vessels, in order to remain moored and without movements that reduce the safety levels of the operations, must be over 5493 kN (Fig. 4). Hence, it can be inferred that if the system retains the moored vessel with 14 robots of 400 kN each, making a total of 5600 kN, it is retaining the vessel with more force as the ropes but without movements (Fig. 5). After 35 knots, it will be necessary to reinforce the

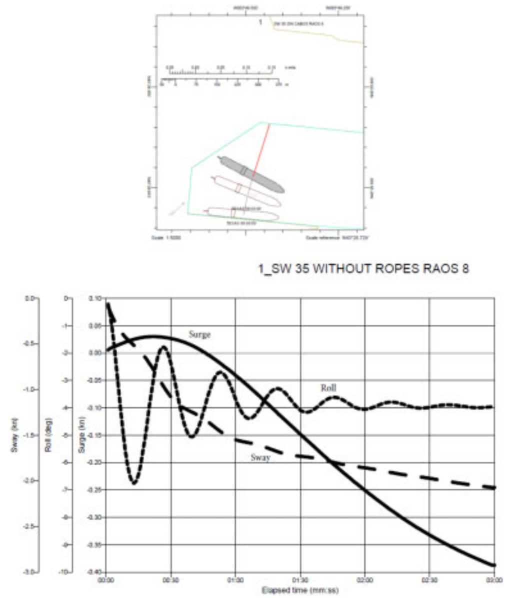

Figure 3. Maneuver n° 1. Scene I, Situation 1Aa. Simulation: Raos Quay 8, with 35 knots of SW wind. Duration 3 minutes. Data on Surge, Roll and Sway.

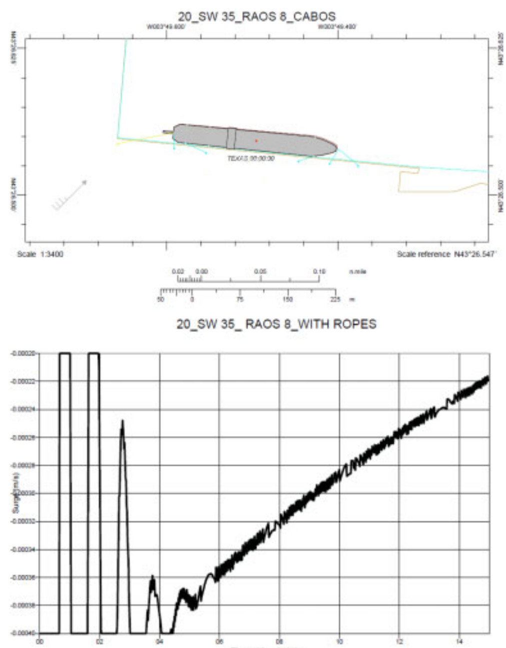

Figure 4. n° 20 Scene I Situation 2Aa. Simulation: Raos 8, with 35 knots of SW wind, with ropes, 15 minutes duration. Data on surge.

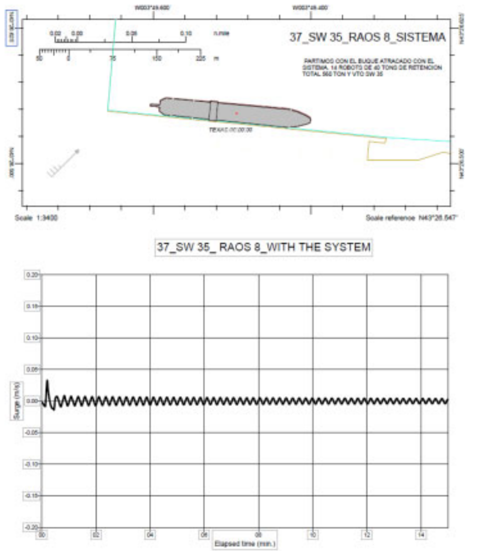

Figure 5. Maneuver n° 37. Scene I Situation 3Aa. Simulation: Raos 8, with 35 knots of SW wind with the automatic mooring system. Duration of Maneuver 15′.

