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VOL. IX No3
DECEMBER 2012

JMR
JOURNAL OF MARITIME RESEARCH

UNIVERSITY OF CANTABRIA

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http://www.jmr.unican.es

Layout: JMR

Printed bay: Gráficas Ebro, S.L.

ISSN: 1697-4840

D. Legal: SA-368-2004

JMR

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 3 - 10

ISSN: 1697-4840 www.jmr.unican.es

Simulation-Based Team Training for Maritime Safety and Security

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ARTICLE INFO

Article history:
Received 02 June 2012;
in revised form 04 June 2012;
accepted 30 July 2012

Keywords:
Maritime Education and Training, Simulation Exercise, Maritime Safety and Security

ABSTRACT

Emergency Response, Crew Resource and Crisis Management are some of the most important parts in maritime education and training. The STCW Manila Amendments set into force on 1st January 2012 reflect that there is a major priority to train ship's officers and crew with sufficient skills and appropriate procedures which can provide adequate protection and ensure the safety of all passengers and crew especially on ferries and cruise ships. The best way to achieve experience and to gain corresponding skills are practice runs on specially designed simulators which realistically represent the complex shipboard conditions on such vessels after emergency alerts. This paper introduces the basic concept of a safety and security training simulator and describes research work related to the implementation of training scenarios. Selected results of a case study will be presented. A shorter version of this paper (Baldauf, Nolte-Schuster et al., 2012) was presented at the International Conference "Maritime Transport V" in Barcelona in June 2012 and is extended and substantially reviewed.

1. Introduction

Emergency Response, Crew Resource and Crisis Management are one of the most important parts in maritime education and training of nautical officers and engineers. The STCW Manila Amendments coming into force on 1st January 2012 (IMO, 1993, IMO, 1996 and IMO, 2010) reflect that there is a major priority to train ship's officers and crew with sufficient skills and appropriate procedures which can provide adequate protection and ensure the safety of all passengers and crew especially on ferries and cruise ships (Martínez M. 2009). The best way to achieve experience and to gain corresponding skills are practice runs on specially designed simulators which realistically represent the complex shipboard conditions on such vessels after emergency alerts.

Simulators are well recognized as beneficial for ship handling training in real time on well equipped bridges. A new type of simulator was developed for training and research specific aspects of Maritime Safety and Security. Apart from existing regulations as e.g. SOLAS, STCW, ISM, ISPS etc. it is essential to adopt a permanent process of change and development with regard to new precautionary measures to ensure the safety of ship operation and to be prepared in case a hazard occurs on board vessels. Training of human mentality and motivation is vital to create a permanent underlying safety culture.

In his research work World Maritime University's Maritime Risk and System Safety (MaRiSa) research group on is dealing with the development, implementation and integration of simulation-based modules into training units and course schemes. With its new simulation laboratory providing a combined Ship Handling and a Safety and Security Simulator enhanced test facilities are available. The safety and security training simulator allows for 3D visualization of ship spaces. This simulator, certified by Det Norske Veritas, is a procedure trainer and enables officers and crew to move around inside the vessel using safety equipment and available emergency systems on board which can be activated by interactive consoles on bridge or engine control room (Bornhorst, 2011 and Benedict & Felsenstein et al., 2011). In cooperation with the Wismar University's Maritime Simulation Centre in Rostock training concepts and scenarios are developed and tested for training on basic, advance or management level. Functional tests of the developed system are

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running successfully and first practice courses have been carried out. Preliminary studies on user acceptance have shown good results. The new and enhanced simulation laboratory allows also for a wide range of scientific studies. The effects of safety and security plans and planned procedures on board can be tested in a simulation environment and enable more detailed evaluation of their effectiveness under varying conditions and during different courses of events by a different series of simulation runs.

This paper introduces the basic concept of a safety and security training simulator and describes the research work related to the learning objective oriented development of a training scenario. Selected results of a case study will be presented.

2. Enhanced soft- and hardware for integrated simulation exercises

Although there are existing international regulations – as e.g. SOLAS, STCW (including the Manila Amendments), ISM, and ISPS - it is useful and necessary to apply a permanent process of correction and development with regard to improving safety and security precautionary measures both in port as well as on board. This also includes a constant review of training methods. Training is vital for creating a permanent high level of safety and security awareness on board to guard against human complacency on duty and to better motivate ships' crews.

Specifically for such training but also for research purposes a new type of simulator has been developed. Among others, the conceptual implementation of the enhanced simulation system is characterized by 3D visualization design. The enhanced simulator was originally developed by manufacturer Rheinmetall Defence Electronic Bremen in collaboration with the Maritime Simulation Centre Warnemuende (MSCW) of Hochschule Wismar in the frame of a funded research project (Felsenstein & Benedict at al, 2009). Recently such a safety and security training simulator (SST) is also established in the Maritime Simulation Laboratory of MaRiSa research group at World Maritime University, Malmö (Sweden).

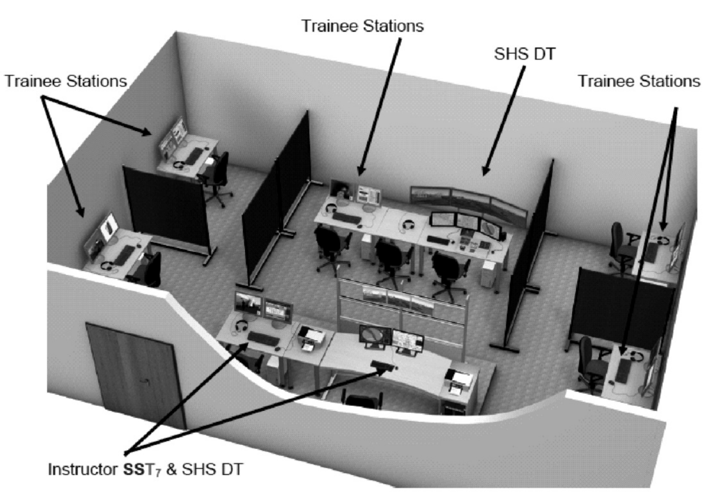

Figure 1: Configuration of the combined Ship-handling and Safety and Security Training Simulator

As a particular unique feature of WMU's system outline the SST is combined with a Ship-handling simulator. This configuration allows for a wide range of applying simulation in MET, including complex team training of safety related scenarios. The combined simulator will also be used for research, e.g. for more detailed in-depth study of the effectiveness of safety and security plans and procedures on board or more profound evaluation and scientific investigation of their efficiency under different conditions and during varying courses of events that can be generated in individually created simulation runs.

However, while having available more and more sophisticated simulators with various facilities and its technical options it becomes more and more important to thoroughly consider the processes of the accumulation of knowledge in general and to ensure effective learning. In this regard the learning environment is mainly structured by means of multimedia which itself can be seen as a different and challenging approach for learning, especially compared to the rather conventional and "traditional" methods. Therefore and in order to define the design and control functionalities of any simulation platform, it might be useful and necessary to sum up the main aspects of the related substructure. With regard to the computer simulation the next chapter is to look at the cognitive aspects of the underlying methodology.

3. A systematic approach to develop training scenarios

From spotlight reviews it is known that even today, the most common method in use for the development of simulation exercises is event driven. Very often scenarios of real accidents or near-misses (mostly experienced by one of the instructors) are implemented in order to discuss what mistakenly has been done or just gone wrong, which failures happened and should be trained to avoid by trainees in such reconstructed scenarios. In the same way as sometimes engineering is driven by the identification of a specific lack or failure that lead to the development of a new technical device or another additional sophisticated safety system, it is expected that accidents of such type will never happen again. But, despite new technical systems, despite new rule and regulations and despite more and more realistic simulation systems, unfortunately, accidents still occur. Having this in mind it is assumed, that the approach of event-driven design of training scenarios is not yet effective enough.

Therefore and as a consequence of thorough studies into learning theories (as e.g. Atkinson & Shiffrin, (1968) and Sweller (1988)) it seems to be more appropriate to focus on the learning objective-oriented simulation and its specific scale as a tool for maritime education and training. With view to the increasing number of sophisticated simulators with various facilities and technical options, it becomes obvious that simulators technically provide wide-ranged options for increased learning effectiveness. However, the process of a trainee's knowledge-accumulation has to be taken into account when implementing training scenarios. Especially educational potential of the simulation platform design and its control functionalities has to be identified accordingly. This can be realized when the event-driven scenario design is at least accompanied or even substituted by a learning-objective oriented development of training scenarios.

4. Learning objective oriented development of training scenarios

Based on a comprehensive literature survey (i.a. Carson-Jackson, 2010, de Jong, 1998, Kristiansen, 1995, but also Nikitakos & Sirris, 2011, Prasad, Baldauf & Nakazawa, 2011, and Rigaud et al., 2012) and further investigations into principles of development of scenarios for simulator training carried out by (Baldauf & Carlisle et al., 2011) a systematic approach for scenario development was described. The core elements of this approach basically developed in the frame of the MASSTER project (de Jong, 1998) are visualized in the following figure.

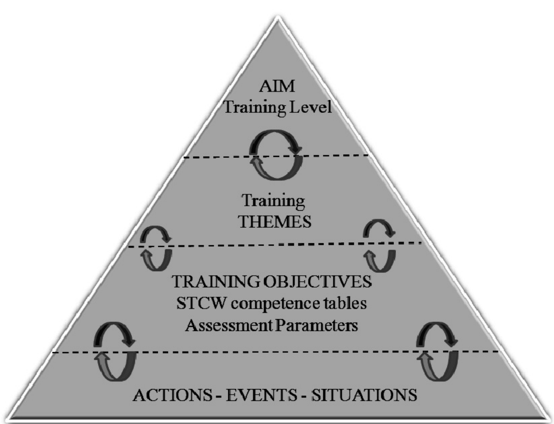

Figure 2: Principle layers and elements of scenario development process.

The four principle layers represent the main basic phases of the development process. Furthermore feedback arrows from the training objectives to the general training aim and from the sequence of events to the training objectives are depicted. Feedback between the different layers is essential for the efficient development of well adjusted training scenarios. The first feedback loop, covering AIM and THEMES, takes place between the simulator operator and the 'customer'. The following loops are the most important ones to be carried out by the training institutions. These loops are foreseen for consideration of the appropriateness of the sequence of events in relation to the training objectives within a specifically selected theme. It is seen that the training objective(s) should define the sequence and course of events of the scenario.

Because each and every simulation exercise is dedicated to fulfill a well defined goal, there is a compelling need to clearly define the general objective within a certain course program. They are dependent, among others, from the trainees' initial level of qualifications and skills and the required competencies to be reached.

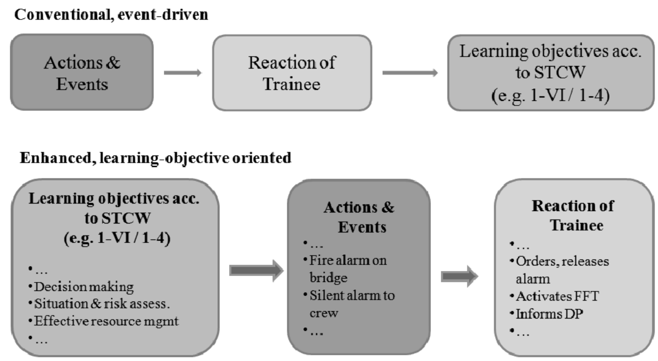

Figure 3: Basic steps for conventional and enhanced learning objective-oriented approach to scenario design.

From the general objectives several detailed objectives have to be derived. Finally, during the evaluation and assessment the trainees' performance will be mirrored and compared to the corresponding requirements.

5. Applying STCW competence-based training objectives

In this section the exemplary application of the sketched method will be explained by means of the STCW required learning objective "Crowd-management" with its relevant actions in case of evacuation. Evacuation has risen again to the top of discussed subjects after the "Costa Concordia" disaster (Schröder-Hinrichs, Hollnagel & Baldauf, 2012). Crowd management training is listed in STCW A- V/2 as a "*mandatory minimum requirement for the training and qualification of masters, officers, ratings and other personnel on passenger ships*". In the detailed description of the required competence for this subject, the STCW – Code firstly mentions "*the awareness of life-saving appliance and control plans, including*:

1. Knowledge of muster lists and emergency instructions,
2. Knowledge of the emergency exits,
3. Restrictions of the use of elevators.

As a competence of this STCW requirement the trainee should be able to assist passengers en route to muster and embarkation stations. On a more detailed level it is stated that the trainee should be able to:

1. "Give clear reassuring orders,
2. Control the passengers in corridors, staircases and passageways, and
3. Maintain escape routes clear of obstructions".

The further description of the required competences of the trainee mentions also the "*methods available for evacuation of disabled persons and needing special assistance*" and also the "*search of accommodation spaces*".

Finally the STCW- Code requires the knowledge of mustering procedures, which means more specifically that the trainee is able to "*use procedures for reducing and avoiding panic*". Generally he should be aware of the importance of keeping order and he should know how to use passenger list for evacuation counts. Overall the trainee should be able to ensure *"that the passengers are suitable clothed and have donned their lifejackets correctly"*.

The implementation of the exemplarily mentioned learning objectives in a training scenario can be structured in different directions. With respect to available options of a particular training-platform it can be stated that the trainee e.g. can show a certain response by 'interaction' with avatars or he may give a spoken or written answer (alternatively reply to a multiple choice question or similar option as integrated) or any other option that might be appropriate to demonstrate knowledge and specific competence respectively. In general the response of the trainee might be internal and implemented in the scenario and then also modify the development and course of following events of the training scenario or it might be external by given answers as part of a direct assessment. After clear definition of the objectives, they can be implemented into either a dedicated scenario but also combined e.g. with a complex fire fighting scenario to provide realistic situational background. A potential exercise is summarized in the table 1.

Table 1: Draft framework for a suggested simulation training scenario

Draft sample exercise scenario	
Identifying number	**Shipboard Emergency Situation - FIRE -** response actions after fire detection by fire-alarm system on the bridge
Training objective(s)	• actions to be taken relating to co-ordination, conduction of search and rescue, actions to be taken by a ship in distress and by an assisting ship); distress signals; log-book entries • action in the event of fire; handle emergencies situations; radio distress traffic
Simulator tool	(Preferably) Full mission simulator – with integrated Safety & Security components
Standard of competence	Master and chief mate (management level) Chief and engineers
Configuration	RoRo-Passenger Ferry (L_{oa} > 200 m)
Traffic situation	Simple (e.g. only two or even just only one further ship in the scenario)
Environment	Coastal area, daylight, moderate wind & sea; no current, good visibility
Duration	Long, > 30 min
Event description	• fire-alarm system on the bridge is indicating fire in on car deck (e.g. Advisory System Ship's Safety - indicates smoke on car deck by an acoustical alarm and CCTV screen as well) • OOW starts alarming procedures; fire-fighting team to be equipped and instructed to investigate the situation and prepare for fire-fighting • FFT gets fire under control (or not – needs reinforcement) • Team leader informs the bridge all team members have left the deck and all doors and other apertures are closed, use of fire sprinkler system • simultaneously beginning preparation of evacuation preparing the system (communication with engine room) and releasing the system • temperature indicator indicates normal temperature on car deck • fire has been extinguished

6. From real situation to simulation-based training

During the studies and investigations performed to develop a systematic methodology for scenario design and control, comprehensive material (i.a. DMA, 2010, MAIB, 2011, Schröder, Baldauf & Ghirxi, 2011 and Ziarati, Ziarati & Acar, 2011) of a real fire onboard accident has been reviewed and analysed and a basic event chart (as it is used in accident investigations) has been drafted.

Based on such diagrams and further material gathered during field studies on board including the participation in real life fire-fighting drills, basic input was provided for the development of the detailed reference scenario (Baldauf & Carlisle et al., 2011). According to the learning objectives to be applied by the customer, decision points can be integrated to further develop the event chart and the simulation scenario accordingly.

As first step for drafting the reference scenario, an actors-and-action graph for the initial situation was developed. This graph visualises the specific events and conditions with the actors with an estimated timeline for the scenario script.

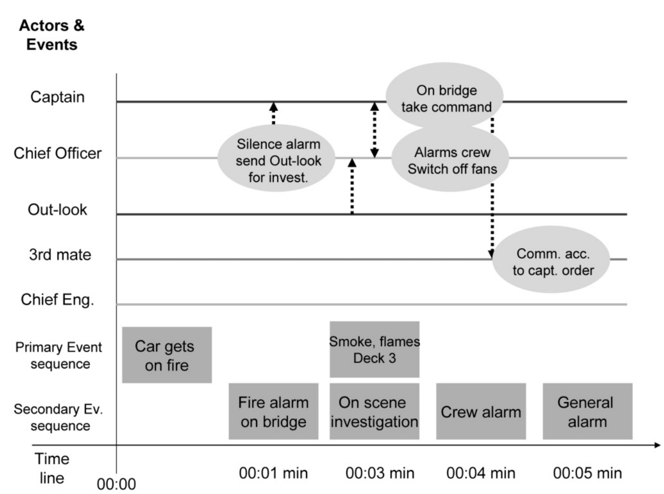

Figure 4: Actors-and-action graph of the reference scenario's initial situation.

Following this, the processes of action and communication were drafted (see next figures) for the main chain of events. In order to create foremost a general approach the potential activities as described in the ISM procedural listings are taken as the recommended actions. The action steps (for OOW on bridge) up to the point when the Master takes command of the vessel are described as “Call the Master”, “Bring bridge to alert status”, “Raise General alarm”, “Obtain charted position” and at least “Proceed to fire station”. When the Master takes the Command of the ship the following step is characterized by internal and external communication.

Action and communication processes for the complete scenario needs to be drafted and decision points, e.g., for fire-fighting tactics and crowd management, have carefully and reasonably to be integrated. An example is given in the figure below.

The exemplarily shown decisions, to be made at this point of the sequence of events and actions, are foremost linked to fire fighting tactics. The main aspect of this section therefore refers to gaining information of the various parts of the ship involved (cargo information, weather condition, ships plan, etc) and, according to these information the question how to follow up with organising the fire fighting.

The learning objectives can be set according to company specific rules and regulations of the ISM Code and further international regulations as e.g. SOLAS as relevant for the training scenario and the individual situation awareness of the trainee.

Based on the decisions made in this section and especially the decision if there is a need for evacuation and abandon the ship, the scenario should be followed up with the specific steps which are linked to the specific tactics, chosen as an alternative action.

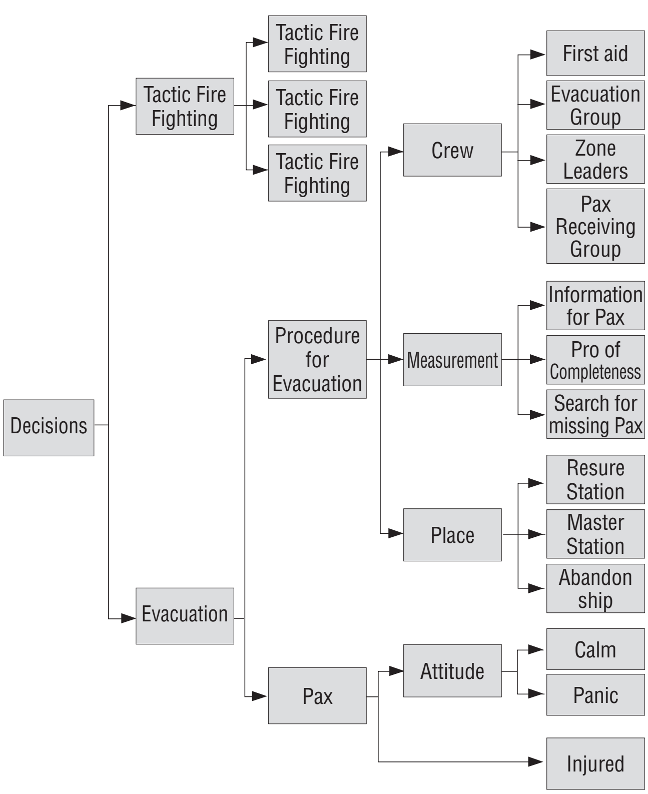

Figure 5: Integration of “Decision points” into a training scenario.

In principle, the working steps of the methodology can be applied to every individual scenario that a shipping company wishes to be trained.

As already mentioned, one of the main aspects when determining the general learning aims with its specific learning objective (according to STCW 95), is the difficulty that every course of action generates an adjusted response and in this meaning a different continuation of the planned and constructed scenario. The difficulty is to measure the appropriateness of the chosen course of action so it might be helpful to create some kind of standard reply patterns for some different scenario- options.

When considering the various aspects of the cognitive model of the learning process it has become obvious that it is either a bottom-up and top-down process of accumulating information and several steps are developing in an unrealized way. For first tests of the methodology and the potential of simulation-based team training the described emergency scenario was implemented in the simulation environment to be used as a basic training module of the MSc course programme at WMU.

Figure 6: Fire on car deck (SST snapshot) and situation assessment and decision making by the bridge team (left).

The students were briefed about the scenario in an extended familiarization session to support handling and controlling the simulations and to get a principle overview of the environment of the ferry implemented in the simulator. The training session was carried out two times in groups with different assignments of tasks, functions and positions of the students (each with mariners' background). The overall task to be performed was to detect a fire on the car deck and to organize and coordinate the fire-fighting on board according to the given generic emergency plan and ISM rules as well as to ensure efficient internal and external communication with all involved parties. The simulation sessions were assessed together with the students during the debriefing using recorded communication and live replay of the actions of the students. The focus of the simulation trials was to learn about the scenario and its potential for varying courses of events and actions. Shortcomings and lacks of the scenario should be identified as well as needed modifications and amendments.

The students were very much motivated and quickly assimilate the handling, controlling of the avatars in the environment. A very important item identified in these tests was that the number of students involved in such a complex exercise has to be carefully determined well in advance and especially take into consideration the capacities (technical capacities of the simulation system but also of monitoring by instructors and co-instructors). It became obvious that for the sake of monitoring and assessing the trainees' performance and behaviour in a simulation session there is a further and substantial need for suitable supporting tools.

7. Summary and conclusion

The Manila Amendments to the STCW Convention and Code require a bundle of new and challenging technical and non-technical skills. With regard to these challenges, state of the art simulation technologies offer a great variety of supporting facilities to meet the related needs for maritime education and training. Nevertheless the provision of high performance graphic visualisation and sophisticated process models and moreover elements of augmented reality by state of the art simulators should not hide the fact that the scientific verification of the learning effectiveness is still pending.

In its research work the MaRiSa research group at WMU in collaboration with the Institute of innovative ship simulation and maritime systems (ISSIMS) at Maritime Simulation Centre Rostock-Warnemuende of Hochschule Wismar develops a learning concept which combines in a novel approach the technique-technological options of modern simulation and the methodological needs for inert learning.

By working on a reference scenario "Fire on-board a RoRo-Pax-Ferry" which in its final stage leads to an evacuation situation including its specific challenges regarding communication, decision-making and leadership, the functional requirements and prerequisites as e.g. an appropriate number of trainees for a simulator training exercise is identified and the basically systematic for learning-objective related simulation could be laid.

Beside first optimistic results it has become obvious that the work on the evaluation of the efficiency of simulator training and its impact on the behaviour and the performance have to be continued.

Acknowledgements

The materials and results presented in this paper have been obtained partly in the research project "TeamSafety" performed under the 7th Framework Program of the European Union, funded by the EC and supervised by the Research Executive Agency. Further research related to the safety and security training simulator is carried out within the LEONARDO project METPROM. Finally, substantial part of the presented material was elaborated under the cooperating project VeSPerPLUS, performed under the Germany's Security Research Program funded by the German Federal Ministry of Research and Education and supervised by VDI Technologiezentrum GmbH, Projektträger Sicherheitsforschung.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 11 - 20

ISSN: 1697-4840 www.jmr.unican.es

Towards the Optimal Solution of Feeder Container Ships Routing With Empty Container Repositioning

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ARTICLE INFO

Article history:
Received 04 June 2012;
in revised form 06 June 2012;
accepted 30 July 2012

Keywords:
Feeder container service, Ship routing, Mixed Integer Linear Programming formulation, CPLEX MIP solver

ABSTRACT

This paper presents a designing method to route a feeder container ship within a hub-and-spoke network that incorporates empty containers repositioning among the ports that are called. It enables to determine the sequence of calling ports as well as the number of full and empty containers transported between any two calling ports. The method is based on a Mixed Integer Linear Programming (MILP) formulation which enables to find optimal transport routes of feeder container ships, i.e. routes that maximize the profit of a shipping company. Our MILP formulation is based on a Knapsack problem and is converted to a location routing problem. The MILP model is tackled by the commercial CPLEX MIP solver. The results of the analysis show that the model can support the decision making process of a shipping company in establishing container feeder transport services. Proposed MILP models can be adapted, by simple changes, to various practical cases.

1. Introduction

Deep sea container shipping is a very competitive business, in which shipping lines compete with each other above all on freight rates. In transporting containers at sea it is difficult for shipping lines to distinguish themselves from competitors on other aspects than the rate level. This makes customers very sensitive to price differences between shipping lines and willing to switch easily from one shipping line to another. As a result the market characteristics force shipping lines to quote sharp freight rates and hence it is evident that controlling costs is of major importance to shipping lines. Shipping lines are keen on ways to control cost to have low cost operations both in exploitation of vessels and container management.

Increasing scale of operations has been a successful strategy to improve competitiveness by exploiting economies of scale. The emerge of ever increasing vessels has been a driving force for the introduction of the hub-and-spoke (HS) service network. In this network the large vessels can become more productive if they are operated in long-distance transport in corridors with large container flows and have a limited number of ports to visit, i.e. sailing in trunklines between mainports (hubs). In such a network, however, feeder services are needed between the hub and destination or origin ports of the containers, i.e. the spokes of the network. The rationale of the HS-system is that the costs of additional handling and the organisation of feeder services are offset by cost savings that arise from economies of scale. A good performance of the feeder service network is therefore a key factor for the success of the HS-system and hence for the profitability and competitiveness of the shipping line. In establishing a successful feeder service network the major decisions to be made include the size of vessels to operate in the network as well as their schedule in visiting seaports.

In order to control the total operational costs of container shipping, equipment management including container repositioning is also an activity that is of great importance to shipping lines (see e.g. Hultén, 1997). De Brito and Konings (2007) report that equipment repositioning accounts for, on average, 20 – 25 percent of the total operational costs of container shipping. The need to reposition containers is caused by cargo imbalances but also by a mismatch in type of equipment that is demanded (e.g. 20 ft containers) and available (e.g. 40 ft containers).

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Shipping lines have several strategies to control and reduce the costs of empty container transport (Konings and Thijs, 2001; Theofanis and Boile, 2008). Some strategies relate to pricing. For instance, shippers can be offered lower rates to use types of equipment that are in surplus. Alternatively, a freight rate surcharge can be imposed on the high demand leg to compensate the repositioning costs in the order direction. Other strategies rather focus on the organisation of container repositioning, such as the interchange of equipment between shipping lines. Concerning organisational strategies (Blanco, Pérez-Labajos, Sánchez, Serrano, López, Ortega, 2010) the design of the service network of the shipping line will also influence the costs of container repositioning. Although empty containers can be more easily repositioned in a larger network, because more seaports are connected with each other, its cost efficiency, however, depends on how well the ports are interconnected.

Since the characteristics of the whole service network of the shipping line are important in controlling container repositioning costs it is evident that the organisation of the feeder service network will also affect the costs of container repositioning. On the other hand the empty container repositioning process is likely to play a major role in the cost performance of feeder container services.

In this paper we will deal with these issues of controlling the costs of feeder container services and the costs of empty container transport. We present a designing method to route a feeder container ship within a HS-network that incorporates empty container repositioning among the ports that are called. This problem consists of determining the calling sequence as well as the numbers of full and empty containers transported between any two ports. The method is based on a Mixed Integer Linear Programming (MILP) formulation for the optimization of transport routes of feeder container ships with the objective to maximize the profit of a shipping company. The rest of this paper is organized as follows. In the next section we present a brief literature review. The description of a feeder container ship routing problem is given in the following section. Next, we propose a mathematical formulation of the problem and discuss the problem complexity. Experimental evaluations and final remarks conclude our study.

2. Literature review

Ship routing problems have strongly triggered research, especially during last three or four decades. In most studies, the results are related to deterministic cases of the ship routing problem, meaning that all input data and assumptions needed to optimise routing of ships were known in advance. On the other hand, relevant routing information (fuel price, container flows, etc) may change after the route has been established and the ship has started its journey. Routing problems that take such changes into account belong to the class of dynamic ship routing problems and are solved by using dynamic programming techniques. We briefly describe here some of the most relevant developments in this field.

Rana and Vickson (1988) proposed a mathematical programming formulation to evaluate chartering options for container ships. The model is developed for the calculation of the optimal sequence of calling ports, the number of containers transported between each pair of ports, and the number of trips the ship makes in the chartered period. Rana and Vickson (1991) extended the model presented in Rana and Vickson (1988) for routing multiple ships. Cho and Perakis (1996) presented routing and fleet design models for a container shipping company. Bendall and Stent (2001) developed a mixed integer program to determine the optimal fleet size and the profitability of a short-haul hub and spoke feeder operation based in Singapore. Castells and Martinez de Osés (2006) studied and identified the feasible short sea shipping routes in SW Europe which appear to be viable solutions for avoiding road transportation problems such as traffic congestion and high fuel consumption, implying the pollution and safety problems.

Shintani at el. (2007) addressed the issue of designing service networks for container liner shipping in deep sea transport, while explicitly taking into account empty container repositioning. A genetic algorithms (GA) based heuristic was proposed to find a set of calling ports, an associated port calling sequence, the number of ships (by ship size category) and the resulting cruising speed to be deployed in the service networks, with the objective to maximise the profit of a liner shipping company. This approach was applied to a case-study on container transportation in Southeast Asia.

Andersen (2010) considered the problem of designing the service network and schedule for a container shipping line in feeder operations with the objective to minimize the cost of operating this network. Two key planning problems, faced by container feeder service providers, were identified: 1) tactical service network design including fleet size and composition of the fleet, together referred to "the master schedule problem" and 2) definition of the sailing schedule and its implementation. Computational experiments showed that the presented algorithms were capable to solve real-world problems on both tactical and strategic planning levels within a reasonable time frame.

Yang and Chen (2010) studied the effects of changing an existing container shipping network that covered several regions in two countries, into a shipping network that consists of trunk and feeder lines on exploitation costs. Jetlund and Karimi (2004) addressed the scheduling of multi-parcel chemical carriers engaged in the transportation of multiple chemicals. The authors developed a MILP formulation for one-ship and multi-ship problems, and implemented a good heuristic based on the one-ship model. Similar work can be found in Hwang (2005) and Al-Khayyal i Hwang (2007). Erera et al. (2005) and Karimi et al. (2005) considered the decision problems (operational tank container management problem, scheduling of the transport and cleaning of multiproduct tank containers) faced by tank container operators.

We propose a new approach to route a feeder container ship within a hub-and-spoke network based on MILP formulation. It takes into account empty containers repositioning, and aims to maximize the profit of a container shipping line in feeder operations.

3. A feeder container ship routing problem

We address a feeder container ship routing problem in which the aim is to maximize the shipping company profit while picking up and delivering containers and taking into account empty container repositioning. Feeder container services, as well as other liner container routes, are usually organized as weekly services. These services are offered for relatively long periods of time, i.e. from several months to several years. Hence the decision to establish a feeder container service has to take into account different factors such as seasonal fluctuations of container flows throughout a year, market developments, etc. Shipping companies estimate the demand for container transport in any potential port of call and these data strongly influence the decision on the routing of feeder container ships. These estimations are usually made on a weekly basis, together with estimates on costs and revenues related to these demand forecasts for the same periods. In addition, a lot of other parameters such as ship speed, ship size, and number of available ships influence the routing decisions of feeder container ships.

Shipping companies assign their ships to specific routes which include more than two ports of call. Transshipment or hub ports are particularly important in this process. These ports are the links between trunkline and feeder container ship routes. Therefore, hub ports are starting and ending ports of call in the feeder service. Regular feeder route links the hub port with few smaller, feeder ports located in the catchment region of that particular hub port. This means that a feeder ship starts its route in the hub port, visits several feeder ports and ends the route by coming back to the same hub port. Containers that are loaded on a feeder ship in one port are usually transported to several destination ports. Schedules of feeder container routes should be known in advance, with arrival and departure times indicated for each port of call.

The following assumptions are made in our model regarding the routing of feeder container ships within container transport networks:

- The routing of feeder ships is considered for one geographical region which includes a number of feeder container ports that are connected to one transshipment or hub container port;
- It is not necessary for the feeder container ship to visit all ports in the region; in some cases, calling at a particular port or loading all containers available in that port may not be profitable due to high port fees, costs of handling containers and/or because the quantity of containers that has to be transported to or from this port is too small;
- The ship can call in one port more than once;
- The starting and ending point on the route should be the same, i.e. in this case it is the hub port where the transshipment of containers from trunkline to feeder container ships and vice versa takes place;
- The shipping company that provides feeder services has to bear transport costs of loaded containers as well as empty container repositioning costs, transhipment costs and port fees;
- The model assumes a weekly known cargo demand for each pair of ports; this assumption is valid as the data regarding throughput from previous periods and future prediction enable to obtain reliable values of these demands;
- Container volume loaded at a port may be less than the number of containers generated in that port; some containers may not be profitable for the feeder container company, primarily because of the small number of containers, low freight rates, destination port of the containers in the considered region not being included in the route, etc.;
- Total number of loaded and empty containers onboard may not exceed the ship carrying capacity at any link of the route;
- The demand for empty containers at a port is the difference between the total traffic originating from the port and the total number of loaded containers arriving at the port for the specified time period; the assumption is valid since this study addresses the problem of determining the optimal route of a feeder container ship for only one ship operator (similar to the case studied by Shintani et al., 2007);
- If a sufficient container quantity is not available at a port, the shortage is made up by leasing containers with the assumption that there are enough containers to be leased (for details see Shintani et al., 2007).

Under those assumptions, we model the following two decisions of the shipping company in operating the feeder network:

1. The number of ports to call and the calling sequence in the route,
2. The size of container batches to be transported between any two ports in the route.

Ports of call, calling sequence and container flows are the factors that directly influence revenue and costs, and hence the profitability of the feeder container service.

The following data (measurement units are given in square brackets if applicable) are included in the model:

L: number of ports;
v: container ship cruising speed, [kts];
R_f and R_l: fuel and lubricant consumption, respectively [t/kWh];
C_f and C_l: fuel and lubricant price, respectively [US$/t];
C_{TEU}: carrying capacity of container ship [TEU];

D: ship displacement [t];
A: Admiralty coefficient;
P_{out}: engine output (propulsion) [kW];
dcc: daily time charter cost of container ship [US$/day];
max_{tt} and min_{tt}: maximum and minimum turnaround time on a route [days];
$zr_{(i,j)}$: weekly expected number of loaded containers available to be transported between ports i and j [TEU];
$r_{(i,j)}$: freight rate per container from port i to port j [US$/TEU];
$l_{(i,j)}$: cruising distance from ports i to j [NM];
ufc_i and lfc_i: unloading and loading cost, respectively per loaded container at port i [US$/TEU];
uec_i and lec_i: unloading and loading cost , respectively per empty container at port i [US$/TEU];
pec_i: entry cost per call at port i [$];
uft_i and lft_i: average unloading and loading time, respectively, per loaded container at port i [h/TEU];
uet_i and let_i: average unloading and loading time, respectively, per empty container at port i [h/TEU];
pat_i and pdt_i: standby time for arrival and departure, respectively, at port i [h];
sc_i: storage cost at port i [US$/TEU/day];
lc_i: short-term leasing cost at port i [$/TEU/day].

4. Problem formulation

This section describes a mathematical programming formulation, in a form of mixed integer linear programming, for a feeder container ship routing problem. The goal is to determine the optimal feeder container route, i.e. the selection of the optimal set of calling ports and sequence of calls, as well as the size of container batches to be transported between any two ports in the route.

At the beginning, it is necessary to introduce a parameter k that refers to the number of segments in the container ship route. Each segment represents a sailing between two consecutive ports (i and j) in the route. Since a feeder container ship should return to the starting (hub) port at the end of its route, the minimal number of segments is 2. On the other hand, the total number of segments K that will be considered should be determined by decision makers of a container shipping line in feeder operations. More precisely, if K denotes the total number segments in the route, than K = 2, 3, ..., n. Each segment in the route is denoted by k = 1, 2, ..., K. Moreover, the navigation on each route segment is characterized by travel time and number of full and empty containers carried onboard. Consequently, the variables in the model are as follows:

x_{ik}: 1 if ship arrives at port i at the end of segment k, 0 otherwise;
q_{ijk}: 1 if ship moves from port i to j along segment k, 0 otherwise;
$pl_{(i,j),k}$: 1 if ship loads cargo (i, j) at the end of segment k, 0 otherwise;
$pd_{(i,j),k}$: 1 if ship unloads cargo (i, j) at the end of segment k, 0 otherwise;
$sb_{(i,j),k}$: 1 if ship carries cargo (i, j) on-board during segment k, 0 otherwise;
$y_{(i,j)}$: 1 if ship serves cargo (i, j), 0 otherwise;
t_k: ship voyage time on a segment k;
t_s: total turnaround time [h];
z_k, w_k: the number of loaded and empty containers, respectively, transported along a segment k [TEU];
a_k: starting port of segment k;
Y^K: shipping company profit for the route consisting of K segments.