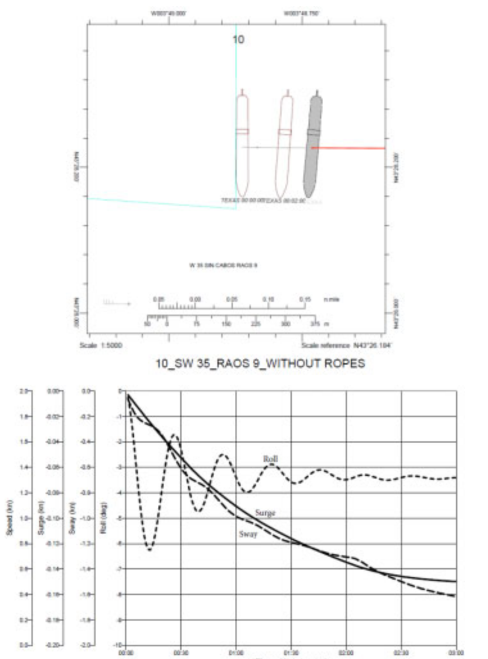

Figure 6. Maneuver n° 10. Scene II Situation 1Ca. Simulation: Raos 9, with 35 knots of W wind, without ropes. Duration 3′.

system with ropes and tugboats may even be required to push on the side. This extreme situation arises on average between 5 and 10 days a year.

Figures 6, 7 and 8 represent the three situations in Scene II, Raos 9, with winds from the W of 35 knots.

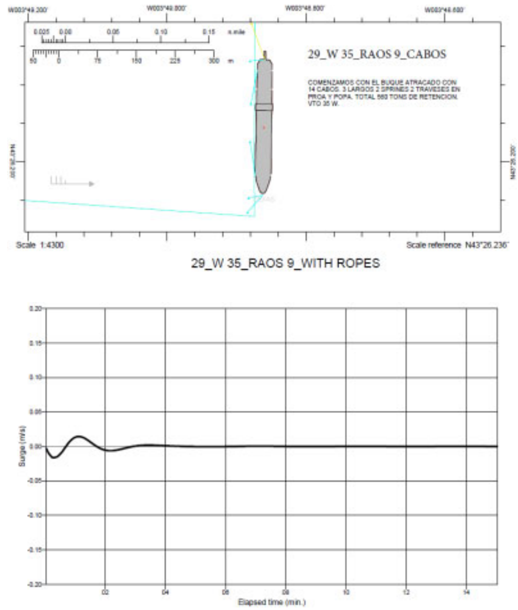

Figure 7. Maneuver n° 29. Scene II Situation 2Ca. Simulation: Raos 9, with 35 knots of W wind, with ropes. Duration 15′.

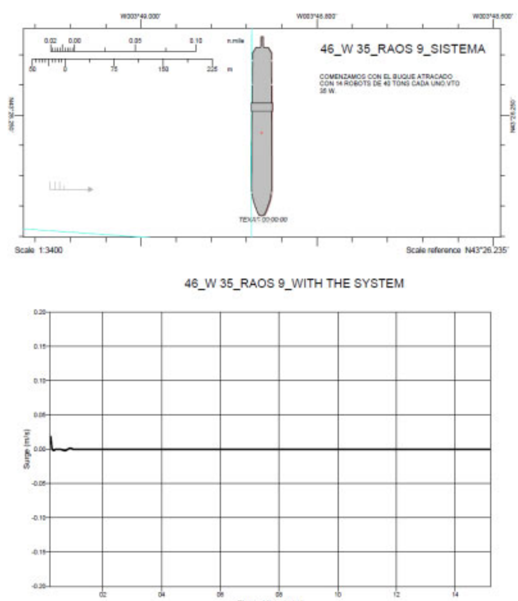

Figure 8. Maneuver n° 46. Scene II Situation 3Ca. Simulation: Raos 9, with 35 knots of W wind, with the automatic mooring system. Duration 15′.

In the simulations without ropes in Raos 9 (Figure 6), it is observed that:

- Maneuver n° 10, with a W wind of 35 knots, the vessel is displaced 155 meters to the east in 3 minutes.

Table 3. Scene I, Situations 2 and 3 alternatives A and B.

Wind speed (knots) SW	Ropes retention (kN)	14 robots system retention (kN)	Wind speed (knots) S	Ropes retention (kN)	14 robots system retention (kN)
35	5797.71	5493.6	45	7161.3	5493.6
45	6749.28	5493.6	50	7455.6	NO BEAR
50	7710.66	5493.6	60	7651.8	NO BEAR

Summary of kN of retention force obtained with simulations with ropes and with the system, in Raos 8 with winds from the SW and S. Source: authors' own table.

Table 4. Scene II, Situations 2 and 3 alternatives y B.