Optimal feeder container ship route consisting of K segments is modelled as follows:

$$\text{maximize} \quad Y^K \tag{1}$$

s.t.

$$\sum_{i=1}^{L} x_{ik} = 1, \quad \forall k = 1,\ldots,K \tag{2}$$

$$\sum_{j} q_{jik} = x_{ik}, \quad \forall k, \ \forall i \tag{3}$$

$$\sum_{j} q_{ij(k+1)} = x_{ik}, \quad \forall k < K \tag{4}$$

$$\sum_{j} q_{ijk} = 1, \quad i = 1 \text{ and } k = 1 \tag{5}$$

$$\sum_{j} q_{jik} = 1, \quad i = 1 \text{ and } k = K \tag{6}$$

$$\sum_{k=1}^{K} pl_{(i,j),k} = y_{(i,j)}, \quad \forall i, j \tag{7}$$

$$\sum_{k=1}^{K} pd_{(i,j),k} = y_{(i,j)}, \quad \forall i, j \tag{8}$$

$$pl_{(i,j),k} \le x_{i,k}, \quad \forall i, j \text{ and } \forall k \tag{9}$$

$$pd_{(i,j),k} \le x_{j,k}, \quad \forall i, j \text{ and } \forall k \tag{10}$$

$$sb_{(i,j),k+1} = sb_{(i,j),k} + pl_{(i,j),k} - pd_{(i,j),k}, \quad \forall i, j \text{ and } \forall k \tag{11}$$

where: if $k = K \Rightarrow k+1$ is replaced with $k = 1$

$$sb_{(i,j),k} \le y_{(i,j)}, \quad \forall i, j \text{ and } \forall k \tag{12}$$

$$z_k + w_k \le C_{TEU}, \quad \forall k \tag{13}$$

$$\min_{tt} \le \frac{t_s}{24} \le \max_{tt}, \tag{14}$$

The round–trip time is calculated as the sum of voyage time, handling time of loaded and empty containers in ports and time required for entering/leaving ports (15).

$$t_s = \frac{1}{24}\left(\frac{\sum_i \sum_j l_{ij} q_{ijk}}{v} + \sum_{i=1}^{L}\sum_{j=1}^{L} zr_{(i,j)} y_{(i,j)} \left(lft_i + uft_j\right) + \sum_{i=1}^{L}\sum_{j=1}^{L} w_{ij} \left(let_i + uet_j\right) + \sum_{i=1}^{L}\sum_{k=1}^{K} x_{ik}\left(pat_i + pdt_i\right) \right) \tag{15}$$

To determine the amount of the revenues and costs, it is necessary to incorporate the appropriate parameters and variables describing the feeder shipping service under consideration. So, on its route, a feeder container ship can call at any port from the set of given ports L (i = 1, 2, ..., L). It is assumed that the port i = 1 represents a transhipment (hub) port, while all other ports, j = 2, 3, ..., L, are feeder container ports in the catchment region.

Constraints (2) force the feeder container ship to visit exactly one port during each segment. Constraints (3) – (6) are network constraints ensuring that the ship starts and ends the route at the transshipment port making a connected trip. The ship is left with a choice of calling or not calling at any port. If the ship is assumed to load a cargo (i, j) at the end of segment k, two conditions should be satisfied. First, the ship must visit the loading port and second, it must service cargo (i, j). Eqs. (7) and (8) enforce that if the ship does not service a cargo (i, j) (i.e. $y_{(i,j)} = 0$), then it cannot load (unload) it at any port. However, $y_{(i,j)} = 1$ forces loading (unloading) of cargo (i, j) at exactly one segment. Constraints (9) and (10) are to ensure that if the ship does not visit the pickup (delivery) port of a cargo (i, j) at the end of segment k, then it cannot pickup (deliver) cargo (i, j) at the end of segment k. Eqs. (11) are applied to force the ship to carry a cargo (i, j) from its pickup port to its discharge port.

Determining a transport route of a feeder container ship belongs to the class of the so called long-term problems. This means that operated period of established routes range from several months to several years and involve a large number of round trips. Therefore, the transportation process should include containers loaded during one round trip and unloaded during the next one (constraints (11) and (12)).

Capacity constraints (13) guarantee that the total number of full and empty containers on-board does not exceed the ship carrying capacity during each sailing segment. Constraint (14) is related to the round–trip time of the feeder container ship (denoted by t_s[h]). This constraint has to prevent the feeder ship ending and calling at port 1 long before or after the arrival of the trunkline container ship.

Methods of determining the total number of both full, z_k, and empty, w_k, containers on-board at any voyage segment k, given by Eq. (13), require further explanations. While calculation of full containers transported along any segment is straightforward, the determination of the number of empty containers on-board is much more complex task. The differences come from the fact that expected weekly containers demand (i, j) to be transported between ports i and j is known in advance. Therefore, the total number of full containers transported along any voyage segment is given as follows:

$$\sum_{i=1}^{L}\sum_{j=1}^{L} zr_{(i,j)} sb_{(i,j),k} = z_k \quad \forall k \tag{16}$$

On the other hand, quantity of empty containers that can be transported depends on the available capacity of the ship for empty containers. In order to deal with empty containers repositioning, we introduce the following auxiliary variables: the number of empty containers to be transported between ports i and j, w_{ij}, the number of containers to be stored at each port i, sW_i, and the number of containers to be leased at each port i, lW_i (Shintani et al., 2007). After the linearization we obtain constraints (17)-(24):

$$S_i - M \cdot g_i \le 0 \tag{17}$$

$$D_i - P_i + S_i \ge 0 \tag{18}$$

$$D_i - P_i + S_i - M(1 - g_i) \le 0 \tag{19}$$

$$Q_i - M \cdot h_i \le 0 \tag{20}$$

$$D_i - P_i + Q_i \ge 0 \tag{21}$$

$$D_i - P_i + Q_i - M(1 - h_i) \le 0 \tag{22}$$

$$lW_i = Q_i - \sum_{j=1}^{L} w_{ji} \quad \forall i \in 1,\dots,L \tag{23}$$

$$sW_i = S_i - \sum_{j=1}^{L} w_{ij} \quad \forall i \in 1,\dots,L \tag{24}$$

where:

- g_i, h_i: auxiliary binary variables, $\forall i \in 1,\dots,L$
- Q_i: the number of demanded containers at each port i [TEU];
- S_i: the number of excess containers at each port i [TEU];
- P_i: the number of containers destined for port i [TEU];
- D_i: the number of containers departing from port i [TEU];
- M: large enough constant.

As it can be seen, empty container flows are defined between any two ports i and j, rather than for each voyage segment k. In order to calculate the total number of empty containers (w_k) transported along segment k, it is necessary to determine the starting port of segment k, denoted by a_k:

$$\sum_{i=1}^{n}\sum_{j=1}^{n} i \cdot q_{ijk} = a_k, \quad \forall k \tag{25}$$

Now, w_k can be calculated as:

$$w_k = \begin{cases} \sum_{i=1}^{k}\sum_{j=k+1}^{n} w_{a_i,a_j} + \sum_{i=k+2}^{n}\sum_{j=k+1}^{i-1} w_{a_i,a_j}, & k=1 \\ \sum_{i=2}^{k}\sum_{j=1}^{i-1} w_{a_i,a_j} + \sum_{i=1}^{k}\sum_{j=k+1}^{n} w_{a_i,a_j} + \sum_{i=k+2}^{n}\sum_{j=k+1}^{i-1} w_{a_i,a_j}, & 1<k<K-1 \\ \sum_{i=2}^{k}\sum_{j=1}^{i-1} w_{a_i,a_j} + \sum_{i=1}^{k}\sum_{j=k+1}^{n} w_{a_i,a_j} & k=K-1 \\ \sum_{i=2}^{k}\sum_{j=1}^{i-1} w_{a_i,a_j} & k=K \end{cases} \tag{26}$$

Finally, the profit of the shipping company, Y^K, is calculated as the difference between the revenue arising from the service of loaded containers (R_K) and the transport costs. These costs are related to shipping (C_K) as well as empty container handling (E_K) (adopted from Shintani et al., 2007). More precisely:

$$Y^K = R_K - C_K - E_K \tag{27}$$

where:

$$C_K = (6{,}54 \cdot C_{TEU} + 1422{,}52) \cdot t_s + \sum_{k=1}^{K} \frac{(C_f R_f + C_l R_l) \cdot D^{\frac{2}{3}} \cdot v^3 \cdot 0{,}7457 \cdot t_k}{A} + \\ + \sum_{i=1}^{L} \sum_{k=1}^{K} pec_i C_{TEU} x_{ik} + \sum_{i=1}^{L} \sum_{j=1}^{L} zr_{(i,j)} y_{(i,j)} (lfc_i + ufc_j) \tag{28}$$

$$E_K = \sum_{i=1}^{n} (sc_i \cdot sW_i + lc_i \cdot lW_i) + \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (uec_i + lec_j) \tag{29}$$

$$R_K = \sum_{i=1}^{L} \sum_{j=1}^{L} zr_{ij} y_{ij} p_{ij} \tag{30}$$

The above described model determines the optimal feeder container route for a given number of segments K. In order to determine the optimal number of segments, one should solve the related Knapsack problem, i.e.:

$$\text{maximize} \quad \sum_K Y^K p_K \tag{31}$$

s.t.

$$\sum_K p_K = 1 \tag{32}$$

$$p_K \in \{0,1\}, \quad \forall K = 2,3,\ldots,n \tag{33}$$

where p_K takes value 1 if the route with K segments is selected, 0 otherwise.

Problem complexity and optimal solution

Our problem can be categorized as a bi-level combinatorial optimization problem. The upper level of our ship routing problem, which selects the best set of calling ports, reduces to the Knapsack problem (well known to be NP-complete, Papadimitriou and Steiglitz, 1982).

On the other hand, the lower level model represents a mixture of several modifications of the standard ship routing problem. As container shipments are smaller than a feeder container ship capacity, our problem is a multi-commodity ship routing problem. Container loading and unloading processes make it a ship routing problem with pickups and deliveries. This problem is also a ship routing problem with time windows as we have limits on round trip time. Therefore, the feeder container ship routing problem considered here can be classified as a multi-commodity Pickup and Delivery Problem with Time Windows. It is an extension of the Vehicle Routing Problem, which in turn is a generalization of the NP-complete Travelling Salesman Problem. Consequently, our problem is strongly NP-complete.

All this implies that generally the problem cannot be solved in polynomial time. However, the examples considered here are not too complex. Therefore, our MILP formulation for this problem used within CPLEX MIP solver enabled to obtain optimal solutions for given instances. The conduced experimental evaluation is described in the next section.

5. Experimental evaluation

5.1. Input data

Due to the luck of publicly available test instances for the considered problem, we generated random test examples. We assume the number of ports equals 7, i.e. $L = 7$. The transport network that is analysed is given in the Figure 1.

Transport distances, expected number of loaded containers weekly available to be transported between any two ports and freight rates per container from port i to port j are derived from practice and are available upon request by the authors. This also applies to port related parameters which are divided in two groups: cost and time related parameters.

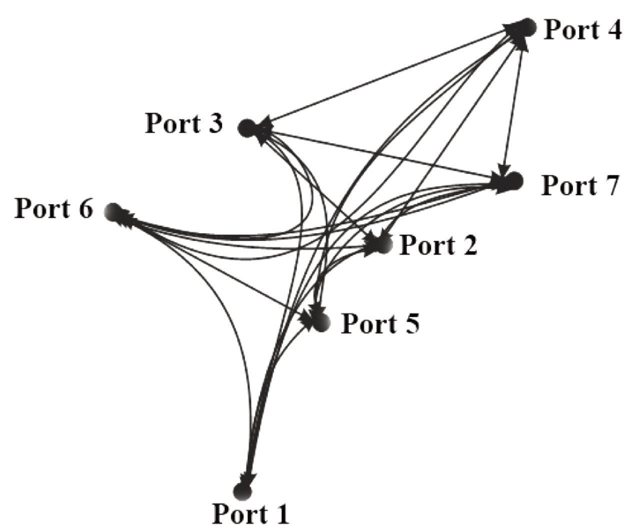

Figure 1. Transport network for routing a feeder container ship.

Settings of other parameters are as follows: C_{TEU} = 750 TEU; D = 13095 t; v = 15 kts; frequency: weekly; C_f = 170 \$/t; C_l: 1000 \$/t; R_f: 140 g/kW/h (0.00014 t/kW/h); R_l: 4 g/kW/h (0.000004 t/kW/h), $\max_{tt}$ = 14 days, $\min_{tt}$ = 13 days.

5.2. Numerical results

Our tests are performed on Intel Core 2 Duo CPU E6750 on 2.66GHz with RAM=8GB under Linux Slackware 12, Kernel: 6.21.5. For exact solving we used CPLEX 11.2 IP solver and AMPL (Fourer et al., 1990, ILOG, 2008) for Linux operating system and compiled with gcc (version.1.2) and the option -o2.

In practice, the maximum number of segments in the feeder container ship route is based on planners' experience. This decision has to take into account parameters like distances between ports, feeder container ship speed, weekly container demands, etc. Therefore, we impose that

Table 1. Results for 750 TEU ship and any number of segments.

Ship speed (knots)	Number of segments (*K*)	Calling sequence	Profit [$]	Total revenue [$]	Total costs [$]	Fleet size
15	5	1 – 7 – 4 – 3 – 6 – 1	18695,4	405420,0	386724,6	2
	6	1 – 2 – 7 – 4 – 3 – 6 – 1	38673,1	462770,0	424096,9	2
	7	1 – 3 – 2 – 7 – 4 – 3 – 5 – 1	36904,1	490885,0	453980,9	2
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	39867,7	526230,0	486362,3	2
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	27087,4	487860,0	460772,6	2

the maximal number of segments in the route equals 9. This means that we have to elaborate the cases where the number of segments goes from 2 to 9, i.e. K = 2, 3, ..., 9. Profit, Y^K, is calculated for each K and the optimal number of segments in the route is determined as K corresponding to the highest profit.

Results indicate that cases for K = 2 or K = 3 are not feasible (cannot generate a route with turnaround time longer than min_{tt}). If K = 4 the optimal solution generates a loss. Results of all the other cases (K = 5,..., 9) are given in Table 1.

By applying eqs. (31) – (33) the optimal solution is obtained for K = 8. Achieved profit, Y^8, in this case equals 39867,72 $/round trip. Total round trip time for K = 8 is 13,981 days.

5.3. Sensitivity analysis

This sensitivity analysis examines the impacts of two types of factors on feeder container ship routing decisions: container ship carrying capacity and sailing speed. Given the transport demands, we have to determine the optimal size of feeder container ship and its optimal sailing speed among available sailing scenarios. The cases when the transport demands change are covered by the application of the same analysis to different input data.

The analysis evaluates the effects of chartering each of the three ships whose characteristics are summarised in Table 2 (taken from Shintani et al., 2007).

Table 2. Basic ships characteristics.

Type of ships	Carrying capacity [dwt]	Displacement [t]	Engine power [kW]	Speed intervals [knots]	Admiralty coefficient
500 TEU	7050	9517,5	4050	9-15	250
750 TEU	9700	13095	5500	11-17	275
1000 TEU	13500	18225	7600	13-19	300

The optimal routes for each ship and speed are determined by changing the number of segments from 4 to 9. As in Table 1 we omit the cases with non-feasible or negative results. The results that are obtained for the selected types of ships and corresponding speed intervals are given in Tables 3, 4 and 5 (for 500, 750 and 1000 TEU ships, respectively).

Table 3. Results for 500 TEU container ship.

Ship speed (knots)	Number of segments (*K*)	Route	Profit [$]	Revenue [$]	Total costs [$]
9	4	1 – 7 – 2 – 5 – 1	16001,5	247765,0	231763,5
	5	1 – 2 – 7 – 2 – 5 – 1	18292,2	271360,0	253067,8
	6	1 – 3 – 2 – 7 – 3 – 2 – 1	9860,4	258910,0	249049,6
10	4	1 – 7 – 4 – 3 – 1	18216,9	259890,0	241673,1
	5	1 – 5 – 7 – 4 – 3 – 1	19885,9	273615,0	253729,1
	6	1 – 5 – 3 – 7 – 2 – 5 – 1	20134,0	311715,0	291581,0
	7	1 – 5 – 3 – 7 – 2 – 3 – 5 – 1	16124,3	311715,0	295590,7
	8	1 – 5 – 3 – 2 – 7 – 2 – 3 – 5 – 1	5197,1	271360,0	266162,9
11	4	1 – 2 – 4 – 6 – 1	11442,3	246060,0	234617,7
	5	1 – 5 – 7 – 4 – 3 – 1	24709,2	304290,0	279580,8
	6	1 – 5 – 3 – 7 – 4 – 3 – 1	30804,0	330005,0	299201,0
	7	1 – 5 – 3 – 7 – 3 – 2 – 5 – 1	20658,2	339715,0	319056,8
	8	1 – 5 – 3 – 2 – 7 – 2 – 3 – 5 – 1	16833,3	337525,0	320691,7
12	4	1 – 4 – 2 – 6 – 1	4725,6	246480,0	241754,4
	5	1 – 5 – 2 – 4 – 6 – 1	24153,23	311550,0	287396,8
	6	1 – 5 – 2 – 7 – 4 – 3 – 1	31797,91	343945,0	312147,1
	7	1 – 5 – 3 – 2 – 7 – 4 – 3 – 1	31697,1	356010,0	324312,9
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	20223,8	330750,0	310526,2
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	9763,8	339715,0	329961, 2

13	5	1 – 5 – 2 – 4 – 6 – 1	20583,7	311550,0	290966,3
	6	1 – 5 – 2 – 7 – 4 – 6 – 1	30328,29	347780,0	317451,0
	7	1 – 5 – 2 – 3 – 7 – 4 – 3 – 1	31680,9	372985,0	341304,1
	8	1 – 5 – 2 – 3 – 7 – 4 – 3 – 5 – 1	31750,28	384410,0	352659,7
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	17679,4	346150,0	328470,6
14	5	1 – 7 – 2 – 4 – 6 – 1	11113,14	298355,0	287241,9
	6	1 – 5 – 2 – 7 – 4 – 6 – 1	26395,0	347780,0	321385,0
	7	1 – 2 – 5 – 3 – 7 – 4 – 3 – 1	30252,7	376220,0	345967,3
	8	1 – 5 – 2 – 3 – 7 – 4 – 3 – 5 – 1	30578,0	401385,0	370807,0
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	26666,9	400920,0	374253,1
15	5	1 – 7 – 2 – 4 – 6 – 1	11521,0	312785,0	301264,0
	6	1 – 5 – 7 – 4 – 2 – 6 – 1	21426,7	356915,0	335488,3
	7	1 – 2 – 5 – 3 – 7 – 4 – 3 – 1	25857,1	376220,0	350362,9
	8	1 – 5 – 2 – 3 – 7 – 4 – 3 – 5 – 1	26501,1	401385,0	374883,9
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	24103,6	413715,0	389611,4

Table 4. Results for 750 TEU container ship.

Ship speed (knots)	Number of segments (K)	Route	Profit [$]	Revenue [$]	Total costs [$]
11	4	1 – 7 – 2 – 6 – 1	12667,0	332775,0	320108,0
	5	1 – 2 – 7 – 4 – 3 – 1	33178,1	382010,0	348831,9
	6	1 – 5 – 2 – 7 – 3 – 5 – 1	32029,2	435640,0	403610,8
	7	1 – 5 – 3 – 2 – 7 – 3 – 5 – 1	22229,6	417115,0	394885,4
	8	1 – 5 – 3 – 2 – 7 – 2 – 3 – 5 – 1	6231,1	377975,0	371743,9
12	4	1 – 7 – 4 – 6 – 1	12241,2	331615,0	319373,8
	5	1 – 2 – 7 – 4 – 3 – 1	31857,6	401865,0	370007,4
	6	1 – 2 – 7 – 4 – 3 – 5 – 1	36681,3	432825,0	395963,7
	7	1 – 5 – 3 – 7 – 2 – 3 – 5 – 1	28286,4	453710,0	425423,6
	8	1 – 5 – 3 – 2 – 7 – 2 – 3 – 5 – 1	19085,9	444545,0	425459,1
13	4	1 – 4 – 7– 6 – 1	6768,3	331615,0	324846,7
	5	1 – 2 – 7 – 4 – 6 – 1	29170,1	389230,0	360059,9
	6	1 – 5 – 7 – 4 – 3 – 5 – 1	37137,3	448435,0	411297,7
	7	1 – 3 – 2 – 7 – 4 – 3 – 5 – 1	40173,4	463360,0	423186,6
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	24690,4	426195,0	401504,6
	9	1 – 5 – 3 – 2 – 3 – 7 – 2 – 3 – 5 – 1	5246,32	430115,0	424868,7
14	5	1 – 2 – 7 – 4 – 6 – 1	24164,7	389230,0	365065,3
	6	1 – 5 – 2 – 7 – 4 – 6 – 1	35545,0	440395,0	404850,0
	7	1 – 3 – 2 – 7 – 4 – 3 – 5 – 1	41218,5	490885,0	449666,5
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	35286,2	479740,0	444453,8
	9	1 – 5 – 3 – 2 – 7 – 4 – 7 – 3 – 5 – 1	18282,1	432810,0	414527,9
15	5	1 – 7 – 4 – 3 – 6 – 1	18695,4	405420,0	386724,6
	6	1 – 2 – 7 – 4 – 3 – 6 – 1	38673,1	462770,0	424096,9
	7	1 – 3 – 2 – 7 – 4 – 3 – 5 – 1	36904,1	490885,0	453980,9
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	39867,7	526230,0	486362,3
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	27087,4	487860,0	460772,6
16	5	1 – 7 – 2 – 4 – 6 – 1	8189,9	388450,0	380260,1
	6	1 – 2 – 7 – 4 – 3 – 6 – 1	33373,4	462770,0	429396,6
	7	1 – 3 – 2 – 7 – 4 – 3 – 6 – 1	39922,5	494845,0	454922,5
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	37961,4	540405,0	502443,6
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	34503,0	532840,0	498337,0
17	6	1 – 5 – 7 – 4 – 3 – 6 – 1	23980,3	468685,0	444704,7
	7	1 – 3 – 2 – 7 – 4 – 3 – 6 – 1	37632,5	508915,0	471282,5
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	32973,9	540405,0	507431,1
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	32266,3	553245,0	520978,7

As can be seen from Tables 3, 4 and 5, the shipping company should choose a 750 TEU container ship with sailing speed of 14 knots to operate the route with 7 segments (K = 7). The optimal ship route consists of calling at the following ports: Port 1 – Port 3 – Port 2 – Port 7 – Port 4 – Port 3 – Port 5 – Port 1.

Table 5. Results for 1000 TEU container ship.

Ship speed (knots)	Number of segments (*K*)	Route	Profit [$]	Revenue [$]	Total costs [$]
13	5	1 – 2 – 7 – 2 – 6 – 1	20488,0	480110,0	459622,0
	6	1 – 5 – 2 – 7 – 4 – 3 – 1	30616,6	516100,0	485483,4
	7	1 – 5 – 2 – 7 – 4 – 3 – 5 – 1	15976,8	485385,0	469408,2
14	5	1 – 2 – 7 – 4 – 6 – 1	17004,2	466230,0	449225,8
	6	1 – 5 – 2 – 7 – 4 – 3 – 1	32866,0	540265,0	507399,0
	7	1 – 5 – 2 – 7 – 4 – 3 – 5 – 1	28312,7	538775,0	510462,3
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	13000,5	510090,0	497089,5
15	5	1 – 7 – 4 – 3 – 6 – 1	14425,8	482345,0	467919,2
	6	1 – 5 – 2 – 7 – 4 – 6 – 1	28137,1	522785,0	494647,9
	7	1 – 5 – 2 – 7 – 4 – 3 – 5 – 1	34268,1	580515,0	546246,9
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	21937,8	555480,0	533542,2
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	1308,9	512865,0	511556,1
16	5	1 – 7 – 4 – 3 – 6 – 1	8473,4	482345,0	473871,6
	6	1 – 2 – 7 – 4 – 3 – 6 – 1	29223,7	540515,0	511291,3
	7	1 – 5 – 2 – 7 – 4 – 3 – 5 – 1	30903,3	590465,0	559561,7
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	26960,5	598695,0	571734,5
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	8695,9	556035,0	547339,1
17	6	1 – 2 – 7 – 4 – 3 – 6 – 1	22777,2	540515,0	517737,8
	7	1 – 5 – 2 – 7 – 4 – 3 – 5 – 1	25314,5	590465,0	565150,5
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	27114,8	630210,0	603095,2
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	13087,3	595175,0	582087,7
18	6	1 – 2 – 7 – 4 – 3 – 6 – 1	15939,9	540515,0	524575,1
	7	1 – 5 – 2 – 7 – 4 – 3 – 6 – 1	26736,7	598665,0	571928,3
	8	1 – 5 – 3 – 2 – 7 – 4 – 3 – 5 – 1	23849,2	644385,0	620535,8
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	14945,3	628700,0	613754,7
19	6	1 – 5 – 7 – 4 – 3 – 6 – 1	3590,8	553390,0	549799,2
	7	1 – 5 – 2 – 7 – 4 – 3 – 6 – 1	24943,2	621375,0	596431,8
	8	1 – 5 – 3 – 2 – 7 – 5 – 3 – 5 – 1	17459,5	644385,0	626925,5
	9	1 – 5 – 3 – 2 – 7 – 4 – 2 – 3 – 5 – 1	13524,6	646770,0	633245,4

6. Conclusion

As the volume of containers transported worldwide continuously increases, the organisation of container transport services becomes more and more complex and the need to improve the performance of services is gaining importance. This paper deals with one aspect of the organisation of container transportation and this concern the routing of feeder container ships. We addressed the feeder container ship routing problem as a problem of maximizing the shipping company profit while picking up and delivering containers with empty container repositioning.

We propose a mixed integer linear programming (MILP) formulation for the considered problem and show that it can simplify the decision making process in the shipping company engaged in the feeder service. In particular, we resolve routing decisions and sizing of container batches in calling ports for feeder container ships. Our results indicate that the planning process in the container shipping company could be improved by applying the proposed decision support system based on optimization routine, which would significantly impact the business results of a shipping company. The model presented in this paper could be a very useful practical tool for container carriers to make long term strategic decisions about establishing feeder container transport services. They can solve their practical problems, test different solutions of the problems and choose those which are most suitable for their own needs. Therefore, the proposed method provides a quick insight into potential business results, the profitability of the feeder container ships in particular. In addition, it considerably facilitates the decision making process in a shipping company engaged in feeder container service.

We treated this problem by applying CPLEX 11.2 MIP solver and AMPL for Linux operating system. This solver was able to optimally solve small size problem instances with maximum seven calling ports. However, like in many other combinatorial optimization problems, real-life situations may be too complex to be solved to optimality within a reasonable amount of time. Therefore, the use of metaheuristic approaches which are the common way to tackle these kinds of problems is obviously a further research direction.

Moreover, this study can be extended in several directions. The extension to a multi-ship problem is straightforward. Stochastic modelling of some parameters (like container demands, service time) may also be included, although it will significantly increase the complexity of the problem. In addition, the lack of real data for the considered problem imposed us to generate random test examples. Therefore, verification of the proposed formulation through some real situations could be of particular importance for the future research.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 21 - 26

ISSN: 1697-4840 www.jmr.unican.es

A Decision Making Approach for Operational Voyage Performance Analysis

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ARTICLE INFO

Article history:
Received 02 June 2012;
in revised form 04 June 2012;
accepted 30 July 2012

Keywords:
Voyage performance, decision making, voyage efficiency, vessel port operations

ABSTRACT

Nowadays economic operation of ships become more important for ship owners, ship managers due to escalating oil prices, global economic situation and environmental awareness, therefore vessel operation times and bunker expenses should be analysed to reduce time loss and expenses due to operation and bunker. These operational and bunker data should transfer from vessels, keep safely in a database and has to be ready when an analysis needed. Then according to analyse results an appropriate vessel operation strategy and a proper bunker management can be found.

In this paper, an application developed as a decision support for vessel performance analysis especially for operational and bunker performance. According to analyse results with application's decision making support, reduced vessel operational times, operation cost and running cost resulted. With improvement of this application and run more analyse for vessel voyage performance will effect positive to costs and time loss, environmental awareness.

1. Introduction

Decision making is a cognitive process which is a direction of action between several alternative scenarios that resulting in the selection of a direction (Mclean et all., 2008). Every decision making process produces a final choice (Reason, 1997). The output can be an action or an opinion of choice.

Considering the improvements in ship design and building, still vessel operational costs are not stable as expected. One important issue is global economic situation, especially uncertain oil prices, current prices wave between $ 735.00 and $ 740.00 per metric ton (pmt) (http://www.bunkerworld.com/prices/) depends on port locations. This situation affects vessels' daily expenses for ship owners and charter rates for charterer. At this point affective ship operation becomes more important matter for ship owners, ship managers moreover monitoring vessel under charter is important issue for charterer side. Charterer would like to find appropriate vessel with reasonable price for his cargo. Mostly charterer's broker offer the vessel then both sides agrees on terms with a contract. This contract called charter party, which is an agreement between the ship owner and the charter for the use of the vessel. The charterer takes over the vessel for either a certain amount of time this called Time Charter Party or for a certain point-to-point voyage called Voyage Charter (Charter Party, Wikimedia Foundation Inc., 2012). In a time charter, the vessel is hired for a stated time in the time charter party agreement. The owner still manages the vessel but the employment of the vessel, voyages and sub-chartering the vessel decision given by the charterer. Vessel performance compare to time charter party is remarkable analysis if charterer hires the vessel or a fleet periodically because owner assures vessel's speed, fuel consumption and other operational activities in the charter party therefore performance measurement of the vessel to compare with charter party agreement would be remarkable benefit for the charterer.

In this paper, voyage performance analysis studied from a charterer side as operational and bunker cost. An application developed using Microsoft Visual Studio 2008 C# programming language (Visual C#, 2012) as a decision support for vessel performance analysis for operational and bunker performance. According to analyse results, reduced vessel operational times, operation cost and running cost resulted. This paper organized in 5 sections. Section 2 pres-

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ents methodology used for work flow, database structure, inputs and outputs. Section 3 gives an introduction of application interface and its sections, Section 4 shows analyse results and conclusion presented in Section 5.

2. Methodology

The main application has two modules one for vessel side and the other is for office side use, Microsoft's database technology entity framework (Entity Framework, 2012) used to generate a database model. Application's database structure presents in figure 1 and work flow of the application both for vessel and office side shown in figure 2. firstly, vessel should input all data, these data stored in a database then it is exported as an excel document to use for official "stamped document" and analyse input file for application at office side. When this file arrived into charterer office it imported into application as a voyage data set of the vessel, then the application compares input data with charter party agreement data and gives results and reports as an output so the responsible person at the office can easily check this analyse results and make a decision about the vessel performance and can negotiate further terms with the owner or take action for possible voyage plans and make decision on operational strategy.

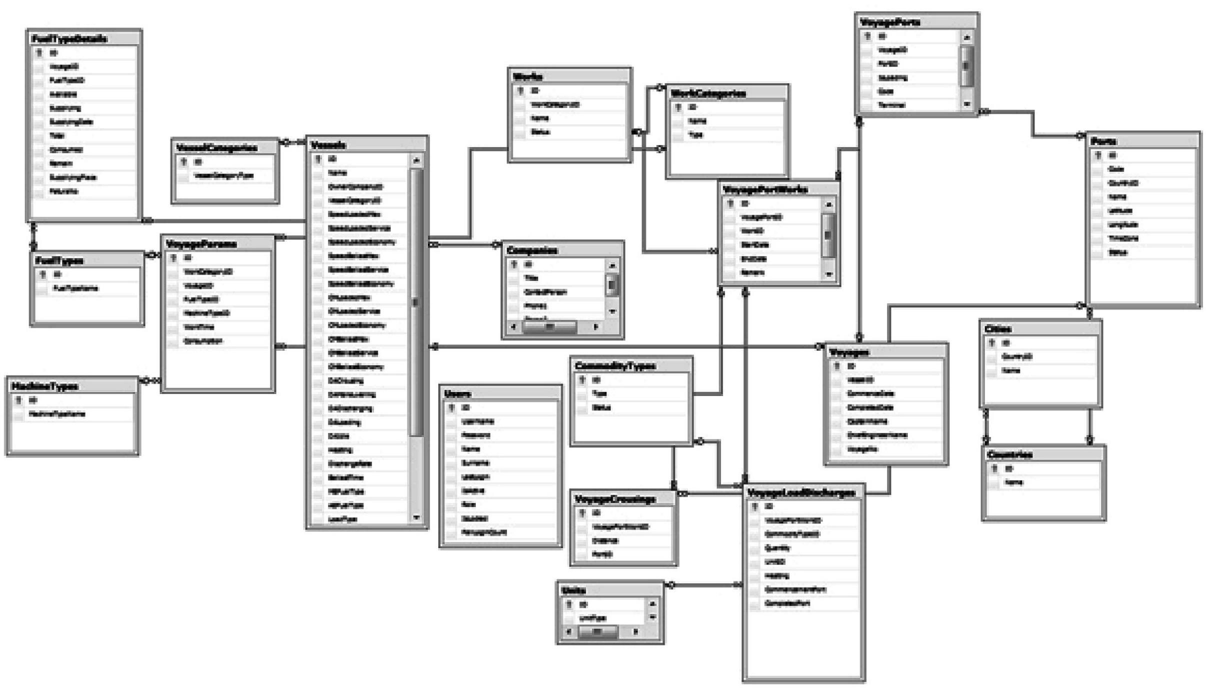

Figure 1. Database Structur.

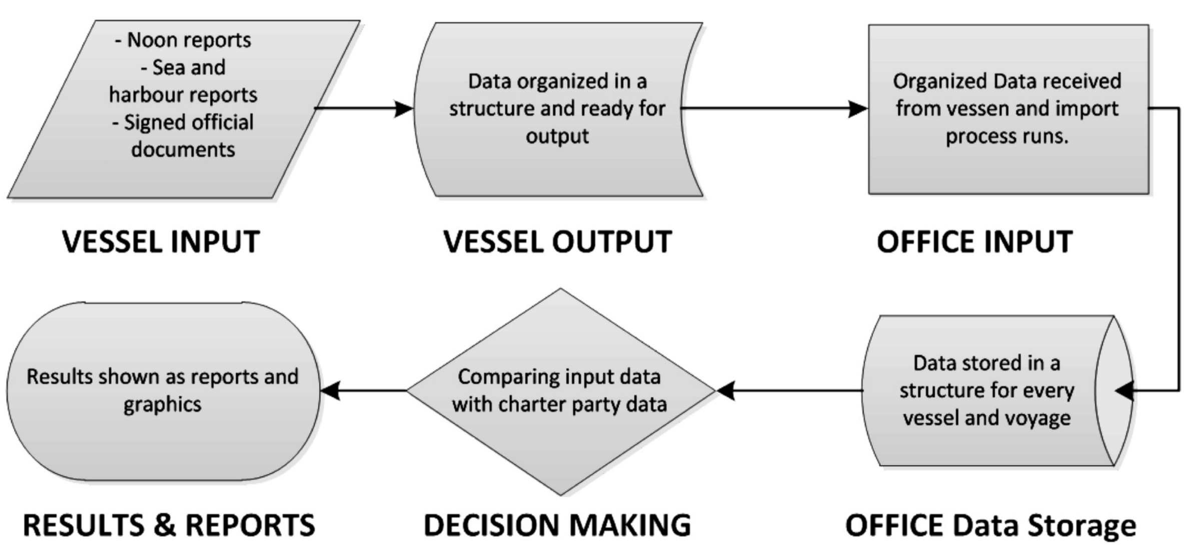

Figure 2. Application Work Flow.

3. Computer based application

In this section screens of application sections presented. In figure 3 it is shown main page of vessel side application. Vessel name, voyage number is defined at menu bar left top side also an export to excel button exist to convert input data to excel sheet. Ports list for the voyage listed under the menu bar, the ports which vessel load and discharge will be input here. Work codes tab keep the list of works during voyage and port operations. Captain enters voyage summary table which is below the work codes tab, then Voyage Result shown on the right side of work codes tab. After this step its saved and go to the next step to bunkering page.

Bunkering page has Bunker Consumption tab presented in figure 4 here chief engineer enter the consumptions for main engine, auxiliary engine and boiler then it is saved and stored in the application database, now it is ready to export and deliver the data to office for analyse.