Wind speed (knots) SW	Ropes retention (kN)	14 robots system retention (kN)	Wind speed (knots) W	Ropes retention (kN)	14 robots system retention (kN)
35	5189.49	5493.6	35	6170.49	5493.6
45	6082.2	5493.6	45	7553.7	5493.6
50	6867	5493.6	50	8691.66	NO BEAR

Summary of kN of retention force obtained with simulations with ropes and with the system, in Raos 9 with winds from the SW and W. Source: authors' own table.

- Maneuver n° 13, with winds of 45 knots, it is displaced 245 meters to the east.
- Maneuver n° 16, with winds of 50 knots, it is displaced around 267 meters to the east.

Obviously, the higher the wind speed, the greater the movements.

Maneuver n° 29 (Figure 7) shows that for west winds of 35 knots, the capacity of retention of the ropes, in order to remain moored and without movements that reduce the safety levels of the operations, must be greater than 5493.6 kN. For winds of 45 knots, 7553.7 kN of retention will be required and for winds of 50 knots, 8691.6 kN.

6.3 *Analysis of the simulation results*

The analysis has been based on the results of the maneuvers performed with the vessel moored with ropes and with the automatic mooring system, taking into account, as mentioned above, that the maneuvers without ropes were undertaken in order to demonstrate that the simulator faithfully reflects reality.

Maneuver n° 46 (Figure 8) shows how the vessel remains steady with winds of 35 knots due to the use of the automatic mooring system.

From the simulations performed for the SW and S winds in Raos 8, it can be concluded that the stay of the ship is much safer when moored with the automatic mooring system than with the ropes.

With ropes, it would be necessary to add tugboats at the side after 35 knots while with the system this would not be necessary. If, at one point, the wind should blow at over 50 knots, with the vessel moored with the system, it could be reinforced with ropes, avoiding the use of a tugboat pushing at the sides, which means that the vessels are self-sufficient (Table 3).

In Scene II, Raos 9, the results shown in Table 4 are obtained for SW and W winds. With ropes, it would be necessary to add tugboats after 45 knots while this is not the case with the automatic system If, at one point, the wind should blow at over 50 knots, with the vessel moored with the system, it could be reinforced with ropes, avoiding the use of a tugboat pushing at the sides, which means that the vessels are self-sufficient.

Table 5. Structure of the installation costs. Repayable.

Structure Of Installation Costs (*Repayable*)	*Scene I* €	*Scene III* €
Civil Works	1.190.000	2.380.000
Equipment (Robots)	6.700.000	13.400.000
Total Installation Costs	7.890.000	15.780.000

Source: Authors' own table.

7 ECONOMIC-FINANCIAL ANALYSIS OF THE AUTOMATIC MOORING SYSTEM

When it comes to assessing a project in order to determine its economic-financial viability, an analysis is made of the economic results of its installation, in the predicted conditions, and it is determined whether the project can be undertaken. The profitability of the project to be carried out is generally determined using the NPV and IRR investment assessment methodologies mentioned above in the methodology. To this end, an estimation of the costs is made as well as a prediction of the revenues, and of the accounts that make up the financial plan. The plan has been executed, as is generally the case, on the two basic levels, one related to the capital cycle or to long-term operations (investments in fixed assets and basic funding) and another related to the cycle of the exploitation or current operations (investments in short-term circulating assets). The financial instrumentation of these economic cycles has been formalized using the budgets of capital, exploitation and treasury. Finally, the NPV and the IRR have been estimated for the predicted scenes.

7.1 *Estimation of costs*

The present section presents the formalization of the results of the estimation performed both of the costs and expenses of installing the automatic mooring system and of the costs directly associated to its productive process (exploitation) without VAT (21%). The estimation is based on the data provided by companies that operate with similar mooring systems. All of the estimations have been applied in the two different, though complementary, scenes, in which it is intended to undertake the activity: Scene I (RAOS Quay 8) and Scene IIII (RAOS Quays 8 and 9).

7.2 *Installation costs*

The installation costs are the investment and expenses required to set up the automatic mooring system, before it can begin to be exploited (Table 5). These are the works and installations that must be carried out and are susceptible to amortization (structural adaptations, electrical installations, equipment and systems, external adaptations and conditioning of the surrounding area).

The exploiting company starts under the premise that the Port Authority of Santander will take charge of the installation adaptation works. Hence, the exploiting company will only have to repay the equipment, recovering its investment in 30 years.