At the office side application has more tools such as creating ports, port operations as work codes, entering charter party details. In figure 5 it shows main page of the application at office side. In office application it has vessel list menu to reach whole fleet data. When the exported file from vessel arrived to the office it can be imported to application and it will automatically put the data exactly into vessel's voyage with reference number in this screen charterer have 2 different fleet one is called black and other one is white fleet. It can be seen the vessel Ana's 12/10 voyage data inputted and listed in the voyage summary tab. User in the office can check easily entered data from this screen and see if any problems occurred during transfer or mistaken input of data.

Then user can pass to next tab, bunker supply consumption tab shown in figure 6 in this tab, user see the details of bunker consumption inputs by vessel.

After that user pass to the next tab charter party details tab. This is one of important part, in here user enter the terms of agreement with the ship owner according to charter party time agreement. This data will be stored in the application and will be used to compare the information given by the vessel. In this part vessel's speed, main engine and auxiliary engine

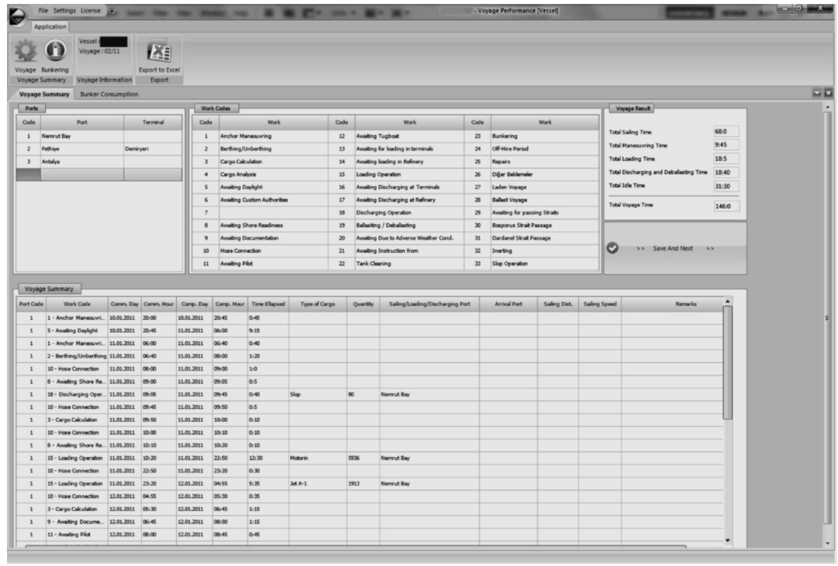

Figure 3. Vessel Voyage Input Tab.

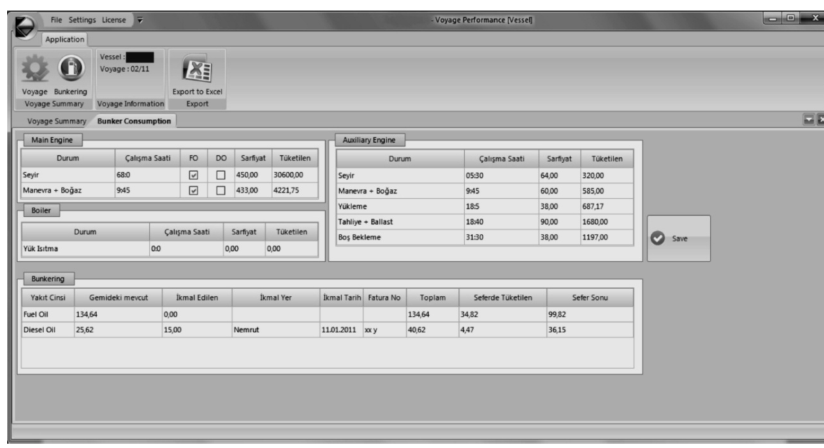

Figure 4. Vessel Bunker Input Tab.

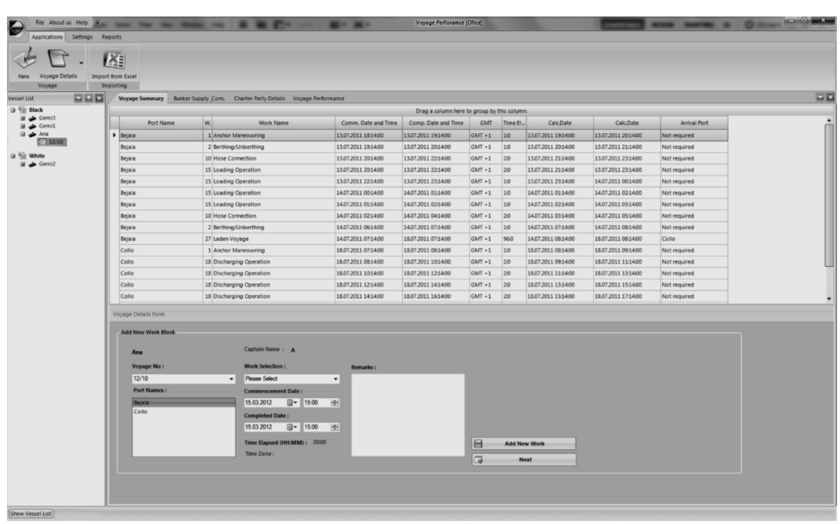

Figure 5. Office Voyage Check Tab.

consumptions, other technical information for vessel entered (Moreira, Guedes Soares, 2011). There is also a guidance inserted into the right side of the page. Office user will enter this data for one time and save it to use for all calculations for the vessel performance.

After checking that information at last, user goes to the next and final tab voyage performance tab as shown in figure 8 all the entered information will be stored and analysed with the application decision making approach and presented in this tab for user to see the results of the voyage and get final reports. In this tab every operation group called work groups have their own tabs and graphics.

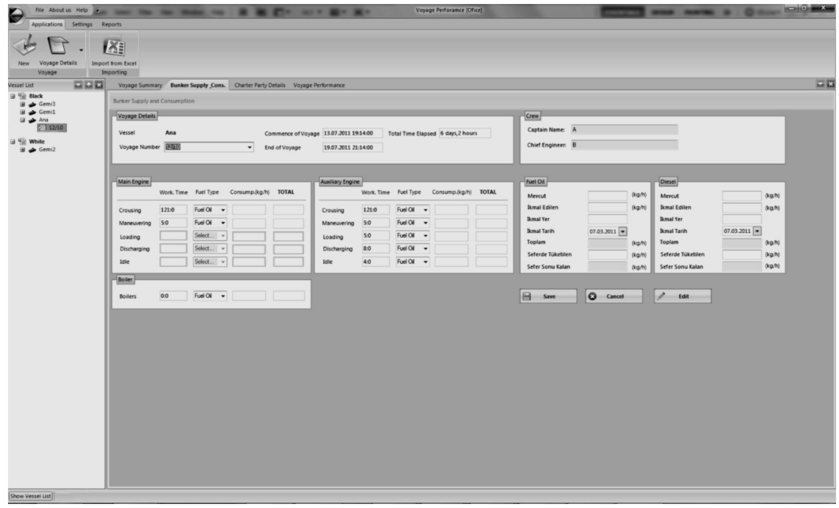

Figure 6. Office Bunker Check Tab.

4. Analyse results

Application tested with past 10 voyage records of a 6900 DWT chemical/oil tanker in 2010. Analyse results and charts helped to see exceed operation times, gaps between port operations and their reasons, outrun bunker usage according to terms in charter party agreement. From this point charterer can use these results as analyse report as a decision making support.

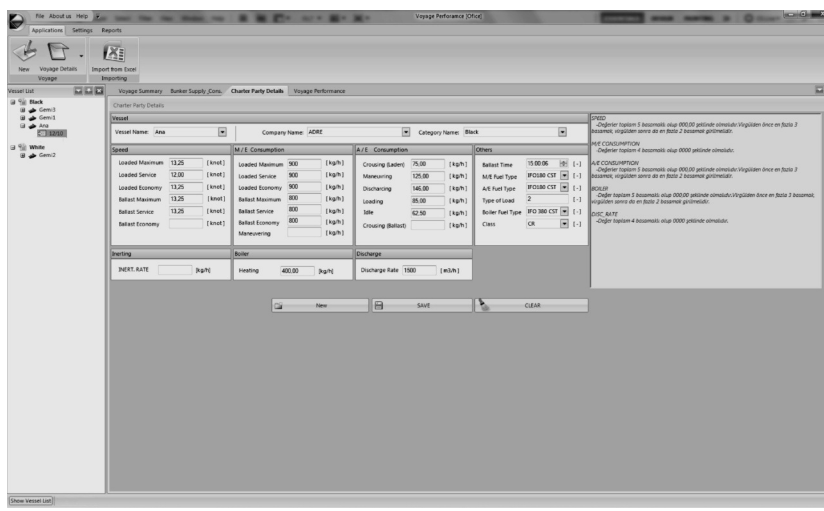

Figure 7. Office Charter Party Input Tab.

5. Conclusion

The analyse results presented as a voyage performance report to the charterer of the vessel as a support document and discussed. Suggestions from charterer will be considered for further studies.

The next step in this researched would be analyse various types of vessel's voyages and improve analyse techniques. With improvement of this analyse methods and run more analyse from different range of vessels will improve application's analyse capability which will affect positive to reduce operation costs, exceed bunker usage, time loss, operational loss and negotiate terms by owner. It is planning to prepare further study and make application available to use online and test analyse results on *www.voyageperformance.com* in next year. This research contributes to the knowledge base in voyage performance measurement from charterer view by proposing a decision making approach with a software application.

Figure 8. Office Voyage Performance Result Tab.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 27 - 32

ISSN: 1697-4840 www.jmr.unican.es

A Proposed Rule-Based Bayesian Reasoning Appoarch for Analysing Steaming Modes on Containerships

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ARTICLE INFO

Article history:
Received 06 June 2012;
in revised form 08 June 2012;
accepted 30 July 2012

Keywords:
Containership, Super Slow Steaming, Bayesian Network Method, Rule-Based Method

ABSTRACT

Super slow steaming can make savings on fuel consumption and bunker fuel cost while also releasing fewer greenhouse gas emissions. The sustainability of this speed is beneficial when the bunker fuel price is high enough to offset the additional costs of operating the vessel and the additional inventory costs. A Rule-based Bayesian Reasoning model is therefore proposed for analysing the necessity of super slow steaming speed under uncertainty. The outcomes can be used by shipping companies to determine a suitable steaming speed in a dynamic operational environment.

1. Introduction

From 2000 to 2008, most shipping companies enjoyed very high profit margins in business operations on all routes (Cañero, Cerbán, Piniella, (2011). However, from the middle of 2008, many shipping lines suffered a downturn in their vessels' operation due to the global financial turmoil, the global economic recession and sharp increases in bunker fuel prices. Consequently, the volume of trade demand dramatically decreased on all major routes and ultimately caused a surplus of containerships services. Also, the new regulation of air emissions introduced by the International Maritime Organization (IMO, 2010) has put shipping companies under pressure. Such issues have had an immense impact in determining the suitable speed of containerships on any specific route.

A super slow steaming speed is a speed between 14 and 16 knots (Bonney and Leach, 2010). This speed has been pioneered by Maersk Line after it initiated a trial involving 110 vessels beginning in 2007 (Kontovas and Psaraftis, 2011). Furthermore, China Ocean Shipping Group and its partners in the CKYH alliance (K Line, Yang Ming Marine and Hanjin Shipping) were also reported to introduce super slow steaming on certain routes from November 2009 (Lloyd's List, 2009). Such a speed saves on fuel consumption and bunker fuel cost whilst also releasing fewer greenhouse gas emissions. Therefore, this paper intends to analyse the necessity of having super slow steaming speed on containerships under uncertainty using a combined methods called a Rule-based Bayesian Reasoning (*RBR*) method.

2. Background of methods

2.1. A Trapezoidal Membership Function

According to Pedrycz and Gomide (1998), a membership function associated with a fuzzy set $\tilde{A}$ depends not only on the concept to be represented but also on the context in which it is used. The "Core" of a fuzzy set $\tilde{A}$ is the set of all elements of X that exhibit a unit level of membership functions in $\tilde{A}$ and is denoted by Core ($\tilde{A}$) (Kruse *et al.*, 1994). The core (m,n) of $\tilde{A}$ can be shown using a trapezoidal membership function as described in Fig. 1 where Core $(\tilde{A})=\{x \in K | \mu_{\tilde{A}}(x)=1\}$ between m and n, while the lower and upper bounds are represented by a and b.

A set of questionnaires will be sent to a number of experts for their evaluations. All feedbacks received from all

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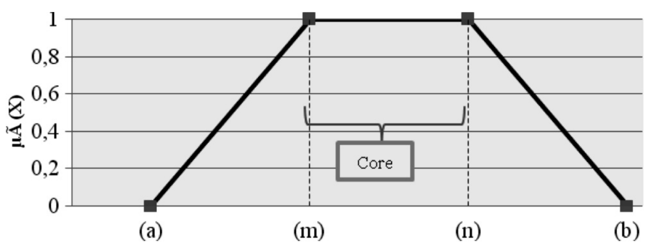

Fig. 1: Trapezoidal membership function.

experts will be aggregated and an average value of expert judgement will be computed using Eq. 1.

$$A = \sum_{n=1}^{N} E_n \times \frac{1}{N} \quad (1)$$

where E_n is the judgement rate given by the expert n, while N is the total number of experts. A is the average output value of the expert judgements.

If the average value of expert judgements for a particular node is within the "Core" of the linguistic term, automatically the belief degree value of that linguistic term is equal to 1.0. If the average value of expert judgements for a particular node is between the lower (a) and upper (b) bounds of two linguistic terms, the belief degree value of each linguistic term ($u(H_i)$) can be calculated using Eq. 2.

$$u(H_i) = \frac{V_{max} - V^l}{V_{max} - V_{min}} \quad (2)$$

where V_{max} is the preferred number of the linguistic term (H_J), V_{min} is the preferred number of the linguistic term (H_1) and V^l is the average value given by experts of the linguistic term (H_i). The utility of a linguistic term H_i is denoted by $u(H_i)$ and $u(H_{i+1}) > u(H_i)$ if H_{i+1} is preferred to H_i (Yang, 2001).

2.2. A Rule-Based Method

A rule-based method consists of *if-then rules*, a bunch of *facts* and an *interpreter* controlling the application of the rules given the facts (Abraham, 2005). These *if-then* rule statements are used to formulate the conditional statements that comprise the complete knowledge base. A single *if-then* rule assumes the form 'if x is A then y is B' and the *if* part of the rule 'x is A' is called the *antecedent* or *premise*, while the *then* part of the rule 'y is B' is called the *consequent* or *conclusion* (Abraham, 2005; Yang *et al.*, 2009). The modern style of a belief rule-base (*BRB*) consists of a collection of belief rules and is defined as follows (Liu *et al.*, 2005; Yang *et al.*, 2006):

$$R_k: IF\ A_1^k\ and\ A_2^k\ and\ \ldots and\ A_{T_k}^k,$$
$$THEN\ \{(\beta_{1k}, D_1), (\beta_{2k}, D_2), \ldots, (\beta_{Nk}, D_N)\}, \left(\sum_{i=1}^{N} \beta_{ik} \leq 1\right) \quad (3)$$

with the rule weight θ_k and attributes weights $\delta_{k1}, \delta_{k2}, \ldots, \delta_{kT_k}$ where $\beta_1 ik$ ($i \in \{1, \ldots, N\}$: $k \in \{1, \ldots, L\}$, with L being the total number of the rules in the rule base) is belief degree to which D_i is believed to be the consequent if, in the kth packet rule, the input satisfies the packet antecedents $A^k = \{A_1^k, A_2^k, \ldots, A_{T_k}^k\}$. If $\sum_{i=1}^{N} \beta_{ik} = 1$, the kth packet rule is said to be complete; otherwise, it is incomplete. Note that $\sum_{i=1}^{N} (\beta_{ik} = 0)$ denotes total ignorance about the output given the input in the kth packet rule. θ_k is the relative weight of the kth rule, and $\delta_{k1}, \delta_{k2}, \ldots, \delta_{kTk}$ are relative weights of the T_k antecedent attributes used in the kth rule.

2.3. A Bayesian Reasoning Method

The Bayesian Networks (*BN*) method was developed by Bayes in 1761 and Bayes' Theorem was published in 1763 (Bernardo and Smith, 1994). It has become an increasingly popular paradigm for reasoning under uncertainty. Heckerman *et al.*, (1995) provide a detailed list of applications of the BN method. A *Hugin* (Korb and Nicholson, 2003) software tool will be used in this paper. The characteristics of the *BN* method are described as a Directed Acyclic Graph (*DAG*) consisting of nodes, arcs and an associated set of probability tables (Eleye-Datuba *et al.*, 2006). A *Conditional Probability Table (CPT)* associated with each node denotes the strength of such causal dependence. According to Wang and Trbojevic (2007), *nodes* (usually drawn as circles) represent random (i.e. chance) variables such as events that take values from the given domains. *Arcs* are used to represent the direct probabilistic dependence relations among the variables. There are three types of arcs, namely 1) serial, 2) diverging and 3) converging connections. Each relationship is described by an arc connecting an influencing (parent) node to an influenced (child) node and has its terminating arrowhead pointing to the child node.

Bayes's theorem is a mathematical algorithm used for calculating posterior probabilities. The Bayesian reasoning method can be applied for combining rules and generating final conclusions such as the prior probability of D_i($i \in \{1,2, \ldots, N\}$) which can be computed as follows (Yang *et al.*, 2008):

$$p(D_i) = p(D_i | A_1^k, A_2^k, \ldots, A_{T_k}^k)\, p(A_1^k)\, p(A_2^k) \ldots p(A_{T_k}^k) \quad (4)$$

where A_i^k ($i \in \{1,2, \ldots, T_k\}$: $k \in \{1, \ldots, L\}$) is the referential value of the ith antecedent attribute in the kth rule. T_k is the number of antecedent attributes used in the kth rule and L is the total number of rules in the rule base. p (.) denotes the probability.

3. Modelling the necessity of super slow steaming under uncertainty

Step 1: Model development
A discussion technique with experts is used in this step. A *BN* model is proposed for developing a scientific model for

this study. As a result, there are four parent nodes involved, namely 1) global warming, 2) global economics and financial conditions, 3) bunker fuel prices and 4) operating costs. The node "Global Warming (GW)" has one child node, namely "Emissions (E)" (Fig. 2). Also, the node "Operating Costs (OC)" has one child node which is "Cost Factors". The node "Global Economics and Financial Conditions (EFC)" has four child nodes, namely "Freight Rate (FR)", "Vessel Supply (VS)", "Ship Values (SV)" and "Container Demand (CMD)". The node "Bunker Fuel Prices (BFP)" has two child nodes which are "Global Factors (GF)" and "Voyage Costs (VC)". All the nodes except the output node "Super Slow Steaming" have been grouped into three groups of nodes namely "Vessel Factors (VF)", "Global Factors (GF)" and "Cost Factors (CF)". Such nodes assist shipping companies to make a decision in analysing the necessity of having super slow steaming.

Step 2: Data collection process
A qualitative dataset has been gathered through a set of questionnaires. In the set of questionnaires, the rate of measurement uses the range value between 1 and 10 (Table 1). If the node exists "*VF=high*", it means that there is a "*worst condition*" to shipping companies due to the status of its parent nodes.

Table 1: The linguistic terms of the node "Vessel Factors".

Preference Number	State	Meaning
10, 9	high (H)	*Worst* condition
8, 7	reasonably high (RH)	*Poor* condition
6, 5	average (A)	*Average* condition
4, 3, 2, 1	low (L)	*Good* condition

Given Condition 1 in Table 2 as an example, IF "*E=high*" and "*FR=high*" and "*VS=over*", the experts A and C ticked number eight of the linguistic term "*reasonably high*", while the expert B ticked number nine of the linguistic term "*high*". By using Eq. 1, the average output value of Condition 1 is known to be 8.333. The same calculation technique is applied to all the conditions listed in Table 2.

Table 2: The partial evaluation of the node "Vessel Factors" given by the experts.

Condition	Antecedent Attributes			Vessel Factors (VF)			Average
	Emissions	Freight Rates	Vessel Supply	Expert A	Expert B	Expert C	
1	high	high	over	8	9	8	8.3333
2	high	high	normal	5	6	5	5.3333
…	…	…	…	…	…	…	…
8	low	low	normal	3	2	3	2.6667

The membership functions of the node "Vessel Factors" is constructed using the preference number and linguistic terms listed in Table 1. If the average output value of a condition is within the "Core" of a particular state, then the belief degree value of that state is known to be 1.0000, while the belief degree values of the other states are equal to 0.0000. For instance, the average output value of Condition 2 is 5.3333, within the "Core" values between 5.0000 and 6.0000 (Fig. 3). Consequently, the belief degree value of the state "*average*" is known to be 1.0000.

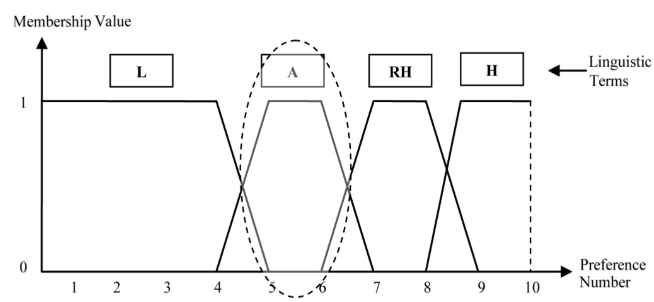

Fig. 3: Membership function of the node "Vessel Factors".

However, if the average output value of a condition is between two states (lower and upper bounds), then the belief degree values of these states are determined using Eq. 2. For example, the average output value of Condition 1 is 8.3333 which is between 8.0000 (the lower bound of the state "*high*") and 9.0000 (the upper bound of the state "*reasonably high*"). By using Eq. 2, the belief degree value of

Fig. 2: A proposed model for analysing the necessity of having super slow steaming.

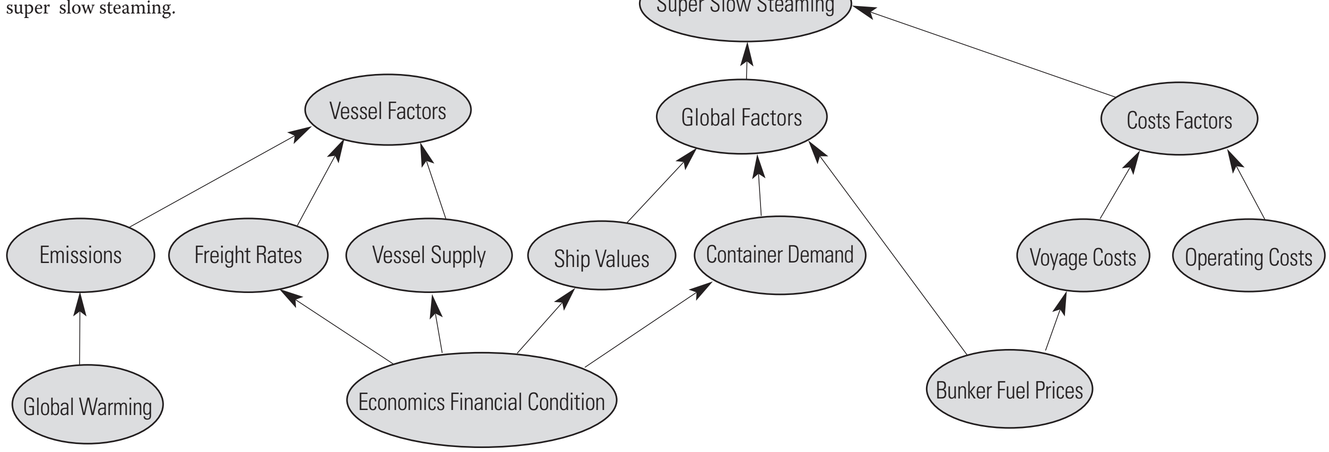

Table 3: The conditional probability table of the node "Vessel Factors".

Emissions	*high*				*low*			
Freight Rates	*high*		*low*		*high*		*low*	
Vessel Supply	*over*	*normal*	*over*	*normal*	*over*	*normal*	*over*	*normal*
high	0.3333	0.0000	1.0000	0.3333	0.0000	0.0000	0.0000	0.0000
reasonably high	0.6667	0.0000	0.0000	0.6667	0.0000	0.0000	0.6667	0.0000
average	0.0000	1.0000	0.0000	0.0000	1.0000	0.0000	0.3333	0.0000
low	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	1.0000

Table 4: The RBR with a belief structure for the node "Super Slow Steaming".

Rules	**Antecedent Attributes**			**Super Slow Steaming (SSS)**				
No	**Vessel Factors (VF)**	**Global Factors (GF)**	**Cost Factors (CF)**	**strongly recommended**	**recommended**	**moderately recommended**	**not recommended**	**strongly not recommended**
1	high	good	high	0.0000	1.0000	0.0000	0.0000	0.0000
2	high	good	normal	0.0000	0.0000	1.0000	0.0000	0.0000
3	high	good	low	0.0000	0.0000	0.6667	0.3333	0.0000
…	…	…	…	…	…	…	…	…
48	low	poor	low	0.0000	0.0000	1.0000	0.0000	0.0000

the state *"reasonably high"* is known to be 0.6667, while the belief degree value of the state *"high"* is 1.0000 – 0.6667 = 0.3333. The belief degree values of the states *"average"* and *"low"* are 0.0000. Accordingly, such output values are transformed into the CPT of the node "Vessel Factors" (Table 3). In a similar way, the CPTs of all other nodes are obtained.

Step 3: Establishment of Rule-based Bayesian Reasoning (RBR)

Three fundamental attributes 1) Vessel Factors (VF), 2) Global Factors (GF) and 3) Cost Factors (CF) are considered as the antecedent attributes in *IF-THEN* rules, while Super Slow Steaming (SSS) is expressed as the conclusions attribute. The linguistic terms of the three antecedents and conclusion attributes are defined as follows: "VF_i *{i = 1(high), 2(reasonably high), 3(average), 4(low)}*", "GF_j *{j = 1(good), 2(average), 3(fair), 4(poor)}*", "GF_k *{k = 1(high), 2(normal), 3(low)}*" and "SSS_l *{l = 1(strongly recommended), 2(recommended), 3(moderately recommended), 4(not recommended), 5(strongly not recommended)}*". By using these linguistic terms and the calculation techniques described in Step 2, the *RBR* with a belief structure for the node "Super Slow Steaming" is partially summarised in Table 4.

By using Eq. 3, the *RBR* with a belief structure can be performed as follows:

R_1: IF *VF1=high* and *GF1=good* and *CF1=high*, THEN *{(0.0000, strongly recommended (SSS1)), (1.0000, recommended (SSS2)), (0.0000, moderately recommended (SSS3)), (0.0000, not recommended (SSS4)), (0.0000, strongly not recommended (SSS5))}*.

Step 4: Bayesian reasoning

The necessity of having super slow steaming can be computed using Eq. 4. For example, given "*GW1=serious*", "*EFC3=recession*" and "*BFP1=high*", the posterior probability values of *P(SSS|VF_i, GF_j CF_k)* are computed as follows:

$$P(SSS) = \sum_{i=1}^{4}\sum_{j=1}^{4}\sum_{k=1}^{3} P(SSS|VF_i, GF_j, CF_k)P(VF_i)P(GF_j)P(CF_k)$$

$$= (0.9206, 0.0794, 0.0000, 0.0000, 0.0000)$$

It explains that the necessity of having super slow steaming associated with *"GW1=serious"*, *"EFC3=recession"* and *"BFP1=high"* is {(*0.9206, strongly recommended*), (*0.0794, recommended*), (*0.0000, moderately recommended*), (*0.0000, not recommended*), (*0.0000, strongly not recommended*)}. The above calculation can also be modelled using the *Hugin* software as shown in Fig. 4.

In a similar way, the necessity of having super slow steaming associated with "GW_i *{i = 1 (serious), 2 (not serious)}*", "EFC_j *{j = 1 (booming), 2 (stable), 3 (recession)}*" and "BFP_k *{k = 1 (high), 2 (low)}*" is obtained as partially shown in Table 5.

Step 5: Results and discussions

Referring to each rule in Table 5, the posterior probability values of more than 50% will be considered as the selected option of the test case. Given Rule 1 as an example, the necessity of having super slow steaming associated with "*GW1=serious*", "*EFC1=booming*" and "*BFC1=high*" is (*0.9409, moderately recommended (SSS3)*). The result is straight-forward and easy to understand by shipping companies. Rules 5, 6, 7, 9, 10, 11 and 12 can be explained in a similar way as Rule 1.

In Rule 2, the necessity of having super slow steaming associated with "*GW1=serious*" and "*EFC1=booming*" and

Table 5: The outputs of necessity of having Super Slow Steaming.

Rules	Antecedent Attributes			Super Slow Steaming (SSS)				
No	GW	EFC	BFC	strongly recommended	recommended	moderately recommended	not recommended	strongly not recommended
1	serious	booming	high	0.0000	0.0148	0.9409	0.0443	0.0000
2	serious	booming	low	0.0000	0.0000	0.0796	0.4682	0.4522
3	serious	stable	high	0.0787	0.4336	0.4758	0.0119	0.0000
4	serious	stable	low	0.0000	0.1258	0.3887	0.3944	0.0911
5	serious	recession	high	0.9206	0.0794	0.0000	0.0000	0.0000
…	…	…	…	…	…	…	…	…
12	not serious	recession	low	0.0251	0.2659	0.5431	0.1616	0.0042

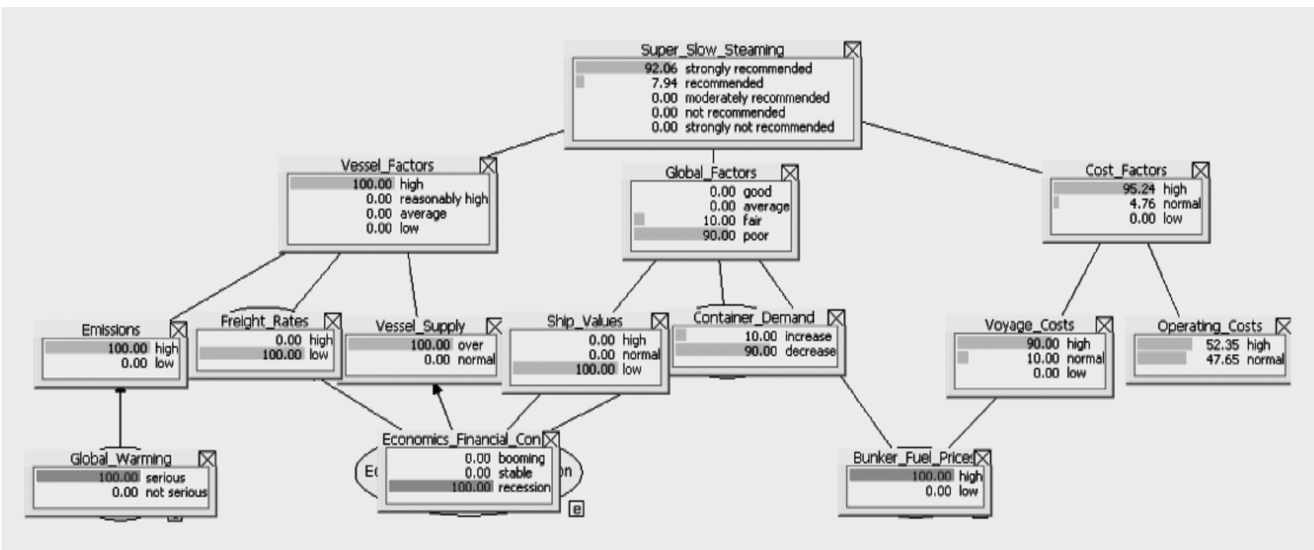

Fig. 4: The posterior probability value of the node "SSS" after giving evidence to nodes "GW", "EFC" and "BFC".

"*BFC2=low*" is {(*0.4682, not recommended (SSS4)*), (*0.4522, strongly not recommended (SSS5)*)}. The posterior probability values of both states are almost similar. As a result, the proposed *BN* model assists shipping companies in making a decision not to adopt super slow steaming speed in operating their vessels. Rules 3 and 8 can be explained in a similar way as Rule 2.

In Rule 4, the necessity of having super slow steaming associated with "*GW1=serious*" and "*EFC2=stable*" and "*BFC2=low*" is {(*0.3887, moderately recommended (SSS3)*), (*0.3944, not recommended (SSS4)*)}. Further investigation of this rule is needed in determining a final decision. This is because the posterior probability values of both states are comparatively large. Such two states are in different categories and shipping companies require more endeavour to decide a suitable steaming speed.

4. Conclusions

The research study carried out was fully conducted using a Rule-based Bayesian Reasoning method associated with the brainstorming and fuzzy set techniques. The qualitative dataset was obtained from the experts' judgement. This method is useful for assisting shipping companies in dealing with uncertain conditions. The outcomes produced can be used by shipping companies to determine the necessity of a super slow steaming speed in a dynamic operational environment. The novelties of this study are 1) the model development and 2) the application of all decision making methods described. An issue related to the results that can be used for future study is the uncertainty of the global situations. A process of identifying the most beneficial shipping business strategy in terms of cost saving, profit and service performance perspectives is needed.

Acknowledgements

The authors would like to thank three anonymous experts (one senior manager from Atlantic Container Liner (ACL) and two senior academics) for their time and effort in explaining details and answering a set of questionnaires about this study. An appreciation is also given to the Ministry of Higher Education, Malaysia and University Malaysia Terengganu for their financial support.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 33 - 38

ISSN: 1697-4840 www.jmr.unican.es

Comparative Analysis of the Dynamic Angle of Heel of a Shipe 888 Project Type Defined of the Calculation and Model Tests

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ARTICLE INFO

Article history:
Received 06 June 2012;
in revised form 09 June 2012;
accepted 30 July 2012

Keywords:
Stability, Warship model,
Laboratory, Dynamic heel

ABSTRACT

Results of initial research on air flow's dynamic impact on a ship model of 888 project type are presented in the elaboration. The research has been executed at a test stand located in the Polish Naval Academy. The ship model of 888 project type has been an object of the tests. Results of executed measurements have been compared with theoretical calculations for an angle of dynamic heel. Input parameters for the tests and calculations have been defined in accordance with recommendations of Polish Register of Shipping (PRS) and IMO (IMO Instruments 1993, 2008, PRS 2007). Determination of a heeling moment by wind operation has been a key issue. The executed research has revealed that the way the criteria of the ship's dynamic stability are defined by PRS and IMO takes a certain safety margin into account.

1. Introduction

During operation, a ship is open to dynamic effects resulting from specifics of marine environment. Among these effects, wind dynamic impact together with a wavy motion is especially hazardous for the ship. Therefore, there are applicable criteria, taking the above said situations into consideration, in classification societies' regulations. A way to calculate a heeling moment originated by the wind operation is given in dynamic stability criteria. One may determine an angle of dynamic heel based on a function of this moment and righting levers' curve. But, assumptions and simplifications accepted by the classification societies result in omission of some phenomena and the angle of dynamic heel, determined based on theoretical calculations, differs from the real one (Moreno, Chaos, Aranda, Muñoz, Díaz, Dormido, 2009). Determination of a real value of the dynamic angle of heel is possible by executing model tests performed with geometric and dynamic similarity scale taken into consideration. Results of theoretical calculations and measurements of dynamic angle of heel, executed with a ship model of 888 project type as an example, are given in this elaboration (Lewandowski, 2010). Results of the presented tests allow formulating practical conclusions that may be used by the classification societies, among the others.

2. Research facility and object of the test

Tests on the wind dynamic impact on a ship have been executed at a facility located in the Polish Naval Academy (Mironiuk, W. 2006). Main elements of the stand are as the following:

Model basin for surface ships of internal dimensions of LxBxH 3x2x0,5 m,

— Ship model of 888 project type,
— Ship model of 660 project type,
— Computer registering parameters of the ship model position,
— Device generating air flow.

There is a set of fans fixed in a casing making a jet of a changeable section on the basin's shorter side. Dimensions of the jet's outlet are sufficient to let the airflow operate on entire flank of the model, with a suitable reserve. There are 5 big and 5 small fans in the jet's housing – all together, they are capable of generating air flow faster than 5 m/s.

A ship model of 888 project type has been the object of the study. It was made in a scale 1:50 in respect to a real vessel. The scheme of the model is shown in the Figure 2.

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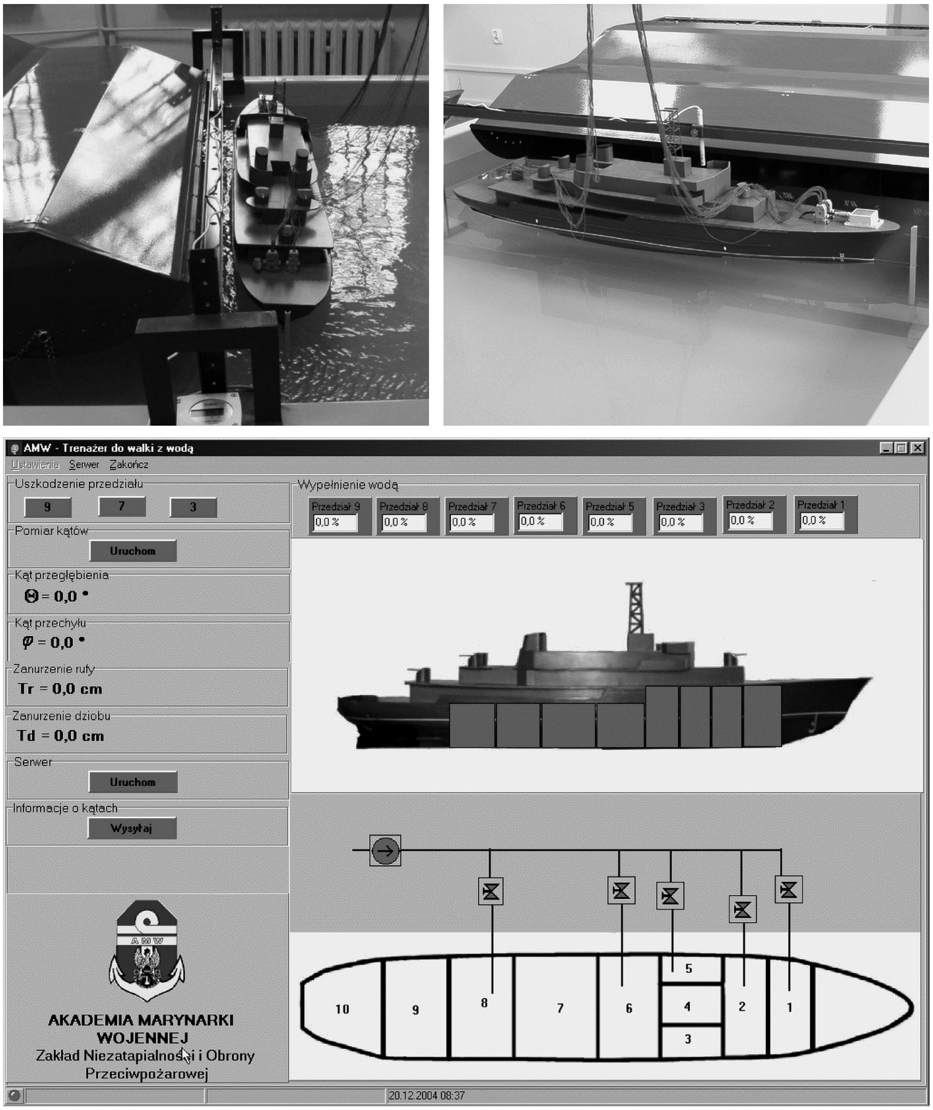


Fig. 1. Facility for tests on dynamic impact of wind.

Its basic data have been as the following (Mironiuk, W. 2006):

— Overall length of the model: Lc = 1,444 m;
— Length between perpendiculars: Lpp = 1,284 m;
— Displacement of the model: D = 13,15 kg;
— Average draught of the vessel: T = 0,078 m;
— Depth of the model's centre of gravity: Z_G = 0,096 m.

1, 2 and 3 - Valves for a puncture simulation in the compartments PIII, PV and PVII; 4, 5, 6, 7 and 8 - Valves for flooding the compartment PVI, PIV, PIII, PII and PI; 9,10,11 - Water level indicators in the compartment PVII, PV and PI; 12. Indicator of ship draught; 13. List indicator.

At the level of floatation line, openings – horizontally arranged – are made in the model's stem and stern frame. Rods limiting the ship's drift caused by the air flow operation may be placed in the openings. Such an arrangement results in defining a fixed axis of rotation of the ship model. In fact, position of the ship model's axis of rotation is not permanent because, it depends – among the others – on dynamics of the wind effect. Location of the ship model's axis of rotation is crucial to determine the heeling moment. The IMO's stability code (IMO Instruments, 1993, 2008,) provides with instructions that the heeling moment's lever should be calculated as a distance from a centre of the topside projected area to the centre of the underwater part of the hull's projection on the symmetry plane, or – approximately – to the vessel's half draught depth. In this connection, results of measurements of and calculations for the dynamic angles of heel, executed in compliance with the IMO's recommendations, shall differ.

A sensor of the heeling and trim angles registering the angles with an accuracy of up to 0,01 of degree is installed on the model. Signals from the sensor are transmitted by means of a cable to a computer. Influence of the cables connected to the model has been omitted because of their insignificant weight and section areas.

3. Problem of geometric and dynamic similarity scale

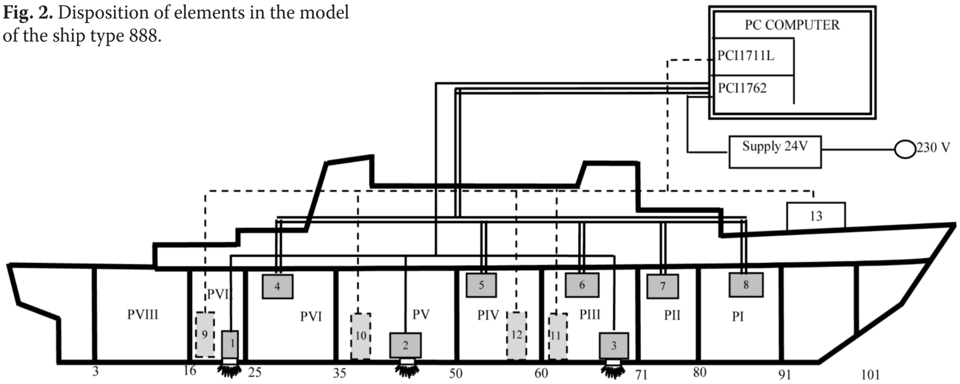
Solving the geometric and dynamic similarity scale problem has consisted in meeting given conditions. The ship model was made in the 1:50 scale - that is why all geometric quantities could have been easily calculated. Values of the righting levers curve of the ship model also have been subject to the geometric similarity principle. The heeling moment should effect in proportion to the vessel's righting levers, i.e. ratio of the ship's righting levers maximum value and value of the wind affected heeling moment's lever should be the same for both the model and the ship, as below:

$$\frac{GZ_{\max o}}{l_{wo}} = \frac{GZ_{\max m}}{l_{wm}} = const \tag{1}$$

where the "o" subscript refers to the vessel, while the „m" subscript refers to the model. Figure 3 makes a graphical mapping of the (1) dependence.

Wind pressure affecting the vessel depends on the wind affected heeling moment. Therefore, the pressure should be defined in compliance with a suitable dynamic scale in

Fig. 2. Disposition of elements in the model of the ship type 888.



relation to the model. Value of the pressure having dynamic impact on a real object, i.e. IMO and PRS regulations (IMO Instruments 1993, 2008, PRS 2007). It is 504 Pa for ships of unrestricted operational water areas and wind operating statically. However, a value 1,5 times bigger, i.e. 756 Pa is given for dynamic wind. A given wind velocity corresponds with this pressure value, and the velocity may be determined with many ways. Using dependence on the dynamic pressure is one of them, as the following:

$$p = \frac{\rho v^2}{2} \qquad (2)$$

The pressure value of 756 Pa gives the air speed of 35 m/s – at the density of 1,2 kg/m³. To determine the wind velocity in respect to the pressure, one may also use table values provided in published references (Dudziak, J. 2006). It follows from them that the velocity should be some 29 m/s for squall of 756 Pa pressure.

The air speed obtained for the ship should be recalculated for a speed for the model. Suitable recalculations may be done with many ways. Using Euler coordinate is one of them (Grobyś 1998), as below:

$$Eu = \frac{p}{\rho v^2} \qquad (3)$$

The pressure of 756 Pa and the speed of 32 m/s both defined for the ship gives the wind velocity of 4,52 m/s, i.e. the velocity that should have impact on the model.

In case the following dependence on the wind affected heeling moment is applied (PRS 2008):

$$M_w = 2 \cdot 10^{-5} \cdot F_w \cdot z_w \cdot v_w^2 \cdot \cos^2\varphi \qquad (4)$$

Where:

F_w – topside projected area [m²],

z_w – distance from centre of wind projected area to waterline positioned at height of T/2 above basic plane, at given load condition [m],

φ – angle of heel,

v_w – wind velocity at height of wind projected flank's geometric centre, defined with the following formula (PRS 2008),

$$v_w = v_{10}\left(\frac{z_w}{10}\right)[\text{knots}] \qquad (5)$$

Where:

v_{10} – wind velocity at height of 10 metres above waterline, v_{10}=80 knots is accepted for the ships of unrestricted operational water areas.

The wind velocity is 4,51 m/s for the ship model.

The presented solutions for the problem of dynamic similarity scale follow to similar results of the air flow speed. Therefore, it is probable that the calculations for the wind velocity have been done correctly.

4. Execution of the tests

The study's programme has been executed in several stages. Determination of the airflow speed distribution has

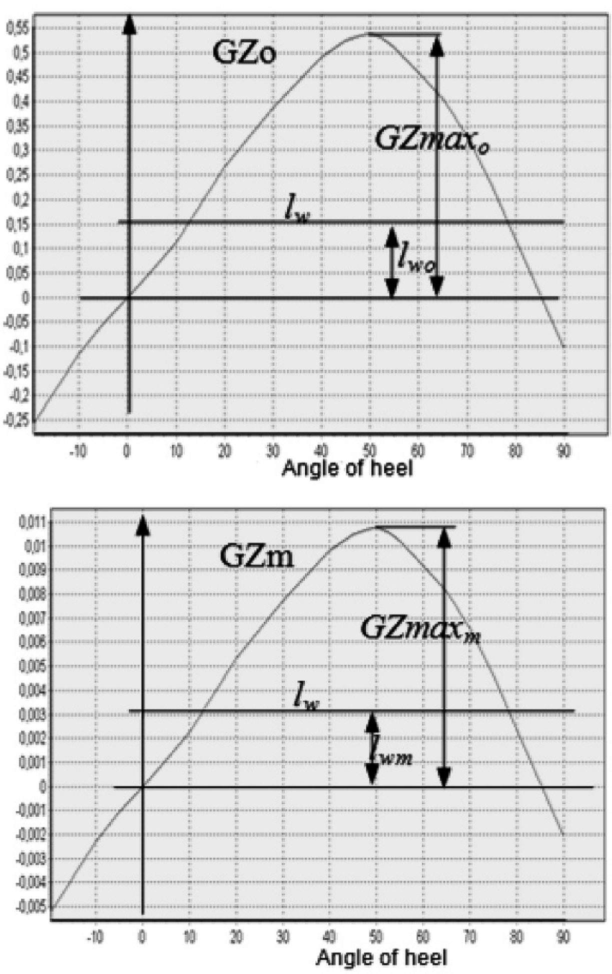


Fig. 3. Determination of wind affected heeling moment lever's value for ship model.

been one of the first activities at the research stand. Measurements of the airflow speed have been executed in 18 points. Results of the measurements for the speed of the airflow generated only by the big fans are given in Table 1. Average value of the speed of the airflow affecting the model had 4,52 m/s.

Table 1. Results of measurements of air flow speed.

Measurement height	Place of measurement and value of speed [m/s]						Average value [m/s]
	1	2	3	4	5	6	
35,5 cm	4,57	4,68	4,69	4,16	4,10	4,53	4,46
18,5 cm	4,67	4,86	4,77	4,53	4,16	4,65	4,61
8,5 cm	4,33	4,63	4,60	4,65	4,65	4,10	4,49
							4,52

Next stage of the research has been to determine the dynamic angle of heel. Tests at the stand have been executed, among the others, for the following values of the angles of heel towards the windward shipboard: 6°, 15°, 18°. Values of these angles result from calculations of weather criteria executed for the ship project of type 888 in accordance with the regulations of IMO and PRS.

The fans have worked with constant velocity during registering the angles of heel what corresponds with constant characteristics of the heeling moment. Results of the measurements of the registered angles of heels are given in Fig. 4.

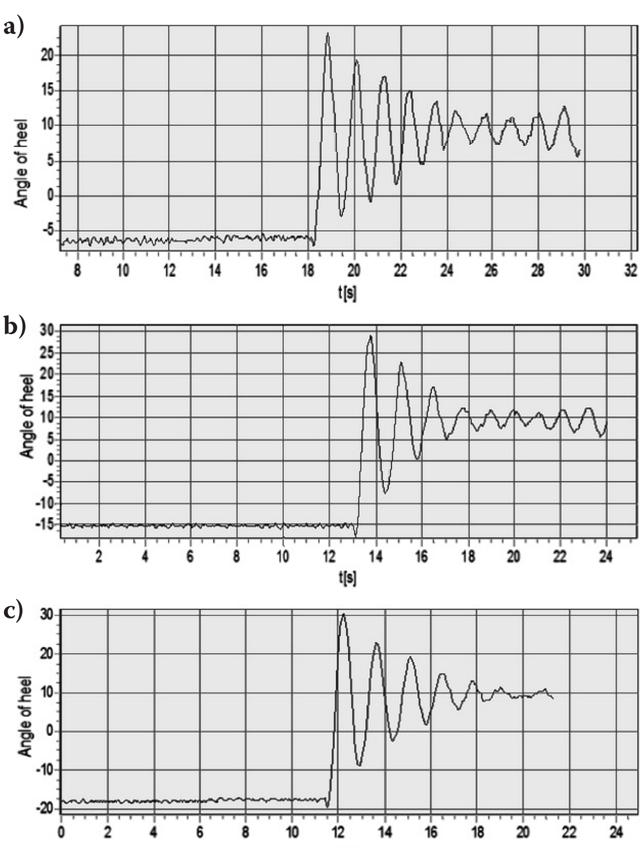


Fig.4. Measurements of dynamic angle of heel after deflecting model towards windward shipboard to angle of: a) 6°; b) 15°; c) 18°.

Table 2 contains a listing of the results for the measurements executed at the stand. The biggest values of the dynamic angle of heel have been obtained when the model has been deflected to the angle of 18 degrees towards the windward shipboard.

Table 2. Values of dynamic angles of heel.

No.	1	2	3
Angle of heel towards windward shipboard [deg]	-6	-15	-18
Dynamic angle of heel [deg]	23	29	31

5. Theoretical calculations

Calculations for the ship's dynamic angle of heel have been executed for the heeling moment defined in accordance with the IMO and PRS recommendations. Based on them, lever of the dynamically operating heeling moment has been determined assuming that the distance of the topside projected area's centre was measured from the half draught depth. The prospected lever has been calculated with the following dependence (IMO Instruments, 1993, 2008, PRS 2007).

$$l_w = 1{,}5 \frac{q_v F_w Z_v}{1000\, g\, D} [m] \tag{6}$$

where: q_v = 504 Pa – wind pressure;
F_w – topside projected area [m²];
Z_v – measured perpendicularly, distance from centre of topside projected area to centre of underwater part of hull's projection on symmetry plane, or – approximately – to vessel's half draught depth [m];
D – ship's displacement [t];
g – 9,81 m/s²;

and for the data:
Fw = 533 m²;
Zv = 6.46 m;
D =1643.7 t,

to result in obtaining value of the wind affected heeling lever equal 0,162 m.

For this value, the dynamic angles of heel have been read on a graph (Fig. 5) and placed in a Table 3.

Table 3. Values of dynamic angles of heel.

No.	1	2	3
Angle of heel towards windward shipboard [deg]	-6	-15	-18
Dynamic angle of heel [deg]	33	40	43

The results show that the values of the dynamic angles of heel obtained from the calculations are seriously bigger than the values obtained from the measurements. The fact that lever on which force of the wind pressure operates was defined from the ship's half draught depth, instead of from the operative waterline, is one of the reasons. Should one

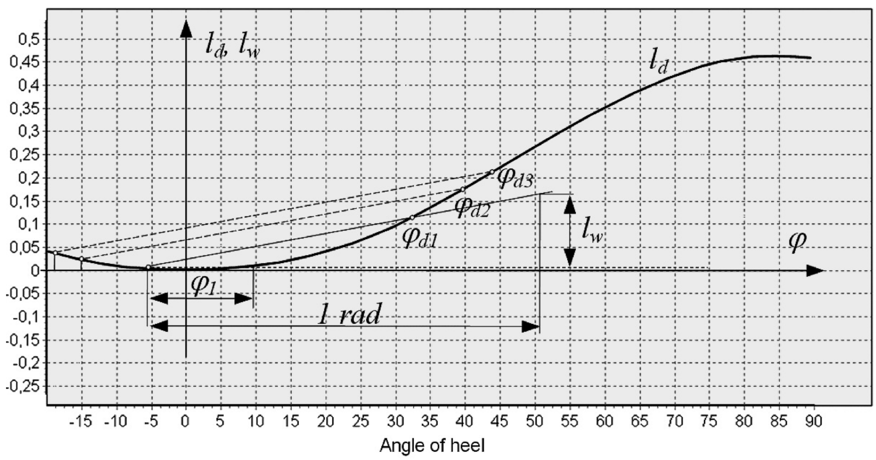


Fig.5. Determination of dynamic angles of heel for ship of 888 project type – for Zv=6.46 m.

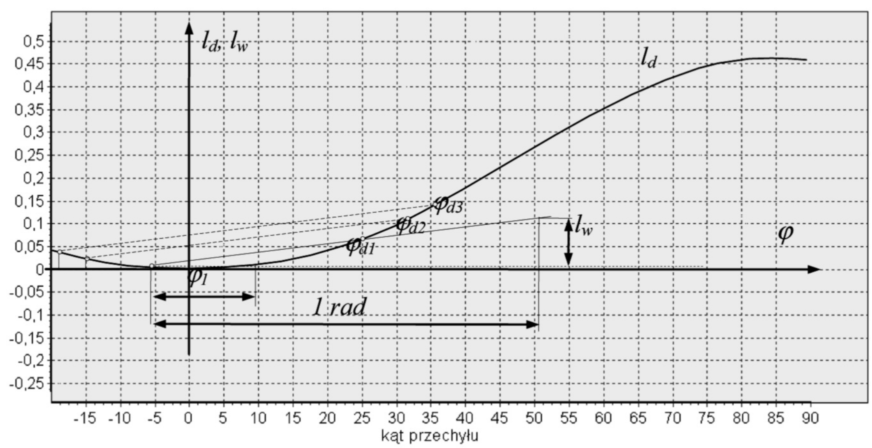


Fig.6. Determination of dynamic angles of heel for ship of 888 project type – for Zv=4.49 m.

take this note into consideration, the wind affected dynamic lever l_w shall equal 0.111 m. A next graph, given on Figure 6, allowing defining the dynamic angles of heel, has been executed for this case. Obtained values of the angles are presented in a Table 4. Moreover, a line with values of the dynamic stability angles measured at the stand has been added - to enable to compare the results.

Table 4. Values of dynamic angles of heel.

No.	1	2	3
Angle of heel towards windward shipboard [deg]	-6	-15	-18
Dynamic angle of heel determined for *Zv*=4.49 m [deg]	25	32	36
Dynamic angle of heel measured at stand [deg]	23	29	31

This time, the results of the dynamic angle of heel calculations and measurements are very similar. Differences are from 10 to 16%. It is possible to obtain more similar results after damping of movement and size of the wind exposed area's projection, which changes during the heel, are taken into account.

6. Summary

The executed initial research on the dynamic influence of the wind affected heeling moment shows high convergence of the theoretical calculations with the measured values. The obtained results prove that the way the wind affected heeling lever is determined has significant impact on the values of the dynamic angles of heel. The ship model has had the fixed axis of rotation, positioned in not waving water plane. Therefore, it has not been possible to compare the measurements results with the results of calculations for the dynamic angle of heel accurately, if determined based on the heeling moment imposed by IMO. Further research on the described issue shall allow executing more accurate analysis.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 39 - 44

ISSN: 1697-4840 www.jmr.unican.es

The Modelling Support to Maritime Terminals Sea Operation: The Case Study of Port of Messina

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ARTICLE INFO

Article history:
Received 08 June 2012;
in revised form 10 June 2012;
accepted 30 July 2012

Keywords:
Modelling, Port capacity,
Simulation, Messina Port

ABSTRACT

The maritime freight and passengers traffic is ever more increasing and the estimation of the sea-side port capacity is an strategic factor to guarantee a high level of ship services quality by means of the optimisation of layout and the improvement of quay services in terms of better time distribution of arrival and departure of ships in port. In the past the authors developed a synthetic combinatorial model capable to analyse sea-side port operation, characterised by the overlap of many different ships traffic, and to evaluate the limit of their capacity as number of ships movement. In the present research the authors have developed a sea-side operation simulation model, based on a flexible and powerful general-purpose platform, structured for capacity estimation and traffic analysis and capable to support both design and operational planning process and to relate the terminal utilisation degree with the quality of the concerned transport services. The paper describes the model and its performances in the case study of the port of Messina, which represents a nervous centre of Italian economy by joining Sicily with the rest of country and allowing a considerable daily exchange of freight and persons, with the daily experience of port congestion.

1. Introduction

The study deals with analysis and simulation of ships traffic in a port, with a specific focus on the capacity assessment under high traffic conditions nearby congestion (Onyemechi, 2010).

The traffic data are acquired from the dynamic web based database *MarineTraffic* developed by the Aegean University in Chios [www.marinetraffic.com/ais/; 2011).

In the present research it was built up a simulation model capable to identify the conflicts between ships and sensible enough to assess the effects of traffic increase till saturation, defined as the maximum amount of daily movements in fixed regularity conditions.

Moreover, the model allows to quantify the effects of possible solutions for conflicts resolutions and/or minimisation.

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2. Modeling Environment

For the model implementation it was selected the software platform *Planimate*®, which is well suited for the modeling of systems characterized by a large amount of data and subprocesses, parallel and synchronized cycles and allows an easy synchronic process control (Baldassarra, Impastato and Ricci, 2010).

Planimate® is based on two typologies of key elements:

- *Objects*: fixed entities (e.g. the quays), which have the capacity to host other entities, thta during the simulation cross them, or to modify their state (figure 1);
- *Items*: dynamic entities (e.g. the ships) moving inside the system through objects and finally exiting; groups of items may be organised in classes.

Figure 1: *objects* in *Planimate*®.

The model construction in *Planimate*® includes 4 phases for the preparation of:

- Objects;
- Flows;
- Objects-flows interactions;
- Graphics.

Figure 2: *items* classes in *Planimate*®.

The 4 phases determine finally a multiple graph representing the static properties of the system, as well as the dynamics are expressed by the graph execution rules, in particular:

An event happens as soon as all the pre-conditions are activated;

The event dis-activates the pre-conditions and activates the post-conditions.

He state of the system is continuously represented by all the active conditions and its evolution is traced by the items moving from an object to the other along paths to be fixed.

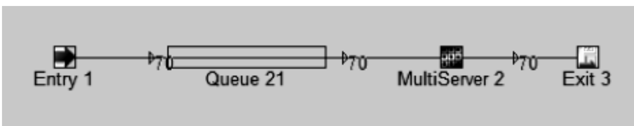

Figure 3: example of path in *Planimate®*.

For each class of items a sequence of steps, animated during the simulation, must be defined and will be used by all the items of that class.

The set of paths defined for a class is a flow and more items may run on this flow (figure 4).

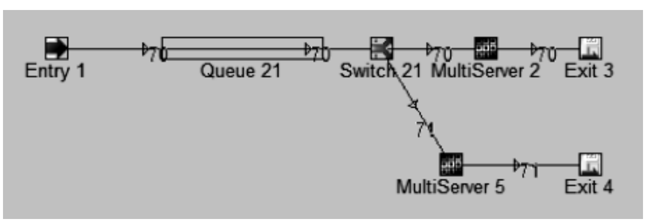

Figure 4: example of flow in *Planimate®*.

An interaction consists into an item meeting an object and passing through it.

The interaction is simple when the object keeps the item for a certain period (e.g. due to a delay in an action to be performed), after that the item is released and free to move again within the graph or to exit.

The interaction is complex when it includes the possibility to act on the item (e.g. loading/unloading), which can require a time depending upon the item itself or the location of the object within the graph.

The graphics phases include the choice of icons, colours, disposition of objects, items, paths, flows and other output representation images (tables, diagrams, etc.).

3. Model structure

The first step of model building up is the definition of two different items representing ships paths according to their typologies in order to take into account variety in dimensions, performances, operational rules, etc.

The starting point of the ships' paths is an *Entry* object, which will represent the anchorage, where the ships are allowed to wait for entering the port itself.

Sequentially the objects *Queue* and *Switch* represent the waiting process due to previous on-going movements and the port mouth itself, where the paths to the various quays are originated and, finally, some *Multi-server* objects, represent the quays themselves, capable to keep the ships according to the timetable.

All the elements above have been linked by *Multi-server* and *Change* elements dedicated to simulate the running time along the paths and the operational rules to be respected by the ships within the port area.

The entering and the exiting paths have been divided into sections characterised by a different speed of the ships, which is the key input parameter of the running time to be calculated by a *Multi-server.*

Other *Multi-server* objects reproduce the evolution phases and calculate the required time, variable by approached quay according to the rotation angle.

A the same time the *Change* objects store, read and write information concerning running time, stopping time, speeds and delays, which may be selected by obtaining once more different outputs.

The last output is the complete timetable, including expected and real time for arrival and departure at/from the anchorage and the quay and the elaboration of stopping times and delays suffered in the port.

The main differentiation in the model are due to the amount of operational rules, which is varied by ships' typology and by traffic density and reflected by a set of specific objects *Queue*, which allow the ships to enter when their specialized quay is free only.

A single queue would have created a delay to all ships waiting for the the release of a quay suited for the first waiting ship.

When all the quays are free the First In First Out (FIFO) rule is applied.

For the management of release and occupation of the path's sections has been setup a dedicated *Change* object, while a *Switch* stops the ships when the section ahead is not free.

The section have a minimum length of about 200 meters, minimum stopping time for the most part of ships' classes.

At the port mouth a *Switch* is dedicated to assign the entering ships to the various paths by highlighting the conflicts between ships.

While a common queue is setup to let the exiting ships wait for starting the manoeuvres according to the timetable order simulating the concerned process based on human decisions, difficult to be modelled.

4. Introduction to case study: The port of Messina

The port of Messina (figure 5) is a natural basin of about 820.000 m^2, fully rounded by quays, protected by a peninsula and with a 400 m wide mouth at NW.

Figure 5: Messina port general map (source: Port Master-plan).

The water depth is variable between 6,5 and 13 m along the quays and reaches 65 m in the middle of the basin.

The operated quays are 11, with a total length of about 1800 m, including the quays for private ferries at W, in San Francesco area.

The port is universally equipped and allows the load/unload of almost any typology of goods, as well as a relevant passenger traffic between Sicily and Italian Peninsula.

The most relevant traffic includes today:

- High frequency road and rail ferries services linking Sicily with Italian peninsula;
- Long distance Ro-Ro services;
- Lo-Lo services for solid bulk;
- High speed passenger services linking Sicily with Italian peninsula;
- Cruises.

By means of *MarineTraffic* portal it has been analysed the traffic for 8 days (1-8 May 2011) (figure 6) with the clear evidence of a relevantly lower traffic during weekends.

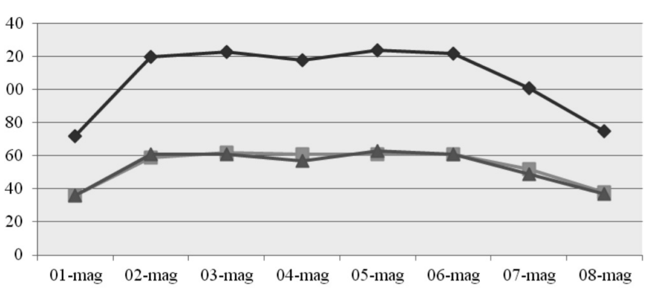

Figure 6: Movements in Messina port during the period 1-8 May 2011 (arrivals in light grey, departures in dark grey, total movements in black).

As a reference day it has been selected Thursday 5th May, where the maximum amount of 124 movements was recorded.

These movements are approximately distributed as follows:

- Short distance ferries: 55 %,
- Long distance Ro-Ro: 3%,
- High speed passenger services: 39%;
- Cruises: 3%,

and operated by the 16 ships fleet summarised in Table 1.

5. Model tuning: Present scenario simulation

The model has been developed taking into account the following operational constraints imposed by the Port Captain:

- Entering and exiting of cruise ships without simultaneous movements;
- Minimum separation of 200 m between entering and exiting ships;
- Paths from the evolution area to quay run by a single ship.

These conditions are imposed by *Change* objects specifically located and structured.

Planned and real timetables for ships' arrivals and departures are reported in tables, where are also highlighted the conflicts between the movements and the corresponding delays suffered by ships resulting from the simulation.

For the arrivals the most critical periods are in the early morning (4:30-6:50) and in the evening (18:50-19:10) with a total amount of 4 conflicts/day.

For the departures the situation is more critical with a total of 19 conflicts/day and the delays more distributed along the day with peaks in the morning (7:00-10:00) and in the evening (18:00-19:00).

The comparison with the real data acquired by *MarineTraffic* has shown minimum deviation.

Table 1: ships classification and movements.

Ship	Arrivals	Departures	Quay	Typology
Alijumbo Eolie	3	3	Rizzo 3	Hydrofoil
Carnival Magic	1	1	Vespri	Cruise
Cartour Beta	1	1	Norimberga Ovest	Ro-Ro
Cartour Delta	1	1	Norimberga Est	Ro-Ro
Enotria	3	4	Invasatura 1	Ferry
Fiammetta M	6	6	Rizzo 3	Hydrofoil
Iginia	5	5	Invasatura 2	Ferry
Isola di Vulcano	0	1	Rizzo 1	Hydrofoil
Msc Fantasia	1	1	Vespri	Cruise
Reggio	10	10	Invasatura 1	Ferry
Riace	5	4	Invasatura 1 and 4	Ferry
Scilla	2	2	Invasatura 2 and 4	Ferry
Selinunte jet	6	5	Rizzo 2	Hydrofoil
Snav Aldebaran	0	1	Rizzo 2	Hydrofoil
Tindari jet	8	9	Rizzo 2	Hydrofoil
Villa	9	9	Invasatura 2 and 4	Ferry

For the timetable optimisation the following maximum delays tolerances have been considered:
- Ferries and Ro-Ro ships: 10 minutes;
- Hydrofoils: 5 minutes;
- Cruise ships: 0 minutes.

This scenario has been considered the nearest to the real operational conditions monitored by *MarineTraffic*.
Additional constraints deriving from existing additional operational rules (particularly the full impossibility of simultaneous movements and the maximum allowed speed of 7 knots) are rarely considered in the daily operation.

6. Effects of traffic increase

After having evaluated by the application of a consolidated combinatorial method developed by the authors (Ricci and Marinacci, 2008, 2010; Malavasi and Ricci, 2005) the capacity in the present scenario, it has been modelled a traffic increase of about 20% (25 additional movements) distributed among all the ships typologies (4 for cruise ships, 4 for RO-RO ships, 10 for ferries and 7 for hydrofoils).
For each typology the staying time has been estimated on the basis of the present average values.
The additional movements generate a limited amount of new conflicts (incompatible movements) along the whole day (figure 7), though the conflicts result globally more equally distributed between arrivals and departures in comparison with the existing situation.

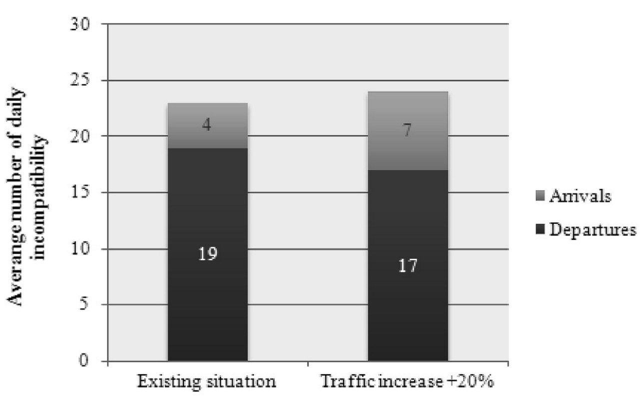

Figure 7: conflicts resulting from the simulation of reference day operation in Messina port.

The delays are acquired by 7 arriving ships (peak period: 19:00-20:00) and 17 departing ships (peak periods 8:00-9:00 e 19:00-21:00).

7. Scenario compatible with the fulfilment of all operational rules

The last analysed scenario derives by the research of a traffic amount compatible:
- With the fulfilment of all operational rules;
- With the thresholds of delays tolerance fixed in chapter 4.

This speculation has been developed by the iterative application of the combinatorial model, which allows the calculation of an Utilisation Degree, which is estimated compatible with an uncongested operation for a maximum value of 0.65.

In order to achieve such a value the total amount of movements should be reduced of about 35%, getting down from 124 to 81 in the reference day (figure 8).

The traffic decrease has been applied homogeneously across the different ships' classes by maintaining at least a couple of movements for each of them.

The major residual conflicts are anyway located in the morning (7:00-9:00) and evening (18:00-21:00) peak periods.

8. Conclusions

The original simulation model developed in the present research demonstrated its high potential to analyse different navigation regimes with a possible wide generalisation of its performances.

With reference to the case study the application of the combinatorial method does not show congestion in the present situation, mainly thanks to the partial application of the operational rules (e.g. simultaneous movements in different port areas have been considered liberalised).

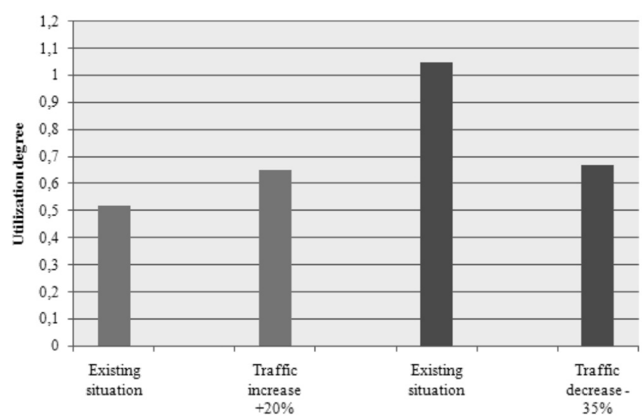

Figure 8: Utilization degree in various traffic scenario with partial (light grey) and full (dark grey) fulfilment of operational rules.

Nevertheless, a full application of these rules would generate a relevant congestion degree.

Moreover the simulation model allowed to estimate the effect of scenarios with a 20% traffic increase and a 35% traffic decrease and to compare the achieved results.

The progressive relaxation of the operational constraints and the traffic reduction allow reaching almost high regularity standard: maximum delays of 5 minutes for the hydrofoils and 10 minutes for the ferry-boats.

The best solution is to be selected on the basis of the right compromise between operational safety and commercial offer of transport services.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 45 - 54

ISSN: 1697-4840 www.jmr.unican.es

Road and Maritime Transport Environmental Performance: Short Sea Shipping Vs Road Transport

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ARTICLE INFO

Article history:
Received 08 June 2012;
in revised form 10 June 2012;
accepted 30 July 2012

Keywords:
Maritime Transport, Short Sea Shipping, Road Transport, Environmental performance

ABSTRACT

Motorways of the Sea (MoS) are part of the European transport strategy towards an efficient, safe and environmentally friendly transport system. This paper develops a model for short sea shipping (SSS) and road transport environmental performance comparison, estimating direct emissions and quantifying their impacts due to air pollutant and greenhouse (GHG) gas emissions. Ultimately a case study is presented to analyse and valuate each transport alternative to design an action plan determining intervening actions favouring the rebalance of the current transport system.

1. Introduction

Even though the actual economic crisis has partially released the European transport system from a sustained increase in transport demand, the current system suffers from capacity and flexibility problems. An acute imbalance in transport shares is the main reason of the inefficiencies of the current system. Almost half of the intraeuropean transport volumes are absorbed by road transport, followed by maritime transport and rail transport respectively as main means of transport (Eurostat Statistics, 2012).

In order to improve the current scenario, the European Union (EU) pursues a rebalancing of the transport system based on a modal shift from road to maritime means and to rail on a lesser extent (European Commission White paper, 2001). Maritime transport has always been pointed as an environmentally friendly mean of transport. However there is a common misconception in this appreciation, although maritime transport overall externalities are believed to be smaller than those of road (European Commission White Paper, 2001), maritime environmental performance with regards to airborne emissions (air pollutants and greenhouse gases) it is not that advantageous (CE Delft, 2008).

As for road, in maritime transportation the main air pollutants are those generated from internal combustion engines. These are CO, VOC, NOx and PM: derived from shoot and related to the engine technology being used; and on the other hand CO_2, SOx, heavy metals and further PM: sulphate-derived and hence dependant on fuel type. The contribution of waterborne transportation means to airborne pollutant emissions is significant for SO_2, NOx, CO_2, CO, VOCs and PM. In some cases, as for SO_2, the share of maritime airborne pollutant can be up to the 80% of total national emissions (EMEP /EEA, 2009).

This leads to the objective of this research that is to develop an environmental performance model for short sea shipping and road transport, estimating direct emissions and quantifying their impacts. Indirect emissions occurring upstream, from well to tank, are set aside (Schrooten, De Vlicgcr, Int Panis, Chiffi, Pastori, 2009).