7.3 *Exploitation costs*

Most of the exploitation costs (Table 6), except for the running and management of the system operators, has been externalized in order to adapt to the variations in demand. In this sense, the maintenance and repair services, consumptions (electricity, water and telephone) and insurance will be provided by companies and personnel from outside the installation.

7.4 *Financial costs*

The initial installation costs are intended to be financed through two different sources. The equipment (robots) will be funded with a loan and the adaptation works will be funded by the Port Authorities.

7.5 *Amortization*

Part of the installation and exploitation costs correspond to works and equipment which are susceptible to amortization, as shown in Table 7.

The linear amortization criterion has been used with a residual value of 15% of the purchase value. The works and equipment will be repaid in 30 years, the vehicle in 10 years.

Table 6. Structure of the exploitation costs.

Structure of the exploitation costs.	Scene I (RAOS 8)		Scene III (RAOS 8 y 9)	
	2014	2015	2014	2015
Installation	7,890,000		15,780,000	
Vehicles		18,000		18,000
Personnel		194,378		194,378
Electricity Consumption		244,944		489,888
Fuel Consumption		324		648
Maintenance		60,300		107,200
Insurance		67,000		120,600
Other outside services		1200		1200
Financial costs		268,720		536,720
Total exploitation costs	7,890,000	854,866	15,780,000	1,468,634

Source: Authors' own table.

Table 7. Annual financial amortization.

Investment Table (Annual Amortizations)			
Works, installations and equipment		Scene I €	Scene III €
Installation Costs	Equipment	219,983	439,967
	Civil Works	39,072	78,143
	Vehicle	1773	1773
	Total Investment	260,828	519,883

Source: authors' own table.

7.6 *Revenues and sources of funding*

The predicted revenues and sources of funding for the development of the activity of the automatic mooring system, as can be seen in Table 8, have three clearly distinct origins: the sale of the mooring services; subsidies from the Port Authority of Santander and loans.

7.7 *Profitability of the investment*

The profitability of the investment in the port terminals has been estimated in keeping with the VAN and IRR criteria for the two scenes. In both cases, the estimations have been made under the assumption of full employment in the terminals.

Scene I: The investment is not profitable. The project is not viable for one terminal and should be rejected, even though low average revenues have been considered in relation to the traffic it is hoped to attract, in order to consider more restrictive conditions.

IRR = −0.46%

VAN = −736,304 €

Table 8. Revenues and sources of funding.

Revenues and sources of funding	Scene I €/year	Scene III €/year
Sale of mooring services	1,080,000	2,160,000
Subsidies from the Port Authority of Santander	1,190,000	2,380,000
Loans	6,700,000	13,400,000

Source: authors' own table. Amounts in current €.

Scene III: The investment is profitable both in absolute and in relative terms, so that it can be undertaken.

IRR = 2.5%

VAN = 1,023,940 €

The investment in the two terminals allows scale economies to be applied.

8 CONCLUSIONS

From the results obtained from the research described above, the following conclusions have been drawn:

1. The use of the real-time maneuver simulator has proven to be a highly useful and efficient tool for the design, development and construction of engineering projects in quays, as it has enabled all of the conditions (variables) that might be found in the real Scene to be accurately reproduced.
2. The use of the automatic mooring system has made it possible to increase safety margins during the stay of the moored vessel. The vessel can remain moored in total safety with stronger winds than the conventional system, without the need to resort to tugboats.
3. The automatic mooring system reduces the total time of the stay in port of the vessels, which means an increase in the available port capacity and a reduction in the risk of congestion.
4. It has been verified that the use of the automatic mooring system increases safety and reduces the movements of the vessel during its stay in the port. On studying the maneuvers performed in the simulator, it has been observed that there are fewer movements with the automatic mooring system.
5. With the automatic mooring system, the mooring service costs are reduced for the full-use traffic flows of the terminals in Scene III. This means that a total of 2,160 calls per year are recorded.
6. The exploitation of the automatic mooring system in the Port of Santander, for the predicted traffic flows (2,160 calls per year), is only profitable if it is installed in the two terminals (Scene III: RAOS 8 and 9) due to the operating scale economies involved.
7. The automatic mooring system would appear to be profitable in ports of great dimensions and high traffic flows, where operating scale economies can be broadly expanded. It might also be profitable in ports where the wind and tide conditions are not too extreme and the system could work with a small number of robots.

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