Proved airborne emissions as the weak point of maritime transport, it will definitely contribute to a discussion on an EU level on future emission legislation and the potential impact of increased co-modality.

Following the introduction, this paper presents in detail explanations of the proposed methodology, a breakdown of the developed emission estimation and impact model,

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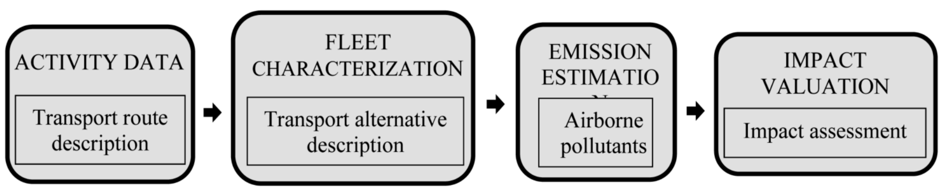
an scenario analysis made by the model considering current and future scenarios based in already in place and scheduled future regulations, a comparative results assessment were all scenario results for each of the considered transportation modes come together and finally the conclusion to summarize the paper and identify future research and improvement areas.

2. Methodology

The environmental performance model, which is able to conduct analyses for six different scenarios for maritime transport and a year by year scenario analysis for road transport, is broke down into the following four major sections:



Source: Own

Figure 1. Generalized model breakdown.

In the first section, activity data, parameters describing the transport leg to be carried out are introduced, e.g.: origin; destination; length of the route to be followed; turnaround time for ships; route breakdown with regards to urban, rural and highway legs for road transport; average speed in each of the considered road legs; truck load factor.

On the other hand in the second section and regarding maritime transport, the type of ship between those usually engaged in short sea shipping activities (container, RoRo, RoPax and ConRo) is selected. With regards to road transport a configuration of a road tractor coupled to a semi-trailer is used, with a maximum permissible weight between 40 to 50 tonnes. For emission estimation purposes the engine type needs to be selected (Euro I-V). In case this is unknown the fleet average option can be chosen, which depending on the presence of the different engine technologies (Euro I-V) in the European truck fleet, adjusts and calculates emission factors.

The third section leads us to an emission index for each of the alternatives, road or maritime transport, and scenarios selected. Once main emission drivers are known, introduced in sections 1 and 2, the tier 3 methodology described in the EMEP/EEA emission inventory guidebook 2009 is used for both alternatives (European Environment Agency, 2009). Emission factors are updated for each of the considered scenarios, following the methodology presented by Entec in its 2002, 2005 and 2007 emission studies. Emissions for NOx, SO_2, CO_2, VOCs and PM are calculated, as these are considered as the most significant airborne pollutants. In the case of road transport NH_3 emissions are also estimated.

Finally the fourth section, using main emission and impact drivers introduced in the first two sections of the model, assesses and quantifies the impact of the estimated emissions. With regards to emission impact assessment two are the projects used in the model as reference, the "Benefits Table Database: Estimates of the Marginal External Costs of Air Pollution in Europe (BETA)" project for air pollutant local impact (Holland and Watkiss, 2002) and "Clean Air For Europe Program (CAFE)"for rural or trans-boundary impact (European Commission, 2001).

Once airborne pollutant emissions have been estimated and their impact has been quantified for each of the considered alternatives and scenarios; a comparative analysis is carried out trying to identify the best of the alternatives, and the strengths and weaknesses of each.

Finally conclusions from the conducted research are drawn pointing out the relevant findings and identifying areas for further research and improvement of the model.

3. Model breakdown

In order to understand maritime and road transport environmental performance with regards to air pollution, it is important to identify and describe emission drivers giving rise to air pollutant emissions, as well as cost drivers determining the sensitivity of the emission area and hence the extent of the produced impact. It is in the activity data and fleet characterization sections where these factors are introduced.

3.1. Maritime transport model

The maritime transport model is built up based on ship types and average ship sizes derived from the analysis of the SSS ships calling at Spanish harbours during the second half of 2011. The user will have to introduce relevant parameters with regards to ship activity. Moreover for air pollutant emission estimation the tier 3 methodology, described in the *EMEP/EEA emission inventory guidebook 2009,* for navigation is used. Finally CAFE and BETA projects are used for the emission impact assessment.

3.2. Activity data

Parameters describing the route being considered as well as the ship type being used need to be selected by the model user in order to be able to perform consequent calculations with regards to the environmental performance of maritime transport in that particular route, ship type and sailing scenario.

Ship movement data

In this section the user describes the route being considered, establishing the origin and destination ports and hence considering the inhabitants around the ports; which indeed result's critical for the local impact assessment. At this first stage the sea area in which the sailing is carried out is also considered, as the area where the pollutants are emitted is relevant for the emissions rural impact. Finally the distance of the considered route is also introduced as this will determine the sailing time and hence the emissions at the cruising phase.

3.3. Fleet characterization

For the maritime alternative the fleet characterization is very important, as depending on the considered ship types and their main characteristics the emission values differ significantly. A bottom up approach has been conducted to provide the research with the consistency given by the consideration of different and detailed input variables. For this purpose the Lineport database (Fundación ValenciaPort, 2012), which records all ships engaged in SSS services competitive with road transport, is used. Once all these ships are identified, using the Fairplay Seaweb database all relevant factors that give rise to airborne emissions from ships are found and introduced into the model´s database.

Table 1. Average ships engaged in SSS services.

	Container ships	Ro-Ro ships	Ro-Pax ships	Con-Ro
Length Over All	178	184,1	197	168
Breadth	25	25	27	24
Draft	10	7	7	7
GT	20205	27486	34052	17330
DWT	24592	9393	6933	10537
ME type	MSD	MSD	MSD	MSD
ME power	16837	17775	29352	11427
EA type	MSD/HSD	MSD/HSD	MSD/HSD	MSD/HSD
EA power	3704	5333	10273	3428
Average service speed	20	21	24	18
Capacity (TEU-s)	1820	na	na	658
Capacity (line meters)	na	3196	2319	2131
Capacity (trailer or CEU-s)	na	213	155	142
Capacity per TEU(tm)	21,5	na	na	21,5
Capacity per trailer (tm)	na	24	24	24
Total capacity (tm)	24592	5114	3710	10537

Source: Own, based in Seaweb and Lineport database

3.4. Main engine type and power

Under the main engine (ME) tab, the engine type and its power are described. In the marine industry diesel engines are the predominant form of power for both main and auxiliary engines (Trozzi, 2010). Emissions are engine type dependent; therefore it is important to identify the engine types for the considered typical ship types in SSS services. Diesel engines are categorised into slow (up to 300 rpm), medium (300-900 rpm) and high (more than 900 rpm) speed diesel engines (SSD, MSD, HSD) depending on their rated speed.

As a result of the carried out SSS ships survey, the developed model considers MSD engines as predominant in the SSS fleet, and hence uses emission factors for this type of engines in the emission estimation phase.

Moreover airborne pollutant emissions are proportional to the fuel consumption or engine power; therefore besides the engine type, the average power for the different typical SSS ship types is also identified.

Auxiliary engine type and power

Auxiliary engines, used to provide power and services within the vessels, also contribute to ship emissions. Therefore these also need to be characterized.

The auxiliary engine (AE) tab is defined by the type, power and number of AEs installed on-board. However this information is not usually available for all ships, even in the most complete ship databases.

Following assumptions done in the Entec study for the Department for Environment, Food and Rural Affairs (DEFRA) of the British government (Entec, 2010) with regards to AE engine types, MSD and HSD engines are considered to be evenly distributed among the fleet. As the number and power of AEs are also unknown, the model also follows Entec 2010 assumptions with regards to the AE/ME power ratio per vessel type.

Service speed and engine load factor

The ship service speed and the engine load factors at each of the considered phases (sailing, manoeuvring and at berth) are also relevant for emission estimation. The service speed for each of the considered ship types is the average value obtained from the SSS fleet survey carried out. It is a significant parameter since it determines the time spent at sea.

On the other hand engine load factors are directly obtained from the study carried out by the Entec for the European Commission regarding emissions from ships associated with ship movements between ports in the European Community, in 2002 (Entec, 2002). As well as the service speed the engine load factor is also an important parameter since emissions are proportional to it.

Sailing, manoeuvring and at berth times

The tier 3 methodology estimates emissions for three well differentiated phases in the maritime transport leg: sailing, manoeuvring and at berth.

Therefore it is needed to know the time that the vessel undergoes in each of the phases as the emissions will be proportional to the time spent. In the case of the sailing phase this is calculated dividing the distance between ports by the service speed. On the other hand the manoeuvring and at berth times are taken either from existing projects (Entec 2002, 2010) or from surveys carried out to certain SSS lines in previous research studies (Usabiaga et al., 2011).

Capacity

The capacity tab together with the covered distance will enable the model to show results (emissions or impacts) in transport work units (per tonne kilometre). The capacity for each of the considered ship types is the result of the average value obtained from the ship survey carried out. Depending on the ship type the capacity is given in units such us twenty feet equivalent unit container (TEU) for container ships and line meters for RoRo and RoPax ships. However following the assumptions illustrated in Table 1, capacities in tonnes are calculated for the considered ship types.

3.5. Emission estimation

The methodology quoted as Tier 3 in the EMEP/EEA air pollutant emission inventory guidebook 2009 is used for the estimation of airborne emissions from ships. This methodology requires detailed ship movement data besides technical information on ships being considered.

Further focusing on the emissions estimation methodology uncovers that this work follows the procedure using data on installed main and auxiliary engine power, engine load factors and total time spent on each navigation phase. The Tier 3 method also employs specific emission factors depending on the engine type, fuel used and navigational phase.

$$Etrip = Esailing + Emanoeuvring + Eatberth \quad (1)$$

$$E_{trip,s,i} = \sum_{p}\left(T_p \sum_{e}(P_e x\, LF_e x\, EF_{e,i,s,m,p})\right) \quad (2)$$

Etrip	emissions per trip (tons)
EF	emissions factor (tons/kWh)
LF	engine load factor (%)
P	nominal engine power (kW)
T	time (hours)
e	engine (main, auxiliary)
i	pollutant ($PM_{2,5}$, SO_2, NOx, VOC, CO_2)
s	ship type (Container, RoRo,RoPax, ConRo)
m	fuel type (Bunker Fuel Oil, Marine Diesel Oil, Marine Gas Oil)
p	trip phase (sailing, manoeuvring, at berth)

Moreover emission factors are different in each of the considered scenarios: as fuel properties, regarding sulphur content, and engine technology, with regards to NOx emissions, vary from one to the other.

The emission factor update is made following the methodology and assumptions described in Entec 2010, study developed for the DEFRA.Five air pollutants emissions are estimated for maritime transport: NOx, VOCs, $PM_{2,5}$, SO_2 and $CO_{2.}$

4. Impact valuation

Once emissions for each of the navigation phases are known, the impact of these must be quantified. Two types of impacts are distinguished for marine airborne pollutants emissions: a site, seaport, specific local impact and a sea or country specific rural impact. Both local and rural impacts are quantified for manoeuvring and at berth phases. However in the sailing phase only rural impact is present.

The local impact is produced just after the pollutants, PM and SOx primarily, have been released. Local impact estimations need of great emission site detail; therefore, a bottom-up approach has been chosen for emissions' geographical characterization (Miola et al, 2010).On the other hand the rural impact is country or sea specific, and for impact quantification purposes that much information is not needed.

For local impact quantification purposes the methodology provided in "Benefits Table Database: Estimates of the Marginal External Costs of Air Pollution in Europe (BETA)" study is used.

The rural impact quantification in each of the navigation phases is an straight forward process as the Clean Air For Europe Program (CAFE) 2005, contains emissions costs for the considered airborne pollutants, and the EU27 countries and surrounding seas.

Moreover the BETA project provides a straightforward estimation of air pollution's overall external costs, putting together both urban and rural externalities. Therefore this is the methodology being used for manoeuvring and at berth phases.

This paper maintains the methodology given by BETA to list urban and rural external costs, but takes updated rural external costs provided by the CAFE program. The cost estimation done under the CAFE program considers human exposure to $PM_{2.5}$, human exposure to ozone, and exposure of crops to ozone. Although more impacts are known, there is not sufficient information to evaluate them with guarantee.

Moreover, in an attempt to achieve comprehensive results, the valuation done by the CAFE program considers four different sensitivity scenarios that lead to four different results for each geographical areas and scenarios being considered.

The resulting maritime environmental performance assessment model is composed of a top-down approach with regards to fleet characterization and a bottom-up approach regarding geographical characterization. In this manner, the model achieves a comprehensive assessment, taking into account the specifics of each emission point as well as the details of the emitting vessel type.

$$I_{trip,i} = \sum_{p}(Irt_{s,p,m,i} + Ilt_{port,s,p,m,i}) \quad (3)$$

$$Irt_{s,p,m,i} = E_{s,p,m,i}\ x\ Ir_{p,i} \quad (4)$$

$$Ilt_{port,s,p,m,i} = E_{port,s,p,m,i}\, x(Is_i\ xPf_{port}) \quad (5)$$

Itrip	impact per trip (€)
Irt	total rural impact per country or sea area (€/tm)
Ilt	total local impact per port (€/tm)
Ir	rural impact per country or sea area (€/tm)
Il	local impact per port (€/tm)
E	airborne pollutant emissions (tm)
Is	standard local impact for 100.000 inhabitants' city (€/tm)

Pf population factor for local impact projection purposes
i pollutant ($PM_{2,5}$, SO_2, NOx, VOC,)
s ship type (Container, RoRo, RoPax, ConRo)
m fuel type (Bunker Fuel Oil, Marine Diesel Oil, Marine Gas Oil)
p trip phase (sailing, manoeuvring, at berth)
port considered port

$$GW_{trip} = E_{s,p,m,CO_2} x\, Ig_{CO_2} \qquad (6)$$

GW global warming impact per trip (€)
E greenhouse gas (CO_2) emissions (tm)
Ig Global impact per CO_2 tonne emitted (€/tm)

5. Road transport model

The road transport model has been built up following the same method as for the maritime model. The methodologies used for airborne emissions estimation (EMEP/EEA tier 3) and their impact assessment (BETA and CAFE projects) are the same for both maritime and road models, therefore the differences between models lie in specific activity data and fleet characterization parameters basically.

6. Activity data

In this section the inputs are the parameters describing the considered road transport leg. These parameters are some of the drivers needed to calculate emissions and impact.

6.1.Truck movement data

Under this tab two are the main inputs: distance covered under each of the considered stages for road transport (urban, rural, highway) and the average people affected under the urban stage.

These inputs are significant and they will permit to estimate, together with the average speed, the amount of emissions in each of the stages and the impact produced on them.

6.2. Load factor

Road transport emissions are proportional to the fuel consumption, and as the latter increases together with the load factor (Madre et al., 2010), this parameter is important within the road transport model.

6.3. Route type

Under this tab roads vertical geometry is described, enabling us to distinguish between flat, average and highland profiles. Once again the fuel consumption is significantly affected by this parameter.

6.4. Average speed

To finish with the activity data section, the last relevant parameter when it comes to airborne emission estimation, is average speed. This parameter will be necessary to determine both the time spent and the quantity of emitted pollutants in each of the road leg's stages (urban, rural, highway).

7. Fleet characterization

Under this section the European truck fleet engaged in freight services is characterized. More in detail, the vehicle park engaged in international freight services and competing with SSS services. The typical truck class engaged in international haulage, the fleet's engine technology (Euro I-V) and capacity are reviewed (AEA, 2011).

7.1. Truck class

Under this tab the truck class considered by the model to simulate the road transport environmental performance is described. The European truck fleet is formed by rigid trucks, articulated trucks and road trains. For calculation purposes the articulated truck, i.e. a road tractor coupled to a semi-trailer, is considered representative of the truck fleet Eurostat statistics for 2008, apportion the 73,9% of the total intraeuropean road freight transport in tm.km to articulated trucks.

7.2. Engine type

Under this tab the engine technology of the considered truck fleet segment is characterized. For this purpose data given by the Eurostat database (2012), with regards to lorries and road tractors age categories, for the year 2008 is used. Once the truck fleet is characterised in percentages according to age categories, engine technologies present in the current fleet are extrapolated.

7.3. Capacity

The EMEP/EEA tier 3 emission estimation methodology, besides the truck class, needs the identification of truck capacity parameter in order to be able to estimate airborne pollutants emissions. In order to achieve a realistic fleet characterization a review of allowed gross vehicle weights in the EU27 is conducted, identifying articulated trucks with maximum gross weights between 40 to 50 tonnes as the most representative category among the ones considered by the tier 3 methodology (AEA, 2011).

8. Emission estimation

In the road transport model the emission estimation is also carried out according to the EMEP/EEA emission inventory guidebook 2009, although this time the tier 3 methodology described in the road chapter is followed.

Once all relevant emission drivers have been introduced into the model, the latter will calculate emission results for each of the considered road transport stages and air pollutants. In the road transport model NH_3 emissions are also estimated besides those already estimated for maritime transport.

SO_2 and CO_2 emissions are proportional to the fuel consumption; however emissions for the rest of the pollutants are calculated according to empirical formulas presented on the EMEP/EEA study for the considered truck class and capacity.

9. Impact valuation

The impact assessment for road transport is conducted just as for maritime transport following same projects and methodologies. Only a few different considerations are taking into account: in this case the local impact is only considered for the urban stage, taking into account the average inhabitants living in the crossed urban areas; on the other hand the rural impact will be quantified in the three of the road leg stages, depending on which are the crossed countries.

As for the maritime model, the impact quantification is achieved following BETA and CAFE projects. The BETA project is relevant for local impact quantification and for the joining of both rural and local impacts in the urban stage; and on the other hand, the CAFE project is relevant as it provides costs per emitted pollutant for each of the EU27 countries.

$$I_{trip,i} = \sum_{s} (Irt_{t,s,i} + Ilt_{urban,t,s,i}) \quad (7)$$

$$Irt_{t,s,i} = E_{t,s,i} x\, Ir_{s,i} \quad (8)$$

$$Ilt_{urban,t,s,i} = E_{urban,t,s,i} x\, (Is_i\, xPf_{urban}) \quad (9)$$

Itrip	impact per trip (€)
Irt	total rural impact for crossed countries (€/tm)
Ilt	total local impact for crossed urban areas (€/tm)
Ir	rural impact per country (€/tm)
Il	local impact per urban area (€/tm)
E	airborne pollutant emissions (tm)
Is	standard local impact for 100.000 inhabitants' city (€/tm)
Pf	population factor for local impact projection purposes
i	pollutant ($PM_{2,5}$, SO_2, NOx, VOC,NH_3)
t	truck type (Container, RoRo, RoPax, ConRo)
s	road leg stage (urban, rural, highway)
urban	crossed urban areas

$$GW_{trip} = E_{s,p,m,CO_2} x\, Ig_{CO_2} \quad (10)$$

GW	global warming impact per trip (€)
E	greenhouse gas (CO_2) emissions (tm)
Ig	Global impact per CO_2 tonne emitted (€/tm)

10. Scenario analysis

Once the general environmental performance model have been developed, scenarios simulating the real performance of both trucks and ships currently and in the future are built up. These scenarios will enable the model to conduct comparative performance analysis not only for current scenarios, but for future ones; providing the model with forecasting and in advance policy measure testing abilities.

This section describes each of the built up scenarios, which are based on environmental policies applicable to trades and transportation modes considered in the paper.

With regards to maritime airborne emissions the regulatory framework applicable to SSS is basically formed by the MARPOL 1973/1978 convention and the so-called EU sulphur directives (Directive 2005/33/EC, Directive 1999/32/EC, Directive 1993/12/EEC).

Baseline scenarios are based in the regulatory framework currently in place and future scenarios are built up taking into account the scheduled development of the regulatory framework which is increasingly stringent.

Table 2. Maritime regulatory framework together with key implementation years.

Construction year	NOx emissions limits
Pre 1990	None
1990-1999	Tier 0
2000-2010	Tier I
2011-2015	Tier II
Post 2016	Tier III

Area	Period	Max fuel sulphur content
Port	Post January 1, 2010	0,10 %
SECA-s	July 1, 2010-2015	1,00 %
	Post January 1, 2015	0,10 %
Global	Pre January 1, 2012	4,50 %
	January 1, 2012-2020	3,50 %
	Post January 1, 2020	0,50 %

Source: Own

Moreover depending on the concerned sea area and ship type some additional scenarios come up, as the regulatory framework varies for certain ship types and especially sensitive sea areas known as emission control areas (ECAs).

Finally NOx emission factors will also vary from current to future scenarios as the engine technology on-board varies together with the ship recycling cycle. Years 2000 (Tier I), 2011 (Tier II) and 2016 (Tier III) are considered key years in this respect, as correspond to new regulation implementing years with regards to NOx emissions (MARPOL, Annex VI, regulation 13). These new regulations forced ships to be built with new engine technologies further reducing NOx emissions. For the purpose of projecting forward 2012, a 25 year ship life cycle is assumed, which is equivalent to a 4% annual fleet renewal rate.

Scenarios considered in Maritime transport model are:

Baseline 2012. Among all the considered scenarios the less stringent and therefore the one chosen as baseline, is that representing the 2012 scenario; with no special characteristics with regards to sensitive areas or specially regulated ship types.

2012 SECA. The difference of this scenario comparing it with the baseline scenario is the sulphur emissions allowed during the sailing phase. The ship is supposed to sail in a SOxECA and therefore must comply with special regulations. Under this scenario the emission factors for the sailing phase are calculated considering the ship to use MDO with 1% sulphur content.

2012 Ro-Pax services. EU sulphur directives besides limiting the sulphur content of principal fuels used at ports, also limit this content for passenger ships during the sailing leg; and establish it in 1,5%.

2015 SECA. Comparing it with the already described 2012 scenario, the projection of the 2015 scenario is made based on the following assumptions. Regarding sulphur content derived emissions, for the sailing phase a maximum sulphur content of 0,1% in the marine fuel used is considered, considering as principal fuel MGO. On the other, when it comes to NOx emission factors the average fleet emission factors are calculated assuming a 4% yearly fleet renewal, representing a significant NOx emission reduction as old tier 0 engines are replaced by far more eco-friendly tier 2 engines.

2016 SECA + NECA. The unique and main change for this scenario comparing in it with the previous one, is given by the condition of sailing in a NOx ECA, which means that all ships engines must comply with Tier 3 emission standards.

Baseline 2020. Finally under the 2020 scenario the change in the global sulphur cap scheduled by the MARPOL convention is the main feature when comparing it with the rest of the scenarios. This cap is planned to be placed at a maximum sulphur content of 0,5%.The model simulates it using 0,5% sulphur MDO during the sailing phase.

Same scenarios are considered for road transport for comparison purposes. However these are only characterized by the engine technology in place within the fleet, as fuel composition is similar in all countries and it is not the driving factor for emission factor compliance.

11. Results comparison and discussion

In this section the Barcelona – Civitavecchia case study is presented. Both road´s and Maritime's environmental performances have been calculated applying the introduced model.The following table shows the considered variables:

Parameters describing the route being considered as well as the ship and truck type being used need to be selected by the model user in order to be able to perform consequent calculations with regards to the environmental performance of maritime and road transport. Table 4 and Table 5 show data input sheets of ship and truck activity and fleet characterization.

Table 3. Case study main parameters.

Route	Barcelona (Spain)-Civitavecchia (Italy)
Maritime Distance (nm)	450 (833 km)
Road Distance (km)	1282
Ship Types	All (Containership, RoRo, RoPax and ConRo)
Engine type ship	Fleet average
Scenario	Baseline (2012), Baseline (Ro-Pax) and Baseline (2020)
Sensitivity scenario	1
Urban (Road)	Average speed 40 km/h
Highway (Road)	Average speed 80 km/h
Load factor	100%
Route type	Medium
Engine type truck	Fleet average

Source: Own

Table 4. Ship activity and fleet characterization data input sheet.

Ship type	RoRo
Engine type	Fleet average
Route distance (nm)	450
Scenario	Baseline (2012)
Sea	Mediterranean sea
Port of origin	Barcelona
Country	Spain
Inhabitants in the port city	1.600.000
Port of destination	Civitavecchia
Country	Italy
Inhabitants in the port city	50.000

Source: Own

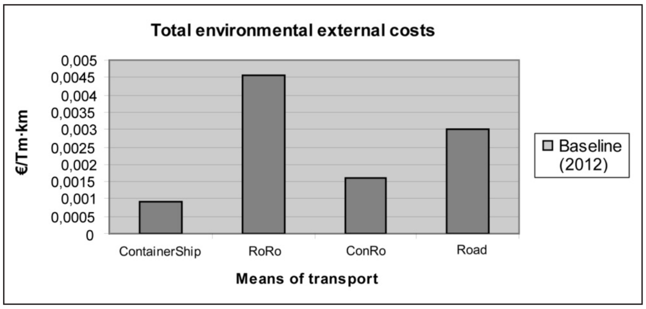
Table 5. Truck activity and fleet characterization data input sheet.

Urban			**Highway**		
Route type (Gradient):	Medium		Route type (Gradient):	Medium	
Load factor:	100%		Load factor:	100%	
Engine type:	Fleet average		Engine type:	Fleet average	
Average Speed (km/h):	40		Average Speed:	80	
Length (km):	100		Length:	1200	
Average inhabitants	1000000		Country1:	Spain	10%
Country1:	Spain	60%	Country2:	France	30%
Country2:	Italy	40%	Country3:	Italy	60%

Source: Own

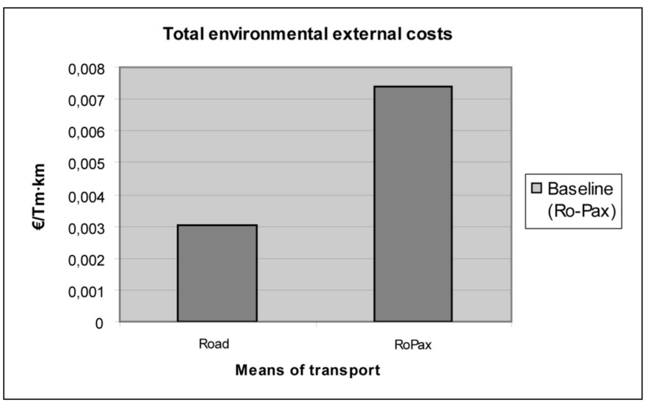
Four ship types (Containership, RoRo, RoPax and ConRo) and three scenarios (Baseline (2012), Baseline (Ro-Pax) and Baseline (2020)) have been considered for maritime transport. This enables to conduct comparative analysis between current and future scenarios. Thus permitting to anticipate to prospective problems and try to overcome them before they arise. Moreover, having considered four different ship types, enables the model to rank them with regards to their environmentally friendly performance and to compare them in an individual basis against road transport.

Figure 2. Total environmental external costs in €/Tm·km of ship types and road transport considering current scenario Baseline (2012).



Source: Own

Figure 3. Total environmental external costs in €/Tm·km of RoPax ship and Road transport considering current scenario Baseline (RoPax).

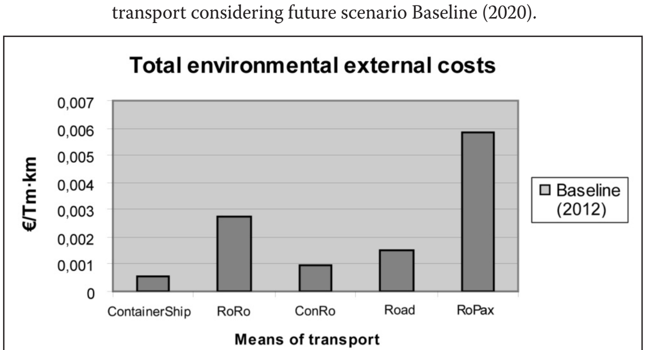


Source: Own

Results in figures 2 and 3 show the current scenario considering two different scenarios for maritime transport (Baseline (2012) and Baseline (RoPax)). This comparative analysis identifies that the best alternative considering total environmental external costs is the container ship and the ConRo ship. RoRo and RoPax ships present higher values than road transport (0.0029 €/Tm·km), 0.0046 €/Tm·km and 0.0073 €/Tm·km respectively.

Figure 4 shows the environmental performance of each of the considered alternatives in 2020. Obtained results confirm that container and ConRo ships continue presenting a more environmentally friendly performance than road transport (0.0015 €/Tm·km) regarding air pollution and global warming. However, RoRo and Ro-Pax ships continue with worse results, 0.0027€/Tm·km and 0.0058 €/Tm·km respectively.

Figure 4. Total environmental external costs in €/Tm·km of mode of transport considering future scenario Baseline (2020).



Source: Own

11.1. Conclusions and areas for further research

Once the model has been developed the Barcelona-Civitavecchia route is taken as case study for a practical application. Thus emissions and derived impacts for each of the transport alternatives and applicable scenarios at this route are estimated. Finally a comparative analysis is carried out trying to identify the best actual and future alternatives.

Although maritime transport is known as the most environmentally friendly mode of transport; it is proved that this is not true in all cases. Results, which emerge from the developed model, prove airborne emissions to be a weak point of maritime transport: especially for RoRo and RoPax ships. The necessity to further improve the maritime environmental performance with regards to air pollution and GHG emissions is demonstrated. Therefore ship owners, port authorities and policymakers bearing in mind these results should consider new greening formulas for the sector.

Today already are concerns about the capability of the sector to comply with already approved, scheduled and increasingly tighter regulations. Hence it is not feasible to try to further improve the environmental performance with an even more stringent regulatory framework. However the success potential of introducing into the market newly developed and greener technologies seems higher.

RoRo and RoPax ships weak performance is related to inherent characteristics such as smaller cargo capacity, higher engine power to ship size ratio and higher service speed; resulting these characteristics in higher consumption and hence higher emission factors per tonne of cargo.

Table 6. Environmental performance summary table.

	Road Transpor (€/tm.km)	Maritime transport			
		Container (€/tm.km)	ConRo (€/tm.km)	RoRo (€/tm.km)	RoPax (€/tm.km)
Baseline 2012	0.0029	0.0008	0.0015	0.0016	—
RoPax 2012	0.0029	—	—	—	0.0073
Baseline 2020	0.0015	0.00052	0.0009	0.0027	0.0058

Source: Own

Looking into 2020 results and comparing them with those obtained for 2012, it is easy to detect that the greening process of road transport takes place faster than that of maritime transport. This is due to a shorter fleet recycling period of road transport, 11 years on average (AEA 2011) against 25 years for maritime transport, which enables the faster introduction of new and greener technologies into the fleet.

The model presented in this paper is the first version and the base for further developments. Together with the first implementations of the model a few improvement areas have been identified, which have resulted in further research areas. The purpose of improving the model is to reproduce transport chains more comprehensively and hence more realistically. The introduction of logistical parameters such as different intermodal transport units (ITU), load factor and utilisation factor will with no doubt improve the model. Moreover a bigger ship database incorporating complete data of years 2010 and 2011 eleven will permit to further characterise the fleet engaged in SSS services, enabling to split each ship type group by size and engine type. The third and final detected possible improvement is to consider pre and post haulage, which will enable to incorporate multimodal transport chains into the model.

Finally and with regards to the strengths of the model, say that this model's strengths lie on the broad array of air pollutants considered together with the good geographical characterization for emission site sensitiveness and hence produced impact assessment. Moreover the ability of assessing both local and rural impacts cannot be contemned.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 55 - 60

ISSN: 1697-4840 www.jmr.unican.es

Methodology for the Design of Residues Reception Facilities of Fishing Ports and Marinas

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ARTICLE INFO

Article history:
Received 09 June 2012;
in revised form 11 June 2012;
accepted 30 July 2012

Keywords:
Fishing Ports, Marinas, Tourism, Residues, Environment.

ABSTRACT

The fishing ports, marinas and mixed, have to develop their activity respecting and caring for the environment. Each port must respect their environment and this environment must be sustainable with either fishing port activity, sports or both. Concern about the consequences of environmental degradation and the problems it creates for people and goods, has an effect on society alarmist. At present, no activity can develop without respecting the environment. The ports need to reduce pollution forms if they want to limit their impact on the environment.

The increase in the standard of living and the increasing availability for free time the population increases in water sports activities sports. These activities enhance the expansion of tourism, quality tourism. The environmental quality becomes a key to the success of quality tourism and other activities developed in ports.

At the present time, we are witnessing empowerment, for sport, for certain ports or portion thereof and the creation of new ports. Environmental management is one of the success factors for a port facility. A marina successful or need to have an environment environmental quality. The marinas of a locality, region, if successful as a whole, will have a multiplier effect on the local and regional economy.

This Article sets methodological basis for the design of a waste reception facility for fishing ports and marinas or for those ports that are developed both. First, perform a conceptual approach of the basic concepts, followed by a methodology to define the layout of the facility. Third base is defined to control the environment and how to improve the environmental quality of the ports. The identification of the residues produced in port activities help us to estimate the type of containerization for residues. Finally, we establish design guidelines for the installation and we obtain some conclusions.

1. Basic concepts

When accessing technical and scientific texts environmental, we detect that many concepts are defined differently. We discovered that many words apply to different situations. Various performances (consequences, phenomena) in the environmental field differently defined. An example is, the different identity that can be taken the same word "contamination" (Lovett and Ockwell, 2009).

For this reason, it is necessary to specify the sense that different expressions are used, while specifying the concepts.

Environmental change can be defined as any change in the environment, either by entirely natural causes or by human actions. Also be attributed to the combination of other or both (Alonso and García, 2008). For example, the modifications caused by an earthquake, for the construction of a breakwater, or the landfill of any toxic substances, are all environmental changes, regardless of the origin, its magnitude or duration.

The environmental effect is defined as the changes caused by human actions, (whether intended or not). This effect may have been directly or might have been an unintended effect. For example, the changes resulting from the filling of a dock (whose effects can be positive or negative) environmental effects are considered. The disappearance of a species in one place, as a result of contamination by a deliberate disposal for uncontrolled release or sudden stroke, it would be an environmental effect. Neither the padding nor the environmental effect would disappear if they are due to natural causes.

The environmental effects are produced or not. Can be measured, litters of fuel spilled meters of coastline affected, number of dead fish. The identification, analysis and quantification of environmental effects can be done in an objective manner and the results achieved will be similar, regardless of who or who perform them.

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The environmental impact is defined as an environmental effect or a set of environmental effects of an action on which has issued a value judgment (George and Kirkpatrick, 2007). It comes to valued environmental effects, which are assigned a rating. This assessment is: "Very little significant, little significant, significant, very significant." These effects are always produced by human activity (Nogueira, 2009).

It is important to differentiate between effects and environmental impacts for demarcating responsibilities. The consequences of human actions cannot only be seen or assessed from different perspectives, but also can produce very different effects. These effects are estimation and valuation, are generally questionable on the environment (Lovett and Ockwell, 2009). One must understand the concept broadly, it not only highlights the effects that occur on the "natural" but also any other that may impact through the media and affect humans. For this reason we have to consider:

1st. Ecological impacts - environmental: Those that result from changes in the "natural" systems. Its incidence is important in the functioning of ecosystems.

2nd. Social impacts: They directly affect humans. Individually or collectively.

The concept of "environmental damage" was defined by Law of Environmental Responsibility 26/2007, (October 23th, 2007) and published in BOE 255 of October 24th, 2007. Identifies the damage caused by human activities on the environment. Defines the basis for establishing penalties and compensation, either by reason of fortuitous accidents, malpractice, negligence or malicious actions. The application requires a methodological basis considering to carry assess the damage and to provide a basis for determining claims and penalties. No difference if the property is public or private (Bretón et al., 2009).

Users expect that society and the environment of fishing ports and marinas (Couce, 2002), is not necessarily different from what society demands of the places where facilities are located recreational (Bau, Lanza, and Usai, 2008), value spaces for leisure and other venues (Borderías and Martín, 2006). This includes the beaches, parks and walking areas. Everything about the ports. Ports must provide conditions similar to those of a mall (Salvador, 2008). The environment of the ports must be of a quality equal to that of protected areas for their natural values (Madariaga, 2012). It is not enough to keep pollution and other forms of environmental degradation under control, it is necessary to correct them.

2. Methodology to determine the design

The fishing ports and marinas are based on having a quality environment. For this reason, their attractiveness and competitiveness depend on improving environmental quality. The port address must always make responsible environmental management. Each port has to be responsible for environmental management and their environments (Borderías and Martin, 2006). These environments are:

Unique: Every environment is different from others. The geological substratum, its geomorphological features, vegetation and wildlife that live in this place, human occupation and surrounding land uses are different in each case.

Complex: These systems are composed of many elements, minerals, plants, animals, humans, etc. Interrelated and subject to multiple processes.

Open: Even where it seems that the boundaries are better defined (waterfront, an estuary) there is a continuous transport of materials and energy.

Dynamic: They are subject to change due to natural causes and also usually intense human pressure in port areas.

We must consider potentially impacting activities from operations in fishing ports and marinas, as well as all actions taken in their environments. These disturbing activities are:

Operational Pollution: The pollution produced in ports for the inlet and outlet of vessels, for the movement of vehicles on the docks, for the port machine operations, for the tasks of provisioning and freight. These operations, on the one hand, carbon oxides, sulphur oxides and solid particulates and aerosols, among these unburned hydrocarbons and otherwise generate noise, in the case of noise or agitation in water. From August 2013 comes into force legislation, which defines the noise level in the maritime sector.

Dumping of waste liquids and wastewater (Martínez, Esparza, 2010): This residues are the more or less watery liquid from the toilet of vessels, engine cleaning, washing tanks or tanks, ballast water and cooling water, etc. (Zambonino, 1998). Ports must have facilities for receiving waste from vessels (EEC Directive 2000/59/EC of 27 November on waste reception facilities in ports).

Maintenance and repair of boats: The activity itself cleaning the boats is done with water, detergents, degreasers, and solvents. The painted and varnished surfaces, installation, repair or replacement of gear, propulsion systems and navigation, etc. produces waste and generates visual impacts on the port.

Ship dismantling and recycling of materials: In many cases, boardwalks become the last of these boats beached creating local pollution and visual impacts for long. Failure to take appropriate action produces substantial environmental costs, (Martínez and Martínez, 2009).

Dredging: The dredging works are for the maintenance the good condition of the funds of the docks (Buruaem et al., 2012), the preservation of the depth and extent of the access channel. They work to promote navigation unavoidable in the dock.

Wastewater and urban runoff: Wastewater is one of the most common sources of pollution in ports. These waters not only from urban discharges, but also on the same craft. In some cases it may also be thermal pollution concentration in marine engines berthing areas of the ports. Considerable and repetitive discharges lead to permanent effects of gravity, with permanent conditions to living beings, creating serious changes of natural systems (Hernández, 2001). This results in loss of habitat, species removal, obstruction of migration, etc. We must also consider the floating and suspended solids that are deposited on the edges of the docks.

An important data to consider are urban water runoff, made up mostly of rainwater from roads (Hernández, 2001). If discharged without mixing other, often have an acceptable quality, but may also carry substantial amounts of other pollutants.

Industrial effluents: For each port must determine the type of industries that are in the area surrounding the port. You have to study the processes of these industries and know if they make capturing and discharges to water.

Farmers Spills: Discharges from livestock farms have a biological oxygen demand much higher than those of urban wastewater, since they are much richer in organic matter than these. Wastewaters from livestock facilities are not free of pollutants other organic matter residues usually have medical or pharmacological, mineral oils and diesel. Must study these processes and determine if the farms make discharges into water.

Contributions via atmospheric pollutants: The loading and unloading activities in commercial ports such as handling of coal, metallic minerals and fertilizers, cement or other building materials, grain and flour, fertilizers or other junk and goods being shipping usually generates a significant amount of solid particles (Buruaem et al., 2012).

In marinas must be taken into mind that the loading and unloading commercial ports affect the cleanliness and maintenance of ships and those of their gear (sails).

Other residues: Solid residues are made by packaging a variety of forms (paper, metals, textiles, plastics, glass, wood), residues of cleaning products, ropes, tires, etc., As well as remains of fishing and food.

3. Environmental control and improvement

The management of fishing ports and marinas or mixed, cannot ignore the environmental (Zambonino, 1998; Madariaga, 2012). The environmental aspects are crucial to enhance the quality of ports and their environment. It is necessary to have an understanding of the environmental features of the environment, "natural" and "human" as well as the activities that take place in the port facilities and around (Alonso and García, 2008).

A useful procedure to have the environmental reality of a port is to establish an environmental monitoring system based on a system of indicators (TRAMA, 2006). A system of this type, well designed and correctly implemented is capable of effective monitoring of environmental quality in a number of ports and in each of them. These systems can rapidly detect any malfunctioning of greater importance and make it easier to port management, both to be standardized for all of them, as to reduce the number of controls, data collections and analyses necessary. It is a procedure that can make communication between specialists, managers and port address are good and fast. We propose to follow some guidelines, which are expressed below (Madariaga, 2012):

— 1st. Act in those fields in which they can have real competence. For example, put small means to prevent fuel spills.
— 2nd. Avoid or limit the ways most serious environmental degradation. For example, to solve the disposal of liquid waste from bilges.
— 3rd. Propose actions whose implementation entail a reasonable installation cost and require operating and maintenance costs in subsequent years assumable (Bau, Lanza, and Usai, 2008). Perform activities whose continuity is not assured is a way of wasting resources (Couce, 2002).
— 4th. Evaluate the actions that involve a reasonable investment (Bau, Lanza and Usai, 2008). The comparison between the cost of activities and the environmental benefits are to be tested by the managers of the ports (López, 2008).

4. Characterization of residues and environmental equipment need

The development, implementation and improvement of a environmental management system for fishing ports and marinas necessarily involve the study of the current situation, so that the data collected to detect needs and wants (Madariaga, 2012). For each port must detail the environmental control equipment available today, as well as the waste generated in the port activities. The general characteristics of a port can be summarized as shown in Table 1. We need to establish the characteristics of commercial fishing vessels and their crews quantified as shown in Table 2. You also need to know the characteristics of leisure sailing craft, their quantification and the number of users, we can evaluate as shown in Table 3. In both cases, commercial fishing and recreational boating vessels differ by their length. This differentiation is the same as provided for the design of berthing areas and rental costs.

Table 1: Summary of the characteristics of the port.

Port area:	Area.
Docks:	Area.
Operative length of docks:	Length.
Fish market surface and offices:	Area.
Ice Maker (storage):	Tons.
Cradles:	Number and tons.
Cranes:	Number and tons.
Cranes jib:	Number and tons.
Balances:	Number and tons.
Storage	Number and tons.

Source: Author

Table 2: Type of commercial fishing boats.

Length.	Commercial fishing boats (Total). Total crew.
> 30 meters.	Number of boats, crew number.
25-30 meters.	Number of boats, crew number.
20-25 meters.	Number of boats, crew number.
15-20 meters.	Number of boats, crew number.
10-15 meters.	Number of boats, crew number.
< 10 meters.	Number of boats, crew number.

Source: Author

Table 3: Boats of nautical sports.

Length.	Craft of nautical sports (Total). Total of users.
> 12 meters.	Number of craft, crew number.
10-12 meters.	Number of craft, crew number.
8-10 meters.	Number of craft, crew number.
6-8 meters.	Number of craft, crew number.
< 6 meters.	Number of craft, crew number.

Source: Author

The crew quantify helps us to define the quantity of residues generated. This generation is not the same on the weekends than during week, as it is the same generation that occurs in the summer than in the winter. For this reason, the location and capacity of the container will ensure the maximum capacity to collect waste that can be generated both by boats and by its users. This measure will prevent our ability to receive waste is insufficient. For the calculation of the waste generated by vessels and its users, we can build on the IMO document MEPC[1] 41/5/1 that commercial fishing vessels are summarized in Table 4 and Table 5. Similarly, as directed by the IMO document MEPC 41/5/1, we can summarize waste generation leisure sailing craft, which showed in Table 6.

Table 4: Generation of waste in commercial fishing boats.

Tonnage	20 - 70 Tons.
Crew:	2 - 15 Crew.
In port:	Variable.
Food residues:	1 - 2 Kg./ person/day
Sanitary and bilge water:	150-200 Liters/person/day
Operational residues	
Scrap metal:	Below 0.5 Tons./year.
Remains of fishing nets:	1-2 Fishing nets/year (max.)

Source: OMI, MEPC 41/5/1

Table 5: Percentage of residues generated by commercial fishing boats.

Food	Packaging	Plastics	Aluminum	Metal/Glass
38%	17%	16%	16%	13%

Source: OMI, MEPC 41/5/1

[1] Presented by "WWF" (World Wide Fund for Nature) to the International Maritime Organization (IMO).

Table 6: Residues generation from a craft nautical sports.

Size:	4-60 Ton.
Crew:	2-15 Crew.
In port:	70-85 % of the year
Food residues:	0,5-3 Kg./ person/day
Sanitary and bilge water:	50-120 Liters/person/day
Operational residues	
Residues of maintenance:	100 Kg./craft/year

Source: OMI, MEPC 41/5/1

In the identification of the residues generated in the fishing ports and marinas, we need to define the activities that are performed in the same regardless of its frequency. We will build on the activities we have considered shocking. The main activities developed in the fishing ports and marinas are shown in Table 7.

Table 7: Summary of port activities.

Port Activities
Download and selling fish.
Cleaning of facilities and methods used in sales transactions and unloading of fish.
Cleaning of decks and hulls.
Repair, maintenance and painting of craft.
Fuel supply.
Manufacture of ice.
Work of maintenance and repair of fishing gear and nets.
Logistics in passenger traffic (tourist movements).
Work maintenance and repair of craft, their engines and rigging (sails).
Activities of restaurants and services

Source: Authors

Once we have identified the activities, must be identified the waste generated in such activities. Each waste will relate to the applicable law either as hazardous or non-hazardous waste. Each residue will interact with international identification, while it will have to consider the law applicable to their proper management. This legislation is European, national, regional and sometimes local levels. Similarly, each residue was relate to the relevant international identification for transport as well as legislation to be enforced. In Table 8 we characterize the waste generated in port activities.

5. Design guidelines

For the design of a waste reception facility will be held the following:

— Types of waste generated in the port.
— Capacity and quantity of environmental equipment (containers) necessary depending on port users and the number of craft.

Table 8: Principal residues that are generated in port activities.

Residues that are generated in port activities	
Oil of marine engines.	Metallic packaging contaminated with oil.
Residues of marine engines.	Plastic packaging contaminated with oil.
Nautical flares.	Absorbents contaminated with oil.
Bulbs	Gloves contaminated with paint and/or varnishes.
Filters for marine engines.	Absorbents contaminated with paint and/or varnishes.
Cloths contaminated with oil.	Cloths contaminated with paint and / or varnishes.
Gloves contaminated with oil.	Cylindrical cells.
Fluorescent tubes.	Aerosols/sprays.
Batteries.	Solvents.
Button cells.	Paintings.
Metal Packaging contaminated with paint and/or varnishes.	
Plastic Packaging contaminated with paint and/or varnishes.	

Source: Authors

— Minimize the visual impacts of everything that pretend to be placed on the port.
— Comply with all applicable laws at the port to manage hazardous residues and non-hazardous.
— Define the ideal area to locate the main facility to receive residues.
— Define locate areas suitable for small groups of containerization.
— The reception of bilge water (hydrocarbon-polluted water) and sanitary water (WC) can be installed in areas of fuel supply (gas station port). This minimizes the visual impact.

The waste reception facility and reinforcement, signage and advertising will need in the port. To facilitate this action, users have to know the residues that are supported in the installation, quantities, schedules and deposit areas (López, 2008). Each container will have to carry identification of the residue that receives according to current regulations both for temporarily storing waste as for transport.

6. Conclusions

1ST. The economic and tourism success of a port depends on the good management of the environmental quality of the port and their environment.

2nd. Each port is different, it is essential to know all the characteristics of the social and ecological environment. The experience gained in a port, can provide guidance for the design and environmental management in others, but cannot be extrapolated without further.

3rd. The construction of residues reception facilities in ports has significant economic multiplier effects on domestic production of a region and directly and indirectly affects many branches of economic activity.

4th. In the placement of the residues reception elements in ports will tend to minimize the environmental and visual impact.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 61 - 66

ISSN: 1697-4840 www.jmr.unican.es

Automatic Control to Improve the Seaworthiness Conditions in Inland Navigation Networks

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ARTICLE INFO

Article history:
Received 10 June 2012;
in revised form 12 June 2012;
accepted 30 July 2012

Keywords:
Inland Navigation Networks, Seaworthiness, Automatic Control, Locks Operation.

ABSTRACT

This paper focuses on the Normal Navigation Level (NNL) control of a hydraulic channel that is located in the northwest of France and belongs to the Europe Inland Navigation Network. This system is a large scale system with several inputs and outputs that nowadays is operated manually by the lockkeepers with the aid of local controllers that try to maintain the level of the channel as close as possible to the NNL in order to fulfil the seaworthiness requirements. Last years, the channel has been equipped with electronic sensors in order to have better knowledge of its behaviour, provide online its state to the lockkeepers and improve its management. In this work, an automatic control based on a Model Predictive Controller (MPC) is proposed. The MPC controller is based on a model of the system and, with the available data, provides automatically the suitable control inputs (flows) in order to maintain the level the channel despite the locks operation that produces wave phenomena and other unknown inputs along the channel. A numerical simulator of the system based on the Saint-Venant Equations and calibrated with real data has been developed in order to verify the effectiveness of the proposed automatic controller.

1. Introduction

The use of Inland Navigation Networks as an alternative to land transport provides economic and environmental benefits (Mihic et al 2011, Mallidis et al 2012). Europe's network of navigable rivers and canals offers access to the continent's urban and industrial centres, allowing for the more efficient, quieter, and safer transport of goods (Brand et al 2012). In this context, navigation channel networks in the north of Europe will have to be able to accommodate large broad gauge boats in few years. Operation researches (Dekker et al. 2011), or simulation tools (Almaz and Altiok 2012), based on Information and Communication Technology (ICT), are proposed in the literature in order to improve the inland navigation. In addition, managers have to improve the seaworthiness requirements of their navigation channels, in particular on the water level which has to be closer to the Normal Navigation Level (NNL) than until present. These strong constraints impose the development and tuning of new control algorithms.

On the other hand, in the last years the use of Information and Communication Technology has dramatically been increased. This increased use allows supporting traffic management in inland navigation and providing inland shipping with a competitive edge over road transport. This information can be used for automatic control purposes that provide more accuracy and reliability than manual control.

By focalizing on the navigation networks of the north of France, in particular on the Cuinchy-Fontinettes Reach (CFR), this paper presents the specific characteristics of this system and the control problems inherent in its operation, particularly the phenomena of waves. The CFR is a MIMO (Multi Input-Multi Output) non-linear dynamic system with variable delays that is equipped with gates, locks and sensors.

The phenomena of waves occur when the locks are operated. They cause waves of more than 10 cm along the channel which interferes with navigation. Thus, one of the management objectives of the CFR consists in reducing the amplitude of the wave by means of automatic control techniques.

Firstly, the simulation model of the considered reach, which is based on the Saint-Venant equations, is proposed and calibrated using real measured data. Then, a control

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algorithm is proposed in order to compensate or to reduce the waves. The control algorithm is tuned and evaluated by considering scenarios of locks operation in simulation using the developed numerical simulator. The preliminary results show the effectiveness of the proposed control technique and the interest in improving it to satisfy the seaworthiness requirements.

2. Description of the system

In the north-west of Europe, a large network of inland waterways is located and used to accommodate large broad gauge boats (*see* Figure 1). The part of this network located in France is managed by the French public institution VNF (Voies Navigables de France) whose role is to operate and develop this network, in order to improve the efficiency of the navigation and resource water management. The inland waterways which are managed by VNF consist of 6,200 km of canals and rivers.

Pas-de-Calais manages more than one hundred of navigation locks, and can control the dispatching of water volume between nearly ten catchment areas. One of these navigation channels, the Cuinchy-Fontinettes Reach (CFR), has a crucial importance due to its localization, *i.e.* between two major catchment areas of this region, and its size, *i.e.* more than *40 km* long. The main use of the CFR is for navigation purposes. However, it can be used to stock water volumes during wet periods in order to avoid or to limit floods on the two catchment areas, and during dry period to supply water to these two catchment areas.

By focalizing on this network, in particular in the north region of France, VNF Nord The CFR is located between the upstream lock of Cuinchy at the East of the town Bethune and, at the Southwest of the town Saint-Omer, the downstream lock of Fontinettes (*see* Figure 2). The first part of the channel, *i.e. 28.7 km* from Cuinchy to Aire-sur-la-Lys, is called "canal d'Aire" and was built in 1820. The second part of the channel, *i.e. 13.6 km* from Aire-sur-la-Lys to Saint-Omer, is called "canal de Neuffossé" and was built in the eleventh century. The channel is entirely artificial and has no significant slope. Considering the navigation flow, the water runs off from Cuinchy to Fontinettes.

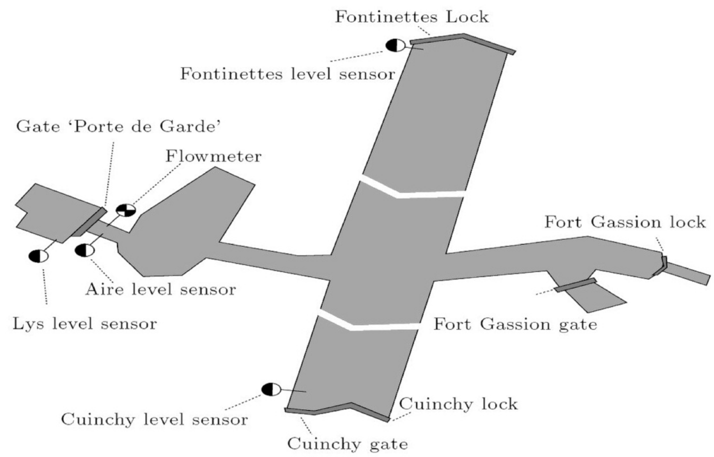

Figure 2: Scheme of the Cuinchy-Fontinettes navigation channel.

By considering navigation constraints, the water level of the CFR has to be maintained at the NNL = *19.52 m* (NNL = Normal Navigation Level). An operating range around the NNL is defined by the Highest Navigation Level (HNL) and the Lowest Navigation Level (LNL). If the water level of the CFR is lower than the LNL or higher than the HNL, the navigation is stopped. The water level of the CFR has to be maintained in the operating range [LNL, HNL], despite perturbations and exceptional situations (drought or flood). These perturbations are due to more than *300* unknown inputs along the reach and the locks operations. The main perturbation is Fontinettes lock operation which produces a wave whose amplitude is more than *10 cm* and travels at a speed of about 20 km/h along the channel which interferes with navigation. When the wave arrives to Cuinchy, it rebounds and come back with and amplitude of *8 cm*. The wave remains in the channel with successive rebounds until steady state, approximately *15* hours, decreasing 1cm the level of the channel. A Fontinettes lock operation is equivalent of a withdrawal of *25,000* m^3 in *15* minutes. The Fort Gassion gate and lock, presented in figure 2, are two of the unknown inputs and are operated for sporting purposes.

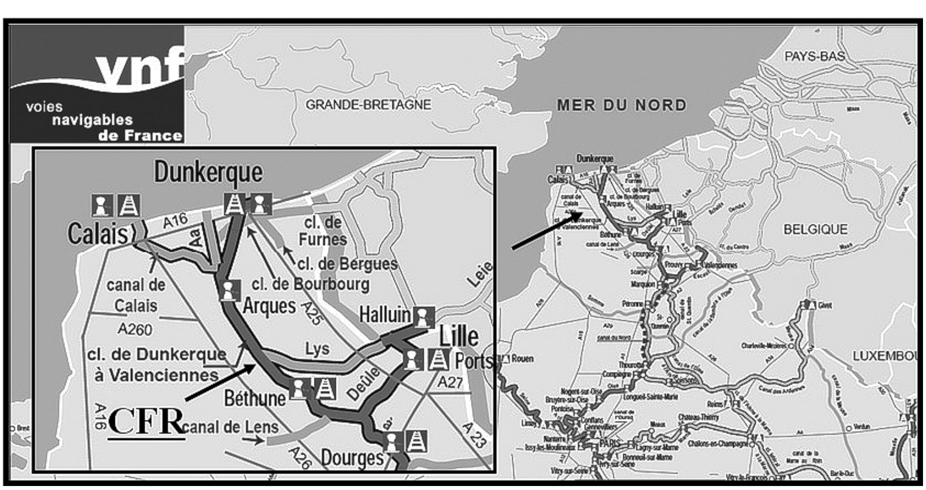

Figure 1: The inland waterways network located in the north-west of Europe.

To reach the aim of maintaining the NNL, VNF has equipped the channel with limnimeters (in Cuinchy, Aire and Fontinettes) and controls the flow discharges in input and output of the CFR at these three points: the first is the Cuinchy lock and gate, the second is the Fontinettes lock and the third is

Figure 3: A ship inside the downstream lock (Fontinettes) during the filling process.

the gate called "Porte de Garde" at Aire-sur-la-Lys. The control of Cuinchy and Fontinettes locks is constrained by the navigation demand. The "Porte de Garde" gate at "Aire-sur-la-Lys" and the Cuinchy gate are used to control the water level in the CFR, without being constrained by the navigation demand. The "Porte de Garde" gate allows exchanges between the CFR and the Lys River, and authorizes the water runoff in both directions, *i.e.* from the CFR to the Lys River, or from the Lys River to the CFR. On the other hand, the Cuinchy gate allows provide extra water to the channel.

Nowadays the operating range of the system, defined by LNL and HNL, is 19.52 ± 0.25 m (level respect to the mean sea level) during the navigation schedule time: 8:00 am-8:00 pm. In the future, in order to accommodate larger vessels, this range will be reduced to 19.52 ± 0.15 m and the navigation schedule time will be expanded to the 24 hours of the day.

Control strategies of the gates and locks in Cuinchy, Aire and Fontinettes have to be designed to limit, particularly, the impact of the operation of the Fontinettes lock. Firstly, it consists in understanding and in modelling the dynamics of the CFR. Then, the designed control strategies have to be tuned, tested and validated by simulation before to be implemented in the real system (Vidan, Kasum, Misevic, 2012).

3. Modelling of the cuinchy-fontinettes reach

The CFR is *42.3 km* long, with no significant slope. Although it is artificial, the CFR is composed of more than *400* different cross sections, with depth going from *0.3 m* for the banks, to *4.79 m*, and a depth average, *h*, around *4.2 m*. As a first modelling approach, a mean profile of the CFR is considered (*see* Figure 4), with the following geometrical characteristics:

- *B*, the bottom width of *34 m*,
- *Z*, the height of *4.7 m*,
- *f*, the average fruit of the banks of *1.73 m*,
- *h*, the average level depth of *4.2 m*
- *NNL*, the Normal Navigation Level and its Higher and Lower bounds

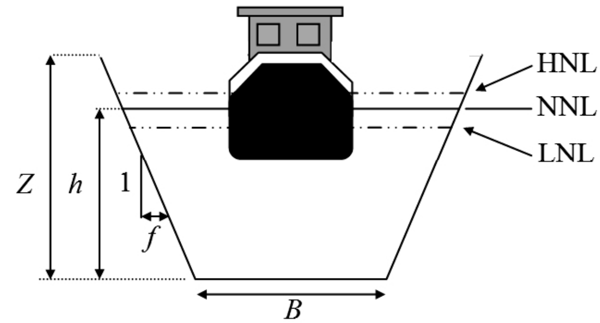

Figure 4: Average geometrical characteristics of the CFR.

In this work, the real canal behaviour has been accurately modelled by Saint-Venant's equations (Chow, 1959) and reproduced using a high-fidelity simulator and implemented in the software Matlab-Simulink©. This simulator solves numerically the Saint-Venant's equations as usually done in existent commercial open-flow canal simulators (Malaterre, 2006) after been calibrated with real data.

The Saint-Venant equations are partial-differential equations that describe accurately the dynamics in a one-dimensional free surface flow. These equations express the conservation of mass and momentum principles in a one-dimensional free surface flow:

$$\frac{\partial Q}{\partial x} + \frac{\partial S}{\partial t} = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{S}\right) + gS\frac{\partial h}{\partial x} - gS\left(I - J\right) = 0 \quad (1)$$

where $Q = Q(x,t)$ is the flow (in m^3/s), $S = S(x,t)$ is the cross-sectional area (in m^2), t is the time variable (in s), x is the spatial variable (in m), measured in the direction of the movement, h is the spatial variable corresponding of water elevation (in m), g is the gravity (in m/s^2), I is the bottom slope and J is the friction slope.

After the simulator has been implemented, different discharge schedules have been simulated in order to evaluate the influence of the time in the filling/empting lock procedure and the level evolution. The results of these simulations are shown in Figures 5 and 6.

Nowadays the time in the filling of the Fontinettes lock is 15 minutes and the amplitude of the wave is approximately 12 cm. If the filling of the lock is carried out slower than it is currently done, this amplitude can be reduced as it shown in Figure 5.

On the other hand, the operation of the Cuinchy lock is much less critical. In the current operation, the time in

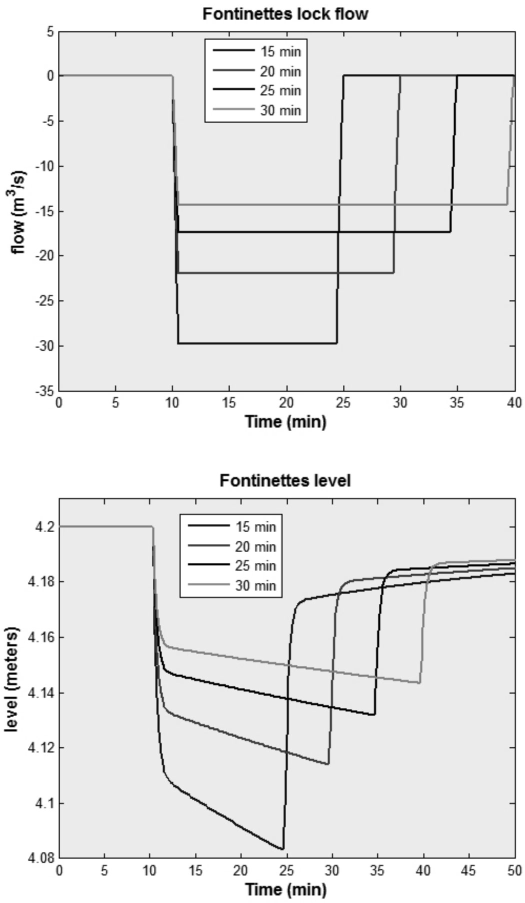

Figure 5: Fontinettes lock flow and level evolution for different discharge schedules.

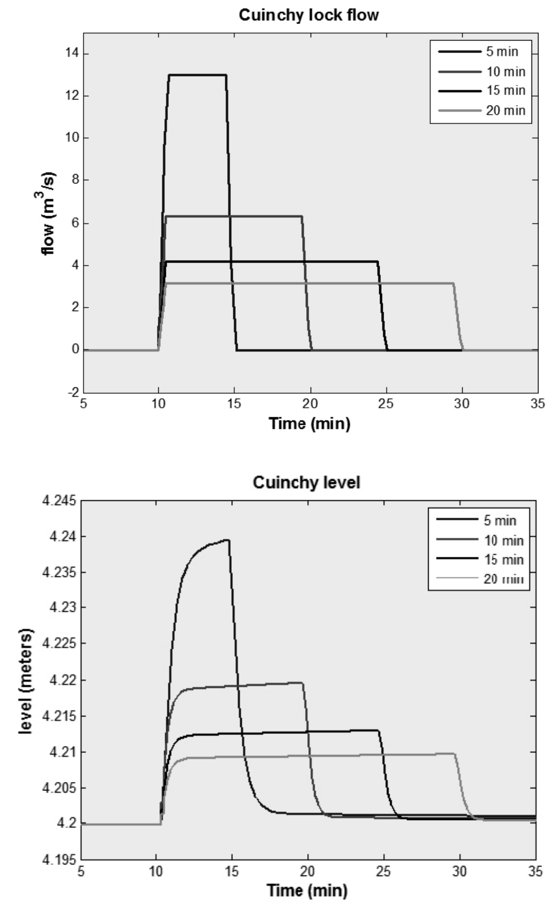

Figure 6: Cuinchy lock flow and level evolution for different discharge schedules.

empting of the Cuinchy lock is 5 minuts and the amplitude of the wave is approximately 4 cm. If the filling of the lock is carried out slower than it is done now, this amplitude can be reduced as it shown in Figure 6.

4. Design of a control strategy

The complex dynamics of the system is basically due to the existence of multiple inputs/outputs and the large delay between them, makes the Model Predictive Control (MPC) a suitable candidate to perform the automatic control algorithm. The Model Predictive Control (MPC) is an advanced method of process control that considers intrinsically these complex behaviours (Camacho and Bordons, 2004) (Maciejowski, 2002). The idea behind MPC is to start with a model of the open-loop process that explains the dynamical relations among system's variables (command inputs, internal states, and measured outputs). Then, constraint specifications on system variables are added, such as input limitations (typically due to actuator saturation) and desired ranges where states and outputs should remain. Desired performance specifications complete the picture and are expressed through different weights on tracking errors and actuator efforts (as in classical linear quadratic regulation). The rest of the MPC design is automatic. First, an optimal control problem based on the given model, constraints, and weights, is constructed and translated into an equivalent optimization problem, which depends on the initial state and reference signals. Then, at each sampling time, the optimization problem is solved by taking the current (measured or estimated) state as the initial state of the optimal control problem. For this reason the approach is said predictive, as in fact the optimal control problem covers the time interval that starts at the current time up to a certain time in the future. The result of the optimization is an optimal sequence of future control moves. Only the first sample of such a sequence is actually applied to the process, the remaining moves are discarded. At the next time step, a new optimal control problem based on new measurements is solved over a shifted prediction horizon. For this reason the approach is also called "receding horizon" or "rolling-horizon" control. Note that the receding horizon mechanism represents a way of transforming an open-loop design methodology (namely, optimal control) into a feedback one, as at every time step the input applied to the process depends on the most recent measurements.

In Figure 7, the scheme of the MPC used for control the CFR system is presented. The inputs of the system are: u_1 and u_2 (in m^3 / s) that corresponds to the Cuinchy and Lys gate flows, respectively. The outputs of the system are: y_1, y_2 and y_3 (in m) that are the Cuinchy, Lys and Fontinettes levels, respectively. Finally, the disturbances are the Fontinettes and Cuinchy locks operations and other unknown inputs along the channel.

The constraints of the inputs are:

$$\begin{aligned} 0 \le u_1 \le 10 \\ -7 \le u_2 \le 7 \end{aligned} \quad (2)$$

And the control objective is to maintain the level outputs inside the seaworthiness conditions

$$LNL \le y_i \le HNL, \quad \forall i = 1,2,3 \quad (3)$$

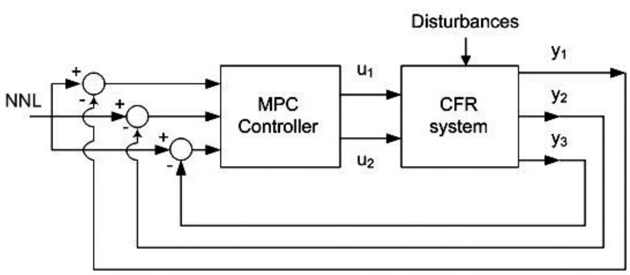

Figure 7: Automatic control scheme.

The objective of the MPC is to keep, as much as possible, the outputs of the system (measured levels in the reach) close to the Normal Navigation Level despite the perturbations of the system by introducing the suitable inputs (flows) computed by the MPC and considering constraints (2). In case of flood and dry scenarios, constraints can be modified and MPC controlled reconfigured.

MPC algorithms need a discrete-time model of the plant in order to compute estimations of the outputs for future time steps as:

$$\begin{pmatrix} y_1(k) \\ y_2(k) \\ y_3(k) \end{pmatrix} = \begin{pmatrix} G_{11}(q^{-1}) & G_{12}(q^{-1}) \\ G_{21}(q^{-1}) & G_{22}(q^{-1}) \\ G_{31}(q^{-1}) & G_{32}(q^{-1}) \end{pmatrix} \begin{pmatrix} u_1(k) \\ u_2(k) \end{pmatrix} \quad (4)$$

Saint Venant equations (1) for an arbitrary geometry lack of analytical solution are not useful for obtain the discrete time model (4).

G_{11}, G_{12}, G_{21}, G_{22}, G_{31} and G_{32} have been identified applying superposition and conventional identification techniques (Ljung, 1987) with a sampling time of T_s = 5 min. First, a sequence of flow, rich enough under the identification point of view, has been applied in Cuinchy gate (u_1) then least squares identification methods have been applied to outputs y_1, y_2 and y_3 obtaining G_{11} ,G_{21} and G_{31}. The same process has been repeated in Lys gate (u_2) to obtain G_{12}, G_{22} and G_{32}.

Once the mathematical model has been obtained, the controller has been applied to real scenarios (based on real data available) reproduced using the Saint-Venant Simulator. In these simulations, it has verified that the MPC controller is able to maintain the seaworthiness conditions (3) in the current operation mode: 8 am – 8pm navigation schedule with 10 operations in every lock. On the other hand, the different lock discharge schedules showed in Figures 5 and 6 have been applied and it has been verified that for slower lock operation it is easier to guarantee the seaworthiness conditions.

Moreover, future hypothetical scenarios that consider 24 hours of navigation schedule with 20 operations in every lock have been simulated and it has verified that the proposed controller is able to guarantee the future seaworthiness conditions (3) with LNL = NNL-0.15 and HNL = NNL+ 0.15.

Figure 9 shows the evolution of the level in the three controlled points of the channel using the MPC controller and increasing the Fontinettes time lock operation 5 minutes. In this figure, the evolution of the gate flows (control inputs) computed by the MPC controller and applied to the system are showed as well. It can be seen that the levels are always inside the bounds that define the seaworthiness.

4. Conclusions

In this paper, a MPC controller has been proposed for the control of the level in an inland navigation channel located in the north west of France. The automatic control provides better accuracy than human operation and allows guaranteeing stronger seaworthiness conditions. These stronger

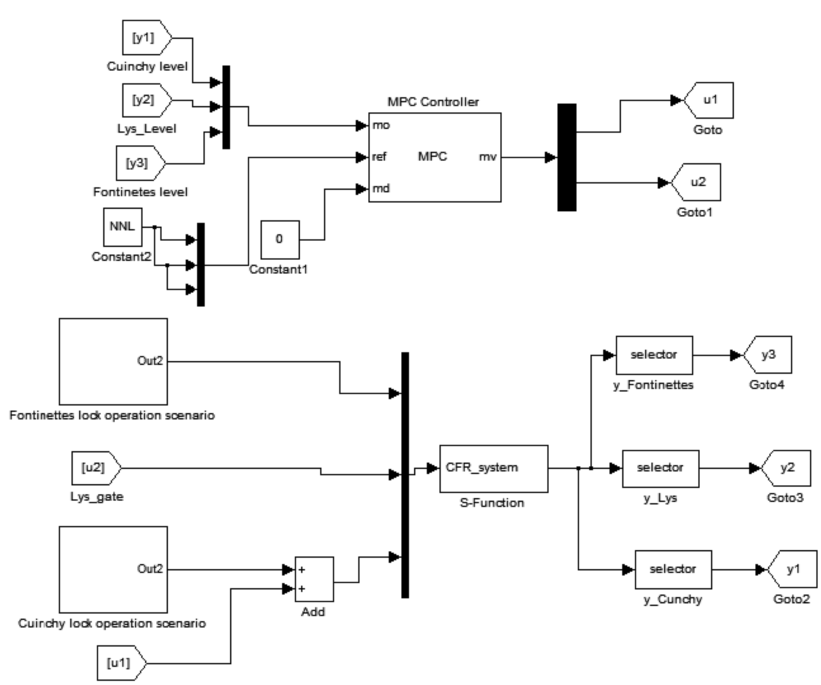

Figure 8: CFR simulator implemented in Matlab-Simulink©.

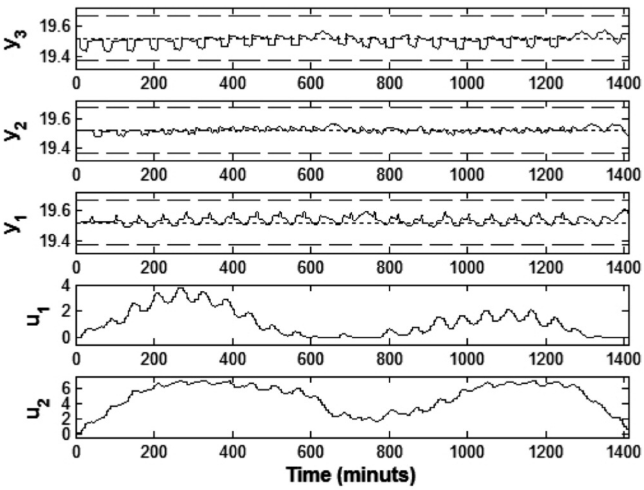

Figure 9: Evolution of Outputs (with seaworthiness bounds) in meters respect to the mean sea level and inputs in m^3/s in a 24 hours hypothetical scenario

conditions are necessary to accommodate large broad gauge boats and expand the navigation schedule. And therefore, provide inland shipping with a competitive edge over road transport. Finally, the proposed controller has been successfully validated in real and hypothetical scenarios using a high-fidelity simulator. The future purposes consist in deal with possible faults that can affect to sensors/actuators of the real system. Another issue will consist in considering the effect of the unknown inputs along the channel. These effects are very important in extreme episodes as flood and drought. Finally, after validation and simulation steps, an implementation on-line of the proposed technique on the real system may be considered at term.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 67 - 74

ISSN: 1697-4840 www.jmr.unican.es

Enhancing the Maritime Curriculum With Online Education and Scholarly Resources

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ARTICLE INFO

Article history:
Received 10 June 2012;
in revised form 12 June 2012;
accepted 30 July 2012

Keywords:
Electronic Resources, Maritime Curriculum, Education Ashore and at Sea, Distance Learning

ABSTRACT

The study "Enhancing the Maritime Curriculum with Online Education and Scholarly Resources" demonstrates how scholarly communication, library technology and information delivery support and enhance maritime teaching and learning at sea and ashore. Maritime College, of the State University of New York, prepares students for careers through a content-centered curriculum and a hands-on, team building approach to learning. The SUNY Maritime College student experience is complemented ashore and aboard the training *Ship Empire State VI* with instructional technology for teaching and learning in the classroom, in library, and virtually from anywhere in the world. The study describes the information technology used for delivering and accessing scholarly content, such as electronic journals, e-books, and online tutorials to distance students and faculty. In addition, the study describes how mobile technology accommodates a number of virtual library services to online/distances learning maritime community.

1. Introduction

The study "Enhancing the Maritime Curriculum with Online Education and Scholarly Resources" demonstrates how scholarly communication, library technology and information delivery support and enhance maritime teaching and learning at sea and ashore. Maritime College is one of the 64 colleges and universities of the Sate University of New York System (SUNY) and one of the six Maritime Academies in the United States granting United States Coast Guard licenses. SUNY Maritime College offers a solid academic program coupled with a structured cadet life in the regiment for both men and women. Maritime College prepares students for careers through a content-centered curriculum and a hands-on, team building approach to learning. The curriculum offers undergraduate and graduate degrees, and a European summer sea term of 90-days aboard the Training Ship Empire State VI, SUNY Maritime (SUNY Maritime College, 2009; González, Carbonell, Saorín, de la Torre, 2011).

The Maritime College Library, named after Admiral Stephen B. Luce, is accredited by professional organizations such as the Middle State Commission on Higher Education and it adheres to the standards and guidelines of the Association of the College and Research Libraries of the American Library Association, American Library Association (2009). The Luce Library collections, print and electronic, as well as the Library's instructional programs in information literacy, support the research requirements of the maritime disciplines in engineering, science, business, marine transportation, and the humanities.

1.1. Online Information Research

In recent years the maritime industry has seen a growing dependence on the use of information technology. New systems are constantly being implemented onboard to aid the seafarer in navigation, safety, and environmental awareness. Whereas our forefathers have used paper charts and sextants, today's mariner must be knowledgeable on use of radar, GPS, electronic charting, and various other electronic publications (Gudelj, Krcum, and Krcum, 2008). Consequently, maritime educators are recognizing the need for students to be trained in information technology.

In the mid 1990s as information evolved in many different formats, maritime libraries increased emphasis on library instruction programs and information literacy emerged as the instructional framework to develop students' competencies in analytical skills and critical think-

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ing. The Association of College and Research Libraries defined information literacy competency standards as "…a set of abilities requiring individuals to recognize when information is needed and have the ability to locate, evaluate, and use effectively the needed information." Information literacy, as defined, is the basis for lifelong learning because a student who graduate with the ability to locate, evaluate, and effectively use information can learn independently and address their own needs and questions in any area of life (Association of College and Research Libraries, 2009).

The information competent mariner is one who is able to apply information technology skills to be able to locate, evaluate, and use information effectively; in other words to be information literate. To train maritime cadets to become information competent, the Stephen B. Luce Library has interwoven a framework of technological tools, library instruction, and assessment activities to design a program that's infused in the Maritime curricula. The library facilitates access to a myriad of digital and print information sources along with some state of the art research tools such as enhance OPAC, federated searching, cross linking with Google, worldwide catalog, and more. Also, technology is incorporated into various pedagogical tools that are used to enhance cadets' training in information competency. In addition, with the tools in place, the Library designed a robust instruction program to integrate information competency in the curricula. Various assessment activities have been implemented to provide much needed feedback on the effectiveness of the information competency training. The Library uses the assessment data to continuously enhance the program. A key component for effective information competence training is to expose maritime cadets to some of the current technological tools. The Stephen B. Luce Library strives to stay abreast with technology developments in both pedagogy and information research and delivery.

1.2. Research Tools for Retrieving Information

OPAC: The online public access catalog (OPAC) is the main gateway to researching the Library's collection and cadets are well trained on its use. With a name of *the Sextant*, cadets easily associate the OPAC as a tool to navigate information. The librarians constantly incorporate new technology to enhance the OPAC as a one-search interface for all print and electronic resources. All electronic books (ebooks), electronic government publications, and other similar sources are fully searchable and are just a click away with embedded URLs in the OPAC. Detailed information on books such as summaries, table of contents, and excerpts are accessible through the OPAC with cross-linking service to Google Books.

Federated searching: Stephen B. Luce Library subscribes to over 70 information data banks with access to more than 47,000 titles of periodicals. With such an array of sources it is often a difficult task for cadets to search each information resource individually. To streamline this process the Library implemented a new information portal, called *the Beacon*, which uses federated search technology. This enables cadets to search multiple information databases through one search interface. Intense training on the use of the Beacon is done during library instruction sessions, where cadets are taught how to construct effective search strings to retrieve relevant results.

Partnering with Google: Today's generation of Maritime students are web savvy and very inclined to do all information research using Google only. It is a challenge for librarians to teach cadets on how to use Google competently and a significant part of library instruction dwells on evaluating web sources and suggests the use of academic versions of Google such as Google Scholar and Google Books. To facilitate the cadets' search habits, the Library has partnered with Google to make its collection searchable via Google search engine. So, as an example, a cadet searching Google Scholar for information on "Ship Navigation" will see results for Stephen B. Luce Library (see Fig. 1).

Access beyond Luce Library boundaries: The Stephen B. Luce Library makes every attempt to increase access to information resources for the Maritime College community. All subscribed electronic resources are accessible 24/7 and from anywhere via special server technology, called EZProxy. Also, through Luce Library membership to resource sharing consortiums, Maritime cadets have access

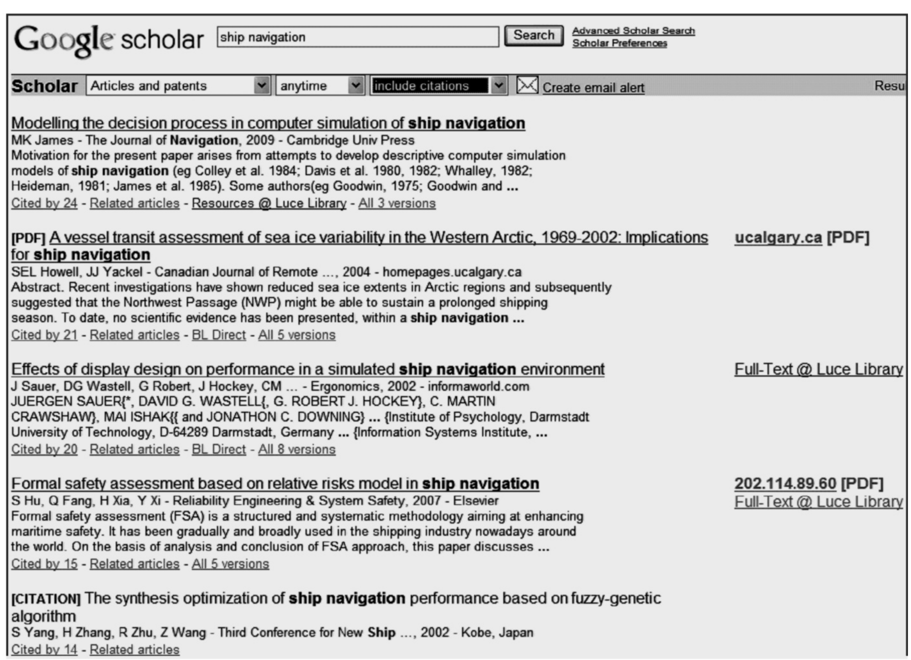

Figure 1: Google Cross Link to Luce Library.

to many more books and other information sources not available in the Library's collections. Using a worldwide OPAC, called Worldcat, cadets can search and request any items from libraries nationally and internationally. This process, referred to as interlibrary loan, is managed by a 24/7 online system with the capability to deliver materials electronically (Shafeek, 2010).

Scholarly Resources at the Stephen B. Luce Library: The scholarly resources are made available through consortium agreements that support university libraries at the State of New York and beyond. Some of these electronic databases are listed below:

EBSCO Databases	EBSCO includes 7 separate databases. They are Academic earch Elite, Business Source Premier, Clinical Reference Systems, alth Source Plus, USP DI Volume II Advice for the Patient, ewspaper Source and Alt-Health Watch. These databases feature full text for a wide range of publications.
FirstSearch	The OCLC FirstSearch service offers a variety of indexes, abstracts and full text databases.
Gale Databases	A collection of databases covering literature, current events, business and more. Includes newspaper, journal and encyclopedia articles, both cholarly and general, in arts and literature, social sciences, current social issues, financial research, and health information. Full text coverage and indexes from 1980 to date.
HarpWeek	The Civil War segment covers the years 1857-1865. HarpWeek is the full-text, full-image electronic version of Harpers Weekly for the nineteenth century.
Homeland Security Digital Library	The Homeland Security Digital Library (HSDL) is the nation's premier collection of documents related to homeland security policy, strategy, and organizational manage ment.
JSTOR - Arts & Sciences I	This JSTOR collection includes full-text ar ticles from the complete back runs of 118 journal titles in various disciplines, including many of the core research and society published journals in economics, history, political science, and sociology, as well as titles in the more science-oriented fields of ecology, mathematics, and statistics.
Lloyd's List	Lloyd's List is the leading daily publication for authoritative coverage on the shipping industry, including global shipping, logistics, global trade, marine insurance, and admiralty law.
Marine Technology Abstracts	The Marine Technology Abstracts database contains bibliographic information providing a reference and description for over 90,000 technical articles, reports, books, conference and transaction papers and other material on all aspects of maritime technology, dating back as far as 1940 and drawn from all major marine engineering publications, published worldwide in at least 10 languages.
Milestone Documents in American History	Salem History's *Milestone Documents in American History* is the first of five primary source resources from the Schlager Group and Salem Press. It combines 130 full-text primary source documents with expert analysis and commentary.
NetLibrary	529 medical and health-related eBooks and 125 new business titles with the original collection of 715 titles, SUNYConnect now provides 1369 purchased eBooks as well as the public (i.e., free) collection of 3823 titles.
ProQuest	**ABI/INFORM Global:** American Medical Association; Newspapers Periodicals; Peer Reviewed **ProQuest Newspapers:** National Newspapers (27); Barron's; The New York Times; Wall Street Journal
Science Direct	Contains 707 scholarly full-text scientific and medical journals. ScienceDirect offers full text access to over 700 Elsevier Science journal titles that cover areas including science, medicine and technology.
Springer Ebooks	A collection of about 17,000 titles of ebooks in 13 different subject areas, including Business & Economics, Chemistry & Material Science, Earth & Environmental Science, Engineering, Humanities, Law, Mathematics, Physics, and more.
TRID Database	TRID is the world's largest and most comprehensive bibliographic resource on transportation research information. It is produced and maintained by the Transportation Research Board. TRID covers all modes and disciplines of transportation and contains more than 900,000 records of published research. Over 64,000 records contain links to full-text documents.
UnCover Reveal/ Ingenta	UnCover Reveal is an automated alerting service that delivers the table of contents of your favorite periodicals to your email inbox.

Technology innovations have made it possible for the library to deliver scholarly content to the students and faculty by enabling delivery mechanisms such as electronic Interlibrary Loan that is initiated by the library user (Stephen B. Luce Library, 2009). Students and faculty are able to initiate borrowing transactions of books and journal material directly from the library's portal and borrow any item from a network of libraries.

Most important is the Library's effort to streamline all library resources in support the courses taught online for the SUNY Maritime College distance learning students. SUNY Maritime initiated its distance learning program in the spring of 2004. During the fall 2011 semester, there were 1,228 students enrolled in 80 blended and 29 online sections and 54 faculty involved across the 109 sections. Figure 2, demonstrates the Library's online module in support of a distance learning courses.

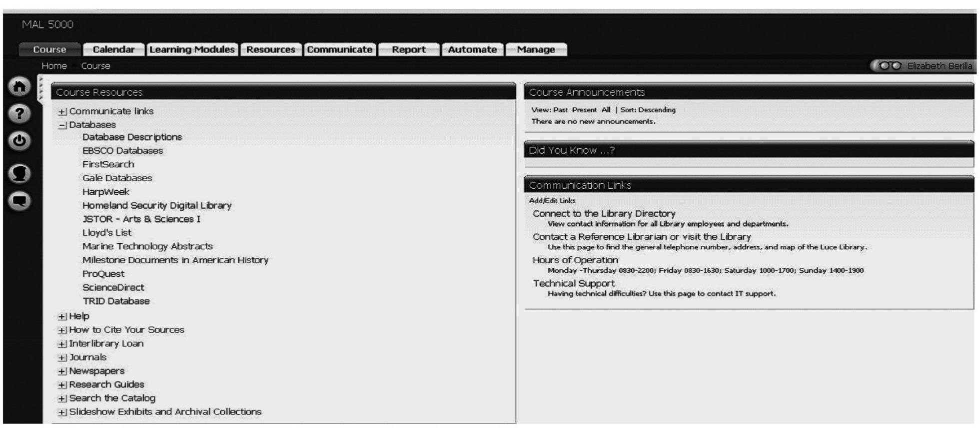

Figure 2: Research material in support of the courses on the "Angel" platform.

1.3. Online Pedagogical Tools

In addition to making electronic resources available to students and faculty, the Stephen B. Luce library has adopted pedagogical tools and methodologies to assist the academic community with using information technology. The new generation of learners arrives to our campuses far more prepared in computer skills, far more skillful in multi-tasking and far more experimental. The students are also far more demanding in their expectations for instantaneous access to information. To acknowledge the students' new mode of learning the Stephen B. Luce Library set forth to bridge the generation gap by ensuring the information and formats through which it is conveyed to students remains relevant. As is the case with other types of instruction, the Library is committed to teaching information competency using various pedagogical techniques to achieve positive student learning outcomes.

All library instruction sessions are computer-assisted, utilizing state of the art equipment for effective multimedia instruction and hands-on experience. A major pedagogical tool for information competency training is the Library's online information literacy tutorial. This full-scale, multi-module tutorial is designed to assist cadets to navigate through the information research process at their own pace. It is also an important tool for distance learning students to learn about the information research process. Based on the demands of the curriculum, the Library continuously creates online pathfinders and online research modules (general and discipline-specific) to address the information needs of students. In addition, the library faculty liaisons collaborate with instructors to create course-specific research guides. Course-specific web tutorials serve to guide students in their research and to reinforce learning beyond the library instruction session. The library's research publications also serve an additional purpose - to provide the student with the choice and the flexibility to complete their assignments independently outside of the classroom teaching environment.

2. Education Aboard the Training Ship Empire State VI

As a part of the STCW requirements, the SUNY Maritime Cadets are required to participate on Summer Sea terms aboard the *Training Ship Empire State VI,* the largest training ship in the United States used for cadet training. The training ship is fitted with classroom space, computer rooms and a fully functioning research facility with access to the library's information systems and electronic resources. The paper "Electronic Access to Library Resources onboard the *Training Ship Empire State VI:* Enhancing the Learning Experience of Cadets at Sea" demonstrates how new technologies on the ship's library information systems support the maritime courses taught at sea.

Similar to Maritime College Library ashore, the Ship's research facility is equipped with the appropriate technology to accommodate cadets' mode of learning and information research. In addition, a faculty member of the library staff performs the duties of the Ship's Librarian. The Ship's Librarian, conducts research sessions on the information needs of all the shipboard community. The Luce Library afloat is the main resource and research facility for all cadets taking courses during the ninety-day summer sea term.

SUNY Maritime education and training continues at sea onboard the 565-foot training ship *Empire State VI.* The educational objectives of the summer sea term are, SUNY Maritime.

1. To provide an understanding of shipboard organization, administration, facilities and functions of the various departments of a merchant vessel.

2. To develop a full appreciation of the principles of

command, to train Cadets in the duties and responsibilities of watch officers and other supervisory personnel, and to promote a complete understanding of the duties and responsibilities of personnel in general.

3. To supplement ashore classroom instruction in professional subjects through practical application aboard the training ship at sea.

4. To promote an understanding, through practical experience, of the leadership, teamwork, techniques, and technical skills required to manage and operate a vessel efficiently, safely and economically.

5. To enhance cultural and professional backgrounds through as many contacts with the geography, history, and national distinctions of other countries and peoples, as the limited time allows.

Cadets pursuing a professional license as a United States Merchant Marine Officer are required to take a minimum of three Summer Sea Terms. Cadets aiming to qualify as a mate undergo extensive (basic, intermediate, and advanced) training in ship operation and management. While onboard the "deckies" are exposed to rigorous training in the areas of communications, navigation, ship handling, ship operations, safety, and meteorology. Under the supervision of the Chief Engineer and the Senior Engineering Training Officer, Cadets qualifying as assistant engineers receive in-depth training in the ship's organization, interrelationship of the components of an operating engine room, and safety of person and ship. Each cadet must take and pass intensive oral and written examinations, SUNY Maritime College.

2.1. Stephen B. Luce Library Aboard the Training Ship Empire State VI

The Library on Training Ship *Empire State VI* is located on deck four and it occupies approximately 2500 square feet. It has a reading room with seating capacity for 55 people and shelving that holds approximately 7,000 books. Electronic resources are made accessible through several networked computer terminals. Similar to the SUNY Maritime College Library ashore, the Ship's Library is furnished with the latest technology to facilitate the teaching and learning objectives of the SUNY Maritime cadets at sea.

2.2. Library Technology Aboard

Technology is a major mode of learning for the new generation of cadets. Cadets are far more technology oriented and thus far more demanding for instantaneous access to information. The decision making process at sea is subject to instantaneous access to information; prime example is electronic navigation, electronic weather reports, electronic communication with other vessels and electronic access to important documents and resources.

Similar to Maritime College Library ashore, the Ship's Library afloat is equipped with the appropriate technology to accommodate cadets' mode of learning and information researching. The Ship's Library is furnished with several computer workstations networked on its local area network, (LAN).

The Library's LAN is networked to the Ship's intranet which is connected the Ship's satellite communication system. All library computers provide access to electronic publications, information on the Library operations and staff, image and data banks, various training software, and the Library's OPAC. Management of library operations is done using LibrarySoft, an integrated library management system. Cataloging of books, circulation, patron record maintenance, statistics and report generation are all managed by LibrarySoft Constantinou & Fazal (2007).

2.3. Access to Maritime Electronic Resources

The Ship's Library technology infrastructure is built on a local area network (LAN). Several computer workstations are networked to the Ship's intranet which is connected to the Ship's satellite communication system. Cadets and crew can access the electronic publications and research material through an image and data banks of various training software. The most updated editions of various official government publications are transferred in electronic format and made available on the library's computers. These publications are on subjects such as ocean conditions, navigations, federal regulations; and several sources on countries/cultures information and ports guide to support travelling to various ports of call. (see Fig. 3).

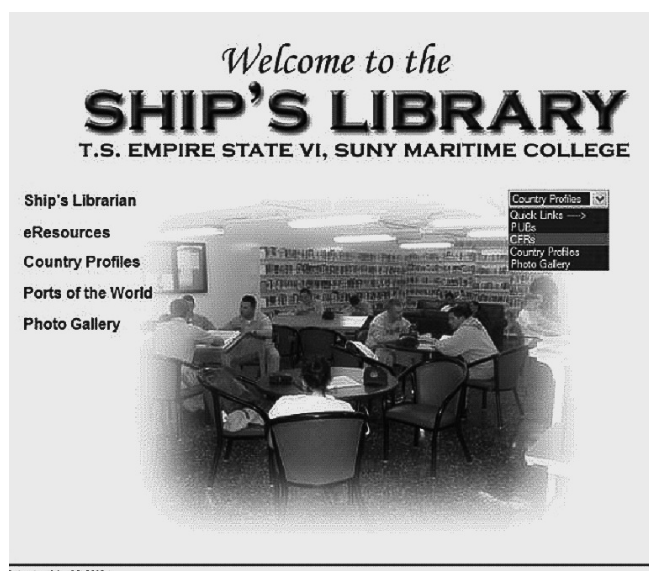

Figure 3.

Cadets and crew have electronic access to titles such as *Bowditch Practical Navigator, List of Lights, International Code of Signals, Code of Federal Regulations, Pilot Charts, Sailing Directions, Radio and Radar Navigation*, and *Sight Reduction Tables, Countries and their Cultures, CIA World Factbook,* and *Encyclopedia of Food and Cultures.* Additionally, access to email enhances the delivery of electronic information to the Ship's Library. The email system is set up to work with the Ship's data satellite service. The Ship's Librarian remains in constant communication with the librarians at the main library ashore. Whenever there is a need for access to additional electronic materials, the librarians are able to transmit the latest information via email to the ship's library.

3. Maritime Specific Electronic Resources

Cadets studying navigation, use one of the leading reference works for marine navigation, the *Bowditch Practical Navigator* (Bowditch Online, 2009). The electronic reference work encompasses thirty-eight chapters, on marine navigation, piloting, electronic and celestial navigation, navigation mathematics, navigation safety, oceanography and marine meteorology. The electronic format of the *Bowditch Practical Navigator* is the digital version of the print book which includes charts, drawings, and mathematical formulas as they appeared in the print version. The *List of Lights* is made available electronically by the Navigation Center of the United States Homeland Security, Coast Guard department (The List of Lights website, 2010). The resource includes the most up-to-date information on the list of lights presented in a PDF format. Electronic access to the *International Code of Signals,* provides the cadets with an overview of the history of the international code of signals and a detailed list with colored pictures of all signal flags.

The *Code of Federal Regulations, (CFR)* is published by the United States Government Printing Office (GPO). The CFR is the codification of the general and permanent rules published in the Federal Register by the executive departments and agencies of the United States Federal Government, CFR (Code of Federal Regulations website, 2010). The most popular sections of the CFR used by the cadets for their studies are CFR-50 *Wildlife and Fisheries; CFR-49 Transportation; CFR-46 Shipping; CFR-40 Protection of Environment, CFR- 35 Panama Canal, CFR-33 Navigation and Navigable Waters. Pilot Charts,* and *Sailing Directions,* provide electronic access to most up-to-date navigation charts. The *Sight Reduction Tables,* are used by all cadets for charting their course during navigation classes (Sight Reduction Tables, 2009).

In addition to the course-specific electronic resources the cadets are required to use during their studies at sea, the library also makes other related non-course-specific resources available through its networked stations. During the ninety days at sea, the Training Ship *Empire State VI* visits five to six European ports. The SUNY Maritime College Cadets have the opportunity to be exposed to other countries, languages, customs, cultures and civilizations. Exposure to other countries customs and ethnic identities is a valuable lesson learned in an international discipline such as the maritime studies.

Electronic access to resources such as *Countries and their Cultures* (Countries and Culture website, 2009), *CIA World Factbook,* (CIA Fact Book website, 2009), and *Encyclopedia of Food and Cultures* (Encyclopedia of Food and Culture, 2009) provide invaluable information on other countries. *Countries and their Cultures* is a searchable database with images and maps with emphasis on the local and ethnic culture of each country. The *CIA World Factbook,* is published and made available by the Central Intelligence Agency of the United States government. It is one of the most comprehensive and current databases on factual country information about the history, government, communication, transportation, population etc. The *Encyclopedia of Food and Cultures* is an electronic book format made available through the library's Gale databases subscriptions.

Conclusion

Traditionally and throughout history young mariners learned how to read and write and received their education from book they read at sea. Advancements in technology have revolutionized maritime studies in the areas of navigation, engineering and communication. All decisions made aboard vessels are based on access to information systems and technology. SUNY Maritime College educates and trains cadets to work under the most technologically advanced environments. Work is underway to develop a complete online information literacy module and library services for mobile technology to incorporate into online courses for the distance learning program. In addition, the library remains diligent in conducting assessment programs and measuring the learning outcomes of our student success.

The SUNY Maritime College Library plays a critical role in providing the academic community ashore and at sea with the most relevant up-to-date information. One of the most important objectives of educating mariners at sea is learning to appreciate and understand access to information as a critical component to decision making.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 75 - 80

ISSN: 1697-4840 www.jmr.unican.es

Combining Weibull Distribution Function and Monte Carlo Simulations in Predicting Corrosion Losses Over Inner Bottom and Hoper Plating of Ageing Bulk-Carriers

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ARTICLE INFO

Article history:
Received 11 June 2012;
in revised form 13 June 2012;
accepted 30 July 2012

Keywords:
Corrosion loss, bulk-carrier, Weibull distribution, Monte Carlo simulation

ABSTRACT

This article gives an overview of main operational parameters that influence corrosion over ageing bulk-carriers' member locations. The particular vessels' hull structure locations being affected intensively by these parameters are identified, as well. The zone identified as the most *vulnerable* one, i.e. inner bottom and hopper plating, has been probabilistically treated. Within the extensive previous probabilistic analysis of the corrosion losses over aging bulk carriers, it has been shown that the considered data exhibit great scattering. The same was with the data which were available to us for the purpose of this research work. In fact, it was difficult to fit the data collected by the regular and standardized ships' measurements on board by the UTM Company "Invar-Ivosevic"[1], to the most commonly used Weibull distribution, which usually in the best manner fits the corrosion wear over considered ageing ships. Consequently, an optimal procedure of pre-processing the collected data in order to better fit them into the Weibull distribution function, has been proposed in the article.

1. Introduction

The corrosion is one of the most important factors affecting structural safety and integrity of ageing bulk carriers. Though, the operational life extension of the bulk carriers' steel structures requires permanent consideration of the plates' thickness losses due to the corrosion. For commercial naval ships, like bulk carriers, the extent of the corrosion losses is usually measured through the classification society ships' surveys (Adamson, Brown, 1999). Besides the regular steel thickness measurements, corrosion protection measures are necessary, as well. These measures include paint coatings and sacrificial anode systems for immersed areas. Since these measures are not always wholly effective, continual maintenance is required, but not always applied (Gudze, Melchers, 2008). In order to provoke and support more intensive maintain measures, several bulk carriers' time-variant corrosion losses probability models have been developed up to now (Paik, Kim, Lee, Park, 1998; Paik, Lee, Park, Hwang, Kim, 2003; Paik, 2004; Paik, Thayamballi, Park, 2004). However, the researchers in this domain are usually faced with some serious difficulties, like: very complex character of the interaction of the ship with its environment and the interaction between the different parts of the ship's hull, the insufficient data for the ship's hull structures deterioration caused by the corrosion, and the lack of the data about the changes of the mechanical properties of the shipbuilding material during its operation and reparations (Ivanov, 2009). The large scattering of the data obtained by the different established corrosion probability, or time-dependant models has been noted. Additionally, most of the corrosion prediction models for the ships take little or no account of the operational parameters, and profile of the ships. Consequently, we did an effort through the analysis being presented in this article to stress the operational parameters that commonly affect the structural safety and stability of ageing bulk carriers' structural member locations (areas/zones), and intensify corrosion processes onboard.

2. On the bulk carriers' structural member locations

Up to now, the group of authors (Sone, Magaino, Yamamoto, and Harada) have analyzed some longitudinal and transversal elements of bulk carriers, i.e. twenty elements of the bulk carriers with the capacity over 50 000 DWT, and fourteen

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elements of the bulk carriers with the capacity less than 50 000 DWT, registered under the Japanese ClassNK register (Sone, Magaino, Yamamoto, Harada, 2003). In the work of Gardiner and Melchers, the cargo holds were examined (Gardiner, Melchers, 2003; Melchers, 2003; Melchers, 1999; Gardiner, C.P., Melchers, 2001; Gardiner, Melchers, 2002; Gardiner, Melchers, 2002; Sone, Magaino, Yamamoto, Harada, 2003; Gardiner, Melchers, 2001), while the ballast tanks have been examined in the study works of Noor, Soares, Gudze, et al., (Noor, Smith, Yahaya, 2007; Soares, Garbatov, Zayed, Wang, 2005; Gudze, Melchers, 2006), as the bulk carriers' areas with the highest risk of the structural errors occurrence. Paik and others (Paik, Lee, Park, Hwang, Kim, 2003) have analyzed the degree of corrosion over twenty-three different longitudinal structural elements of the ship, etc. The authors of this paper have analyzed fuel tanks (Bauk, Aleksić, Ivošević, 2011) as those located between several different media (fuel, cargo, ballast, air spaces, etc.) and consequently in great extent affect by the corrosion processes.

The shortage of the most of the previous research works in this domain is reflected in a limited number of available data on corrosion losses over ageing bulk carriers, and in detail investigation on only few structural elements of the ship. Though, due to our knowledge, there are no studies in this field considering the ship as a whole, including its both longitudinal and transversal structural elements (areas, zones), taking into account their position and orientation, but only its segments were treated separately. In this paper, the complete bulk carrier structure has been divided into eleven structural zones that include both longitudinal and transversal elements, and then they were matched with the operational parameters being previously identified and briefly described.

Within this article, through defining eleven distinguished zones, an effort has been done toward the entire ship analyzing due to the corrosion deteriorations, through both transversal and longitudinal stiffening and plates of its structure (Bauk, Nikolić, Ivošević, 2010; Bauk, Ivošević, 2010; Bauk, Ivošević, Nikolić, 2010). In such manner, the key areas of degradation, due to the operational factors that affect corrosion can be identified, and ultimately the ship's structural strength and stability can be analyzed more easily and effectively. Further analysis in this direction, within each area can determine the corrosion processes, and eventually allow their modeling for the entire ship's structure. The identified eleven areas of the bulk carriers are shown in Figure 1 and listed in Table 1.

Table 1. The longitudinal and transversal member locations of bulk carriers.

Member location/category	Abbreviation	Longitudinal components	Transversal components
1. Upper deck	UD	X	
2. Deck superstructure	DS	X	
3. Bottom and side shell plating	BSSP	X	
4. Hatch cover and coamings	HCC	X	X
5. Structure in top side tanks	STST	X	X
6. Cargo holds transverse bulkheads	CHTB		X
7. Cargo holds main frames	CHMF		X
8. Inner bottom and hopper plating	IBHP	X	X
9. Internal structure in double bottom tanks	ISDBT	X	X
10. After peak structure	APS	X	X
11. Fore peak structure	FPS	X	X

The main structural features of the above listed eleven member locations of bulk carriers (see Figure 1, and Table 1) are described in some more details in (Bauk, Ivošević, 2011; Bauk, Nikolić, Ivošević, 2010; Bauk, Ivošević, 2010; Bauk, Ivošević, Nikolić, 2010). Some operation parameters that usually affect bulk carriers' member locations are described in (Gudze, Melchers, 2008; Gardiner, Melchers, 2003), and they are only listed here, in Table 2.

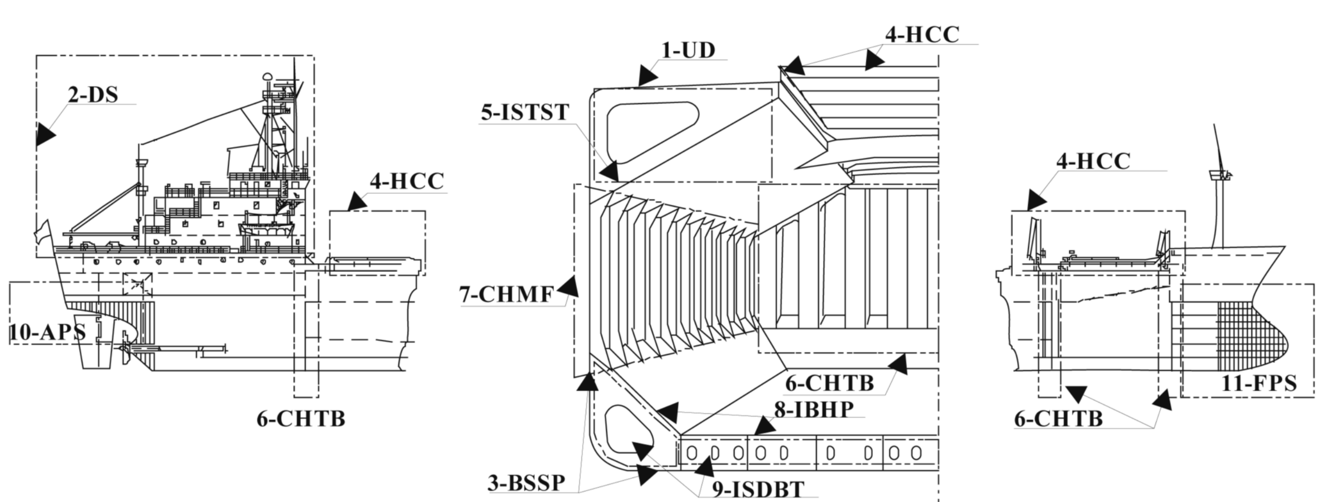


Figure 1. Member locations (longitudinal and transversal ones) of the bulk carrier hull structure.

Table 2. The operational parameters that usually influence corrosion.

Operational parameters affecting corrosion over bulk carriers in exploitation	
1. Sea water	6. Atmosphere (semi-closed, voided spaces)
2. Ballast water	
3. Fuel	7. Manipulative equipment
4. Cargo	8. Maintenance
5. Atmosphere (open atmospheric conditions)	9. Contact zones
	10. Temperature, etc.

Through the authors' previous research work (Bauk, Ivošević, 2011; Bauk, Nikolić, Ivošević, 2010; Bauk, Ivošević, 2010; Bauk, Ivošević, Nikolić, 2010), it has been found out that the most *vulnerable* member location of aging bulk carriers due to the above listed operational parameters (see Table 2), is the inner bottom and hoper plating (IBHP). Namely, during the operational cycle of ships, they carry various kinds of more or less corrosive cargo. The physical-mechanical properties of materials: density, bulk angle, the coefficient of friction, sulfur content, moisture, etc., are some of the factors that influence the progress of the corrosion process. More corrosive cargo will cause early removal of surface coatings (coal, iron ore), while the less corrosive materials (grains) contribute to a slight acceleration of the corrosion process. Increased frequency of cargo exchanges will also requires more frequent use of manipulative equipment. The use of manipulative equipment with abstraction heavy burden (heavy shovels and loading bucket) will contribute to the earlier removal of surface protection over some ships' member locations. Intensive operations with the corrosive cargos will require adequate maintenance system, whose absence will speed up the corrosion process. Cleaning and scraping double bottom cover, or IBHP will contribute significantly to earlier removal of surface protection of the steel plates of ships' holds, so that the corrosion process begin much earlier over this hull structure member area than with other structural elements and areas. A large number of strokes caused by the handling equipment over the double bottom produce the deformation of the steel plate covering the double bottom, which will cause cracking of the surface protection to the underside of the steel plate inside the tank. Due to intense ballasting and shifts wet and dry cycles, the early crack of the surface protection will contribute accelerating the corrosion of steel plate from bottom, or from the ballast tanks. Thus, the intensive corrosion process will occur in these structural areas on both sides, upper (from cargo holds) and lower (from web frames and fuel tanks), which is not the case with other constructive areas. That is why the intensity of corrosion of the IBHP structural zone is much higher than over other zones. Though, the further analysis are directed toward examining data on IBHP deterioration caused by the corrosion, being measured on board ships by UTM "Invar-Ivosevic" Company, and establishing the probabilistic time-dependent model of the corrosion depth over this member location. For this purpose, the particular combination of Weibull distribution function and Monte Carlo simulations has been employed, and the applied methodology is explained in some more detail within the next part of the paper.

3. Applied methodology

As it is still pointed out, in the previous probabilistic analysis of the corrosion losses over aging bulk carriers, it has been shown that the considered data exhibit great scattering (Paik, Kim, Lee, Park, 1998; Ivanov, 2009; Melchers, 2003; Melchers, 1999; Gudze, Melchers, 2006; Bauk, Nikolić, Ivošević, 2010; Bauk, Ivošević, 2010; Bauk, Ivošević, Nikolić, 2010; Wang, Lee, Ivanov, 2008; Ivanov, Wang, Seah, 2004). The same was with the data that were available for the purpose of this research. Namely, we were in position to realize some probabilistic analyses over 17 different aging bulk carriers (Table 3, note: some of the considered ships are the same, but analyzed in different periods of exploitation). More precisely, analysis have been done over 1841 gauged points. More precisely, the measured

Table 3. Features of the analyzed ships in the different points of their exploitation circles.

Ship	Built	Years old at the moment of measuring	Classification society*	GRT	DWT
After 15 years of exploitation					
S1	1996.	15	BV	18495	29292
S2	1984.	15	BV	19045	48826
S3	1995.	15	NK	17040	27837
S4	1994.	15	NK	22147	37055
After 20 years of exploitation					
S1	1984.	20	BV	19045	48826
S2	1984.	20	BV	15200	41900
S3	1984.	20	BV	15220	41920
S4	1984.	20	NK	11368	19496
S5	1984.	20	NK	11356	19496
S6	1984.	20	DNV	24844	42312
S7	1982.	20	BV	17436	47871
After 25 years of exploitation					
S1	1984.	25	BV	19045	48826
S2	1984.	25	BV	15200	41900
S3	1984.	25	BV	15220	41920
S4	1984.	25	DNV	24844	42312
S5	1983.	25	LR	25742	41427
S6	1984.	25	ABS	17599	4239
S7	1978.	25	BV	22372	38972
S8	1983.	25	LR	22112	38110
S9	1982.	25	BV	25056	44504
S10	1982.	25	BV	25056	44504

**Legend:* BV- Bureau Veritas, LR – Lloyd's Register, DNV – Det Norske Veritas, ABS – American Bureau of Shipping, ClassNK –Nippon Kaiji Kyokai.

data on corrosion wear for four bulk carriers being in exploitation 15 years (297 gauged points), for eight bulks being in exploitation 20 years (637 gauged points), and for nine bulk carriers being in operation 25 years (917 gauged points), have been given to our disposal. The collected data set represent the corrosion wear (loss) in the form of corrosion depth [mm]. Namely, these data were provided by UTM "Invar-Ivosevic" Company. However, it was difficult to fit the data collected by regular and standardized ships' measurements on site to the most commonly used Weibull distribution, which usually (along with normal and lognormal distribution) best fits the corrosion wear over ageing bulk carriers (Paik, Kim, Lee, Park, 1998; Ivanov, 2009).

Consequently, it was necessary to find out an optimal way of pre-processing the collected data in the attempt to fit them better into Weibull distribution function. For that purpose generator of random numbers for inverse Weibull distribution function has been used. The proposed algorithm, being employed in the paper, should be explained briefly through the following steps:

— Inserting into the Excel worksheet measured values of the corrosion depth [mm], over the ageing bulk carriers' inner bottom and hopper plating member locations;
— Generating random numbers for the inverse Weibull distribution function with predefined subjectively estimated distribution parameters (α, β, γ);
— Examining where the measured values of corrosion wear, on board, correspond to the pseudo randomly generated numbers, and then forming the new series of that values;
— Identifying the frequencies of appearing of each different measured values in the new-formed series, and
— Finally, by the EasyFit software (ver. 5.5), finding out which of the numerous offered distributions within this software model database best fit the selected data from the set of measured values; while the selection of the data was done, as it is still noted, in accordance with randomly generated numbers from inverse Weibull distribution law. These steps were realized by the Excel special function NTRANDWEIBULL (α, β, γ), and Excel imbedded functions LOOKUP (value, range) and COUNTIF (range, criteria). The function NTRANDWEIBULL returns Weibull pseudo random numbers based on Mersenne Twister algorithm. The function LOOKUP (value, range) returns values from the input data set on corrosion losses being measured on site that belongs to the corresponding random numbers intervals being generated from inverse Weibull distribution. The whole process of finding out the correlation between measured values and random generated numbers has been in accordance to Monte Carlo simulation method. An example of NTRANDWEIBULL (α, β, γ) function realization along with Monte Carlo simulations in Excel worksheet is shown in Table 4.

Table 4. An example of combining random generated numbers from inverse Weibull pdf and Monte Carlo simulation method (segment of the Excel worksheet).

	A	B	C	D	E	F	G	
1	Corrosion [mm]	Weibull RAND	LOOKUP	Diff. corr. ware values	No. of appearing	Frequency		
2	0.0	4.181834	3.1	0.0	35.0	0.062724	Mean:	1.5
3	0.0	2.125919	2.1	0.1	60.0	0.107527	St. dev.:	1.5
4	0.1	1.448396	1.4	0.2	0.0	0.000000	Var.:	2.3
5	0.1	1.209807	1.2	0.3	26.0	0.046595		
6	0.1	2.525701	2.5	0.4	30.0	0.053763		
7	0.1	0.922361	0.9	0.5	37.0	0.066308		
8	0.1	2.065580	2.0	0.6	45.0	0.080645		
9	0.1	7.218747	4.7	0.7	0.0	0.000000		
10	0.1	2.609389	2.6	0.8	35.0	0.062724		
11	0.1	2.382233	2.3	0.9	0.0	0.000000		
12	0.1	0.823797	0.8	1.0	21.0	0.037634		
13	0.1	3.279766	3.1	1.1	22.0	0.039427		
14	0.1	0.093471	0.0	1.2	13.0	0.023297		
15	0.1	0.300497	0.3	1.3	14.0	0.025090		

20 years grain / 20 years iron

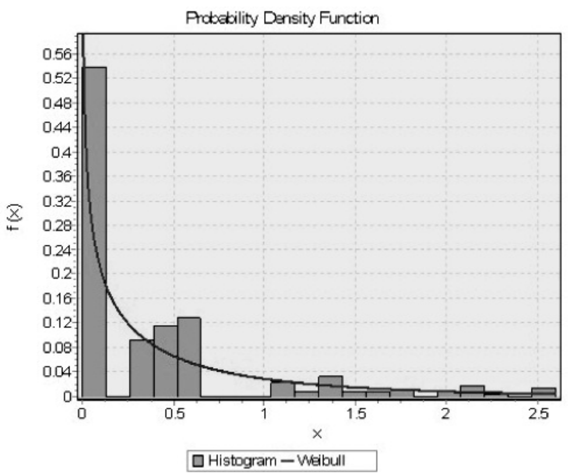
4. Numerical results

Within this subsection are presented some of the numerical, i.e. graphical results obtained by NTRANDWEIBULL function being imbedded into Excel, and combined with the Monte Carlo simulation concept of generating random numbers, along with examining how these random generated numbers correspond to the measured values of corrosion wear over IBHP member location of analyzed aging bulk carriers. Thus, probabilistically have been analyzed the data on the corrosion losses over ageing bulk carries within three different points of time, i.e. after 15th, 20th and 25th year of the ships' exploitation. Both bulk carriers for grain and other smallness (dusty) bulk cargos, and those for iron ore and coil have been taken into the consideration. Since the greater wear of the bulk carriers' structure steel due to the corrosion is observed over the ships which carry the iron ore and coil, than over those carrying grain or other light cargos, these two groups of bulks were treated separately by the previously proposed probabilistic-simulation method, and the following results have been obtained:

In the case of four ships for grain cargo, being in exploitation 15 years, the Weibull distribution function with noted parameters was found out as one that best fits the collected data on site, at 297 gauge points (see Figure 2).

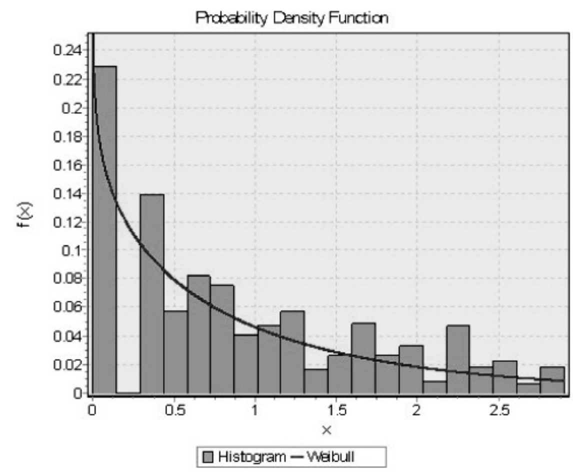
In the case of seven ships for grain and other smallness, dusty bulk cargos, being in exploitation 20 years, the Weibull distribution function, with below given parameters, has been found as one that best fits the collected data over 558 gauge points (see Figure 3). In the case of only one available ageing bulk carrier for iron ore and coil, being in service 20 years, the Weibull distribution has been identified again as one which best fits the gathered data over 79 gauge points (see Figure 4).

In the case of six bulk carries for transportation of iron ore and, being in exploitation 25 years, the Weibull distribution, with given parameters, was found out to best fits the collected data on the corrosion loss over even 679 gauged points (see Figure 5). These probabilistic data may be the subject of further more rigorous and detail analysis, but, they can give a general overview how and to what extent corrosion affects ageing bulk carriers in the certain



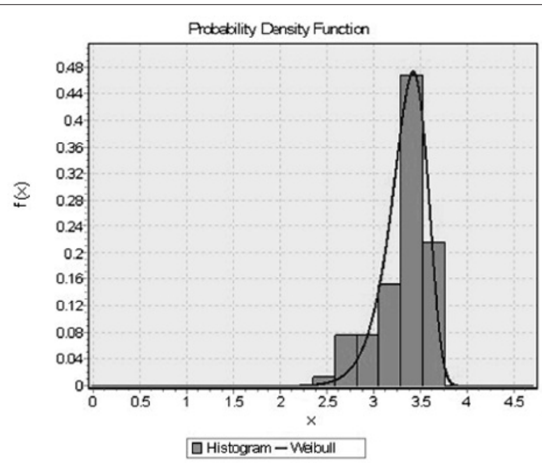
Parameters of the Weibull distribution function: $\alpha = 0.7$; $\beta = 0.51365$; $\gamma = 0$; Mean: 0.65019; Var.: 0.95085; St. Dev.: 1.4624

Figure 2. Corrosion depth [mm] measured over the bulk carriers being in exploitation 15 years (cargo: grain).



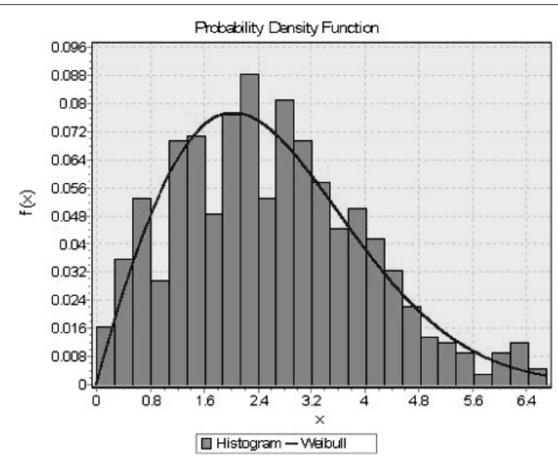
Parameters of the Weibull distribution function: $\alpha = 0.87$; $\beta = 1.0$; $\gamma = 0$; Mean: 1.5; Var.: 2.3; St. Dev.: 1.5

Figure 3. Corrosion depth [mm] measured over the bulk carriers being in exploitation 20 years (cargo: grain).



Parameters of the Weibull distribution function: $\alpha = 18.7$; $\beta = 3.4292$; $\gamma = 0$; Mean: 3.3326; Var.: 0.04858; St. Dev.: 0.22041

Figure 4. Corrosion depth [mm] measured over the bulk carriers being in exploitation 20 years (cargo: iron ore).



Parameters of the Weibull distribution function: $\alpha = 1.9548$; $\beta = 2.9351$; $\gamma = 0$; Mean: 2.6024; Var.: 1.9283; St. Dev.: 1.3886

Figure 5. Corrosion depth [mm] measured over the bulk carriers being in exploitation 25 years (cargo: iron ore).

point of time (after 15, 20, and 25 years of exploitation). What is obvious is that the corrosion wear rapidly grows with time, which the ship spends in exploitation. Namely, the parameter beta of Weibull distribution considerably grows as the time of service becomes longer. As well, the corrosion losses are much more in the cases when bulk carriers were used for the transportation of dense cargoes like iron ore and coil, than in the cases when they were used for the transportation of grain and other smallness, or dusty bulk cargos. By the proper modifications in the input data set (measured values of the corrosion losses on site) it is achieved that some of the collected data are well fitted into the Weibull distribution function, what can be used later effectively for predicting corrosion depth depending on time which bulk carrier spent in service. The modifications are based on matching the collected data by those randomly generated form the inverse Weibull distribution with arbitrary chosen parameters. This model might be proposed as general one for pre-processing data which are likely to be properly fitted to the Weibull distribution function.

5. Conclusions

The structural member locations of ageing bulk carriers are exposed to a range of corrosive environments. The existence and also the influence of each environment do not remain constant throughout the bulk carriers' service lives. Though, the attempts are directed toward developing as reliable as possible time-variant probabilistic based patterns of corrosion that are characteristic to each, and particularly to those spaces that are the most influenced due to the corrosion wear. Due to some previous analysis Bauk, Ivošević, 2011; (Bauk, Ivošević, 2010; Bauk, Ivošević, Nikolić, 2010; Wang, G., Lee, Ivanov, 2008) the IBHP has been identified as the most vulnerable member location (area/zone) of aging bulk carriers, and it was probabilistically treated on the basis of the set of original data on the corrosion losses over several analyzed bulk carriers on sites. The measured data have been pre-processed, or filtered, in accordance with randomly generated numbers from inverse Weibull distribution. It has been shown that the pre-processed measured data well follow the Weibull theoretical probability density function, and their main parameters (mean value, standard deviation, and variance) have been calculated for the bulk carriers' being in service 15, 20 and 25 years (in cases of grain and iron ore cargos). The observed scatterings in the Weibull functions parameters over analyzed data sets of measured corrosion depths, pointed the need for further more rigorous investigation in this field above the larger set of the original data being collected in shorter time intervals. Consequently, corrosion losses over ageing bulk carriers' member locations require paramagnet monitoring and profound analysis over each particular segment, and over the vessel hull structure as a whole, simultaneously.

Acknowledgement

The data for the purpose of qualitative-quantitative and probabilistic analysis in the paper have been provided by the UTM "Invar-Ivosevic" Company. The Company provides marine services of ultrasonic thickness measurements over vessels' hull structures and it has nine valid certificates issued by the recognized classification societies: LR, BV, DNV, RINA, ABS, ClassNK, GL, and RSR. It has inspected more than two hundred vessels. Some more information about the Company can be found at URL: http://www.invar.me/index.html.

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JOURNAL OF MARITIME RESEARCH

Vol. IX. No. 3 (2012), pp. 81 - 86

ISSN: 1697-4840 www.jmr.unican.es

The Environmental Impact of Cruise Ships in thePort of Naples: Analysis of the Pollution Level and Possible Solutions

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ARTICLE INFO

Article history:
Received 12 June 2012;
in revised form 14 June 2012;
accepted 30 July 2012

Keywords:
Environment, Emissions, Cruise Ships, Ports, Cold Ironing

ABSTRACT

The environmental problem in land activity has created a great alarm especially close to highly inhabited zones; for harbours the main problem consists in the contemporaneous presence of a number of ships releasing large amounts of noxious substances in the air and the water. New regulations and limits to these elements have been set up in order to limit the impact on human activities. This problem should be urgently faced in order to avoid very dangerous consequences in such critical zones. One of the ports closer to the centre of the town with a significant influence on its life, lies in Naples, in the core of the urban activities with thousands of people living and working nearby.

In this paper the case study of the port of Naples is developed with particular regard to the exhaust emissions from the cruise ships which frequently berth in Neapolitan bollards, keeping most of their engines on in order to produce the electric energy needed for the auxiliary services onboard. In fact, the contemporaneous presence of four or five cruise ships may create a very dangerous environment, especially for people living close to the harbour.

In the frame of a research program which involves the CNR Istituto Motori and the University of Naples "Federico II", tests on the quality of the air were recently done; first results of this research are reported together with the analysis of the possible solutions to the problem. In this phase, the most important components of pollutants were analyzed: NOx and SO_2.

1. Introduction

It is well known that the environmental question worries all the communities exposed to risks coming from the effects of human activities in terms of pollution of soil, air, water and whatever may have a significant impact with human life.

More recently this concern has been extended to the water cities for their continuous and close contact with several sources of environmental risk. Indeed, in some cases, the operation of ships involves very inhabited zones, where relatively large amounts of risky substances flood the environment.

Lets consider Venice, for example, where thousands of people (and thousands of very important masterpieces) are daily in contact with the exhausts from a multitude of ships operating in the lagoon and in the centre of the town and where the banks of the canals are exposed to the decay due to the wash effect generated by a very intense marine traffic along the Venetian waterways.

Naples, with its port occupying a large part of the coast, is one of the watercities where the industrial activity connected with ship operations has the largest impact on urban life; and such impact is evidently worsened by the position of the mooring points destined to cruise ships which is located close to the main square of the city, in the very centre of it. In some periods, even five or six cruise are contemporaneously berthed in Naples; since many people live and work there, it is very hard to ignore the high impact on the exhaust emissions from the engines of such a ships on the human life in a relatively small but very important area. (Coppola ans Quaranta, 2010; Battistelli et al., 2011, 2012; Battistelli and Fantauzzi, 2011)

2. The port of naples

The port of Naples must be considered a particularly interesting case where several industrial activities (passenger moving, fuels and products treatment, containers and merchandise transportation and so on) are carried out with a

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very important impact on the surrounding areas. Its main characteristics are reported in Table 1.

Table 1: Main characteristics of the Port of Naples.

Coordinates		40°51'19" N - 14°15'36" E	
coast occupation	> 5 km	containers moved (number)	> 300'000
bank available length	> 11 km	containers moved (TEU)	~ 500'000
berths	75	passengers (general)	~ 7'000'000
inner street available length	> 3 km	passengers (cruise)	~ 2'500'000
inner railway available length	2 km	number of cruise ships (per year)	~ 700

3. Rules and effects on the health

Among the noxious contents emitted by marine engines, relevant attention is paid to SOx and NOx emissions; this is due mainly to the relatively large amount of this substances in the exhausts. Other components are either emitted in smaller quantities by diesel engines (NO) or unavoidable for the correct working cycle of engines (CO_2) or their emission is connected with other substances (i.e. PM, whose presence in the exhaust strictly depends on the content of SOx in them).

The only way to contain the NOx emissions is to set the engine with this goal; the IAPP certificate assesses the capability of the engine to respect the imposed limits. Table 2 shows the present limits for engines running at given rpm and those that will be applied after 1/1/2016.

Table 2: Annex VI to Marpol (Tier I & II), rule 13.

Engine Speed	Tier II (< 1/1/2016)	Tier III (> 1/1/2016)
rpm < 130	14.4	3.4
130 < rpm < 2000	44 / $rpm^{0.23}$	9 / $rpm^{0.2}$
2000 > rpm	7.7	2.0

As regards the SOx emissions, they are limited by imposing a max content of sulphur in the bunkered fuel. As an alternative to this, it is allowed to use normal sulphured fuels as long as the content of SOx in the exhaust doesn't exceed 6.0 g/kWh (this can be achieved by installing an efficient scrubber). As a comment to this situation, a severe control of real emissions from ships should be performed in order to asses the environment - friendly quality of energetic systems accepted in ports.

Excessive emissions of noxious elements may lead to serious damages to human health and to environment in general. Consequences of the intake of such substances have been well known for some time to WHO that indicates the maximum exposure to each of them together with possible effects on the human organism.

Table 3 reports these conclusions together with a prediction of possible disease to human health.

Table 3: – main effects of the exposure to SOx and NOx.

Sulphur oxides	
Concentration	*Effects on the health*
	Exposure with limited injury
0,06 mg/m³	possible bronchitis episodes and chest infections
0,3 mg/m³	possible damages to the respiratory system (especially for children and elderly)
0,8-2,6 mg/m³	olfactory sensing of the substance (stimulates search for gas mask and refuge)
	Exposure with serious injury
0,06 mg/m³	possible bronchitis episodes and chest infections
0,3 mg/m³	possible damages to the respiratory system (especially for children and elderly)
0,8-2,6 mg/m³	olfactory sensing of the substance (stimulates search for gas mask and refuge)
Nitrogen oxides	
Concentration	*Effects on the health*
50-150 mg/m³	(for short periods of time) possible harm to lungs
100 mg/m³	serious damages to the breathing apparatus
300-400 mg/m³	lethal

From the point of view of the maximum acceptable limit for the concentration of NOx and SO_2 in the air, the reference rule now in force is the # 155/10: "accomplishment of the DIRECTIVE 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe" Table 4 reports these limits.

Table 4: – allowable limits for the concentration of NOx and SO_2 in the air.

substance	*kind of average*	*maximum acceptable limit*
NOx	1h	200 µg/m³
	civil year	40 µg/m³
SO_2	24 h	125 µg/m³
	1 h	350 µg/m³

4. The data logging campaign in the neapolitan harbour

The first data logging campaign was carried out in the period March 25th - April 10th, 2012. The site is indicated in figure 1. To evaluate and register the composition of the air we used an equipped van with some precision instruments onboard for the monitoring of the main contents in the air. The exact position of the van is given in Figure 1 where it is possible to notice how close to the mooring site of the cruise ships the measurement point was. The sampling rate was about one minute but, for the moment, only hourly averages are available for each component logged.

Beyond the quality of air, also weather - wind characteristics were logged: direction and intensity of the wind,

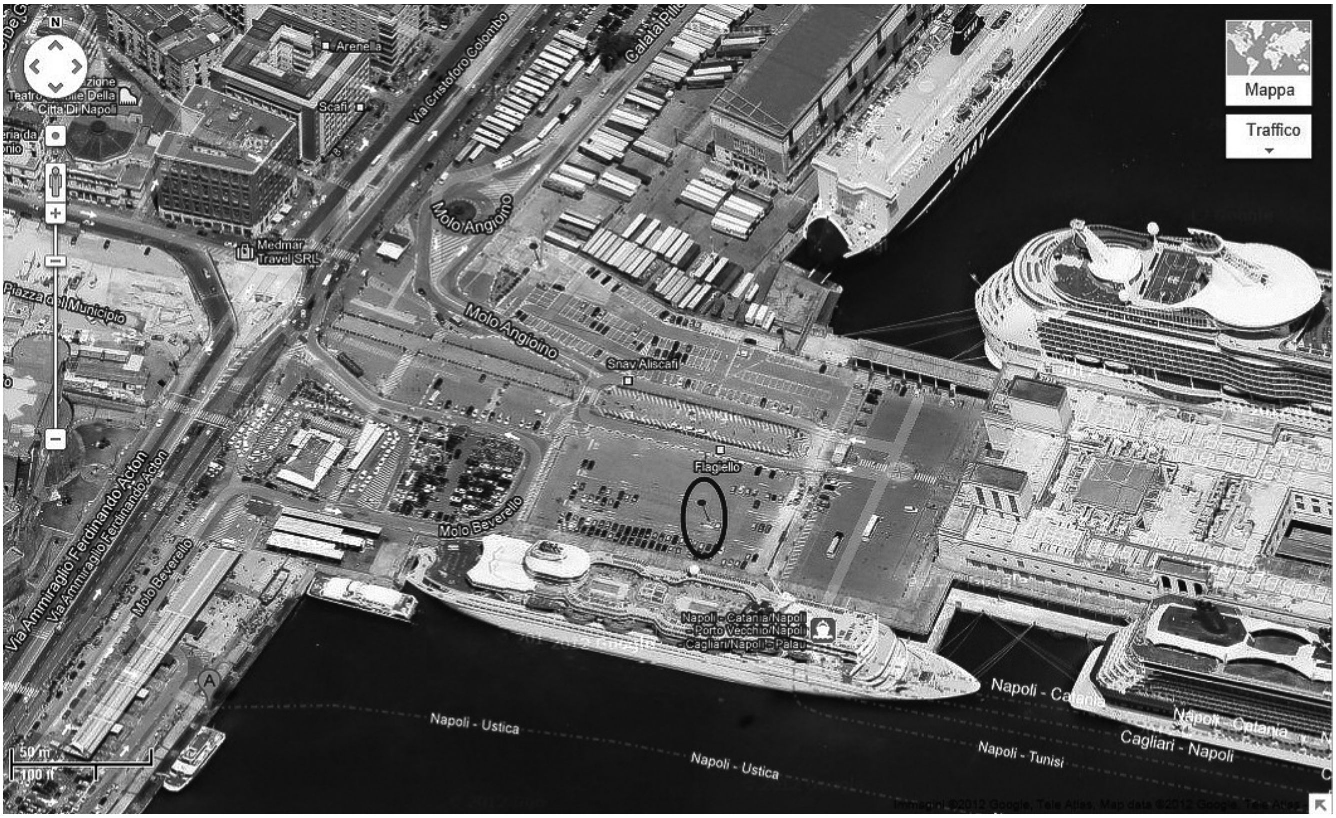

Figure 1: The site were the data logging campaign was done.

pressure, temperature and humidity of the air. These elaborations (the first on this set of data) could not take into account these conditions whose influence on the quality of the air will be assessed in following phases.

5. The results and a first correlation between the emissions form ships and the noxious contents in the air

The final goal of the present experimentation is to build a reliable routine able to correlate the presence of ships in port with the quality of the air in terms of level of main noxious substances in it.

The present step was carried out by setting up a mobile laboratory with various analyzers and leaving it in a given (and strategic) zone of the port for more than 10 days. During this period NOx and SO_2 concentrations in the air were measured; the former with the chemiluminescence method, the latter with the fluorescence.

In order to improve the accuracy of the level of the correlation, also weather, wind and rain conditions were logged (local and general). Of course, also the attendance of ships was registered in the observed period.

A reasonable nexus between the emissions from ships and the quality of the air in the zones close to berths is very difficult to built; to achieve a good correlation, the incidence of weather factors, the diffusion of compounds in the air, the exact positions of ships and many other factors having some incidence on the quality of air, must be analyzed with very accurate methods capable of mapping the emissions from engines (together with all other sources of pollution); it is also important to reveal the real distribution of the noxious substances in the various zones involved in this particular and complex kind of pollution.

In this first application phase of the research program, a series of elaborations were carried out in order to initialize such a challenging operation with present instruments and data.

In the following, the main criteria used for the experimentation will be detailed.

After the results of the pollutant emissions campaign came in, a first level appreciation of the pollutant really emitted by the engines of ships at berth was required. Unfortunately, apart from the very difficult determination of the real state of the load of engines operating during the campaign (and related emissions), for several reasons, it is always very hard to obtain reliable data of the operations of ships.

As a first approach, we got over such a difficult problem by using a database kindly offered by Fincantieri, the Italian national Shipyard Company.

This database contains the values of the main characteristics of the cruise ships built by Fincantieri; among them, overall length, overall power installed onboard, electric motors overall power, summer and winter electric loads for hull and hotel devices.

A quick research on the ships present in the Neapolitan port during the acquisition could reveal only few reliable data; practically, only overall length and ship speed are available for (almost) all of them, other variables are spread in a very non-homogeneous manner and are definitively not usable for a decent statistic elaboration.

Mainly, the most important value to determine was the electric load on the engines acting during the observation period because the emissions of the noxious gases from engines are evidently connected with this parameter. But this was not the only problem to solve: even knowing (or evaluating) the level of the load from engines, how to realize the level of NOx and SOx coming from the exhausts?

Thus, by using the Fincantieri database, a linear regression was carried out to correlate the only available variable – the overall length of the ships – to the winter load in port, the most significant for the spring period when the acquisition was done.

Such correlation gave the results shown in Figure 2, the correct value of squared R was about 0.20, the standard error of about 2100 kW.

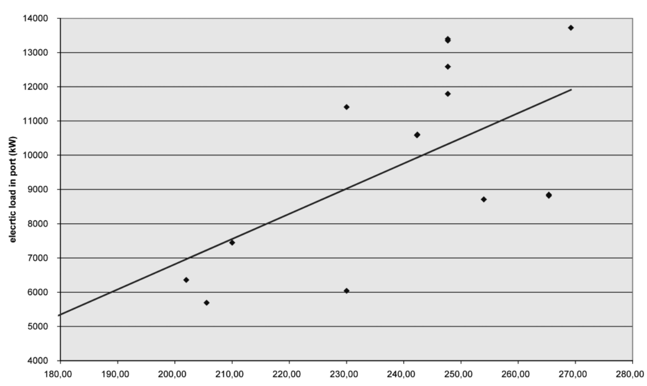

Figure 2: Correlation between the overall length and the electric load in winter conditions for cruise ships.

As for the values of the NOx and SOx really emitted by engines, we also had a complete lack of data; the evaluation of such figures was carried out by assuming the maximum value of the emission permitted by the present reference rule (ANNEX VI to MARPOL, rule 13 which imposes a max value of NOx as a function of the load on the engines); such maximum value, for engines running @ 600 rpm, is 10.10 gNOx/kWh.

This method can be deemed adequate for the evaluation of NOx that is certified by the IAPP document (everyone attempts to set the engine at the most advantageous conditions which, more or less, means the maximum allowable emission of NOx); since the reduction of sulphur oxides is achieved by reducing sulphur in the bunkers, it is very difficult to predict the real emission in SOx.

In this case, the value of 6.0 gSOx/kWh allowed by ANNEX VI has been deemed acceptable for these cases where no low-sulphured fuels are available onboard and such emission can be achieved by using a retrofit (generally, a scrubber device).

With this method, it is possible to obtain the following graphs where, as a function of the time, the measured concentration of NOx is reported together with the predicted value of the emissions from engines of ships present in port. The same was done for the SO_2 emissions.

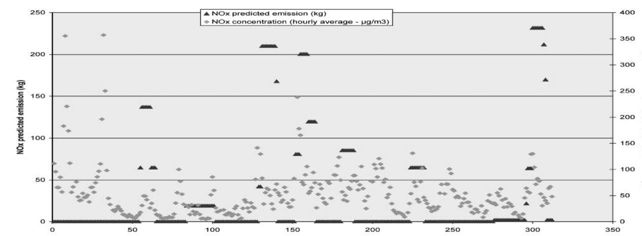

Figure 3: NOx predicted emission and concentration in the air.

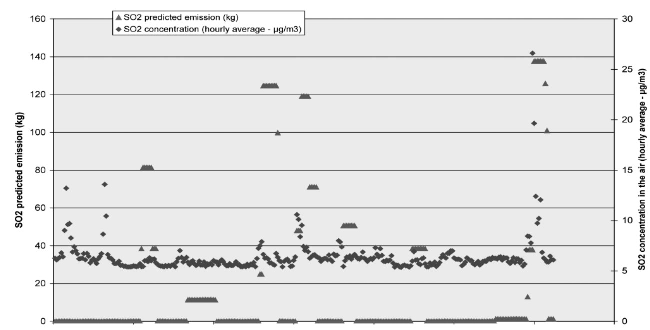

Figure 4: – SO_2 predicted emission and concentration in the air.

A first analysis of these diagrams reveals some dependence of NOx and SOx emissions on the presence of ships at berth; on the other hand, it must be considered that the period of acquisition was not very busy from the point of view of the cruise activity, although, sometimes (including Easter), two contemporaneous presences were registered.

The first evidence is that, in every moment of the day, the level of contents of noxious elements in the air is less than that the maximum one allowed by the abovementioned rule 155/10. The SOx appears always much less then the permitted emission. NOx is closer to the limit but always lower; the weak distance to the acceptable limit, reached in some moments of the acquisition period, could be exceeded when the cruise traffic will be much more intense (May - June and September - October).

By observing the development of the lines, it is evident that in that periods when there are cruise ships in port, close to the acquisition point, the levels of NOx and SOx grow; but also in some moments when no ships are berthed, significant levels of SOx and, in particular, NOx are reported. Unfortunately, apart from the presence of ships, it was impossible to log the effects of any other activity potentially able to produce pollutants; but, evidently, it is possible to assess that there could be other operations, close to port area especially in the first period of observation, producing the logged level of SOx and NOx in the air.

Since logged levels are relatively low, it is very probable that other activities (mainly, urban traffic) could affect these data having a noticeable impact on the overall acquisition. During future data logging campaigns, since the number of cruise ships in the harbour will be much higher, a more direct dependence of their presence on the quality of the air is expected. However, in some sense, this experience can be considered as an ideal "offset" of the air conditions in the harbour area, more influenced by activities in the rest of the town than by port operations.

It is evident that such a method must be improved; indeed, important enhancements must be made in order to outline a reasonable scenario of the emissions from ships in the port of Naples and its consequences on the quality of the air in those zones. On the other hand, a complete investigation involves many aspects of the phenomena taking place in that area; it is not by chance that, although the problem of having five or six ships emitting tons of noxious elements under the nose of thousands of people is very felt, no believable figures are available on this matter hitherto. However, apart from the abovementioned quality of the assessment of emissions from ship engines, other points of weakness appear in the present investigation, due to the following items.

First of all, to connect the emissions from the ship to the real content of NOx, SOx and other substances in the air, a very deep knowledge of the diffusion of such substances in the atmosphere is required; this, in turn, strictly depends on thermal gradient and winds and it should be correlated with them to know exactly the level of possible pollution consequent to certain levels of emissions from ships.

Then, it is to be kept in mind that the Neapolitan port area is adjacent to the very centre of the town, where a great number of industrial activities are carried out; among them the city traffic and the heavy transportation activity – acting very close to the acquisition point – may have a strong impact on the air composition and it can interfere with the interpretation of the real source of the measured pollution.

Thus, in order to achieve a complete and reliable monitoring of the air quality in the Neapolitan port and of its dependence on the sources of pollution, many other elaborations and competences should be involved.

6. Possible remedies

Results arising from the present experimental surveys of emissions can address possible remedies to adopt. Independently of the limitation of surveys to only some pollutants as NOx e SO_2, remedies can be best directed to reduce the entire spectrum of emissions. This involves a careful estimation of economical and environmental benefits and then the implementation of proper methodological approach to investments and interventions.

A drastic reduction of emissions can be obtained preventing ships from using on board electrical generators during berthing, by providing electric energy supply by shore-to-ship service. The used technology is known as "cold ironing". It started in the 80s for military ships, small crafts and ferry-boats, and more recently it was extended to other types of commercial ships which need large power also for berthing, as cruise, container and tanker ships. Table 5 reports the main installations of cold ironing made in Europe end U.S.A. up to 2008.

Table 5: Cold ironing realizations in Europe and USA.

Geographical area	Ports
Europe	Göteborg, Stockholm, Helsingborg, Piteå (Svezia), Anversa, Zeebrugge (Belgio), Kotka, Oulu, Kemi (Finlandia), Lubecca (Germania)
U.S.A.	Los Angeles, Long Beach, Pittsburgh (California), Seattle (Washington), Juneau (Alaska)

Other applications are in progress in eastern countries like China and Japan and in various parts of the world. In Italy, nearly all the most important ports are planning to apply cold ironing technology (García, Castaños, Irastorza, 2011).

Frequency and voltage are main electrical parameters involved and crucial for the connection of on board electrical facilities to the shore distribution grid.

The reference frequency specifications are 50 and 60 Hz, while the voltage values are in the 0,4-11 kV range. The installed powers – both for single berth, and the whole port – depend on the number of service stations and on the ships to be supplied. The sizing criteria mainly depend on the port vocation as well as on the energy and environment policy adopted by the Port Authority. Figure 5 shows a typical scheme of cold ironing.

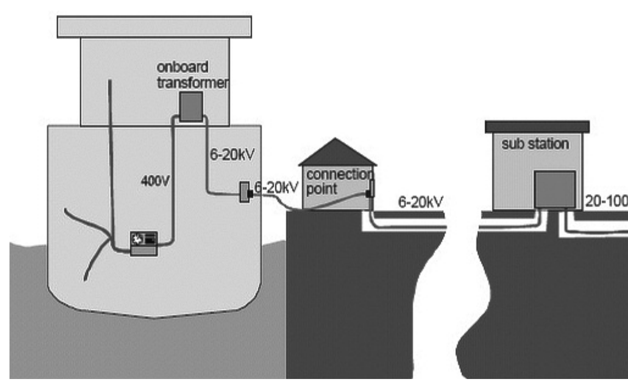

Figure 5: Typical co ld ironing scheme.

In general, we can foresee future ports with a certain number of electrified berths, equipped with interoperable supply stations for the connection with different types of ships having different electrical standards on board.

Starting from cold ironing, remedies for NOx and SO_2 pollution can be provided within wider and systemic plans addressing sustainability in both internal and external port areas, possibly integrated with metropolitan area environment.

In the near future, port areas are expected to become “smart”, with the integration of environmental monitoring to intelligent distributed energy resources, including shore to ship facilities, renewable energy local generation, storage devices, centralized and remote control managed according to the technological “smart grid” paradigms based on active power distribution. In this way, remedies against pollution can have further considerable fallout on both local and global environment.

7. Conclusions

The first results of a wide research program, recently started on the quality of the air in the port of Naples, showed a certain dependence of the presence of cruise ships at berth on the concentration of the main pollutants; for the moment, only NOx and SO_2 emissions were examined. Since the first test campaign was carried out in a down time, when only few cruise ships work, the influence of other activities clearly interferes with the pollution level detected; but, by analyzing and crossing the concentration of NOx and SO_2 with the emission of these substances some correlation appears. Future investigations, planned in a busier period, will clear this aspect and, we hope, will give further tools to estimate the impact of the cruise activity. In this context, the study of a wider application of cold ironing seems to be particularly useful as the most drastic system to move away the main sources of pollution from the most inhabited zones of the watercities.

Aknowledgments

The authors are very grateful to Fincantieri SpA, for the data provided on cruise ships manufactured in their yards, which allowed the prediction of the load on the engines when cruise ships were in port; we also thank the “Autorità Portuale” (Port Authority) of Naples and, in particular its President, Adm. Luciano Dassatti and Mrs. Cristina Tranchino, whose cooperation has been essential for a good success of the data logging campaign on the contents of the air in port.

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