The Future of Ship Design

Part II

DELTA MARIN®

The Future of Ship Design Part 2

Published for Deltamarin Ltd by The Royal Institution of Naval Architects

June 2001

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Compiled by Deltamarin in association with *The Naval Architect* journal

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Printed in England by:
BBH Colourprint Group
Gorse Hill Industrial Estate
Beaumont Leys
Leicester LE4 1BF

ISBN 0 9030 55 67 8

THE FUTURE OF SHIP DESIGN - PART 2

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The Future Of Ship Design Part 2

Introduction

Dear Colleague,

The good feedback we received from the first edition of *The Future of Ship Design Part 1* encouraged us to continue.

The basic text for this *Part 2* volume has been supplied by naval architects, marine engineers, mechanical engineers, and electrical engineers working at Deltamarin Ltd. The articles on passenger evacuation simulations and risk-based design were prepared by Professor Dracos Vassalos, from the University of Strathclyde, in Scotland. We have also received valuable input from Mr Harri Kulovaara, senior vice-president, marine operations, of Royal Caribbean International, and from Mr Rolf Kjaer, technical director of Color Line Marine, for development of the total safety assessment and the passenger evacuation simulations.

The publication has been edited by Tim Knaggs, editor of *The Naval Architect* and other publications of The Royal Institution of Naval Architects.

The first edition concentrated on basic naval architecture and machinery configurations, and presenting built case studies. *Part 2* handles safety, safety simulations, and shipyard planning, but also continues to describe possible modern machinery configurations.

Practical methods are described for safety assessments and simulations. IMO is continually working on safety issues and formal safety assessment (FSA) and has described some fundamental basic guidelines. However, the practical tools have been missing.

Our safety chapter explains a method based on the philosophy of formal safety assessment and gives practical results of how to improve safety and service reliability of existing vessels. The method is also applicable for new ships. Theory for reliable and comparable passenger evacuation simulations is described with some practical verifications.

Designs based on simulation and safety are widely discussed within the shipping and shipbuilding industry. The huge development in technology, also in vessel concepts and size, requires a pro-active approach in safety issues. New concepts should be thoroughly tested before applying. Modern simulation technique and risk-based assessment methods offer an interesting opportunity for design based on risk and simulation before anything is actually built.

I hope this publication offers some thoughts on how to utilise simulation and safety assessment technique in practical ship design. It is obvious that new design methods based on modern 3D computer models and knowledge management systems will allow the industry to carry out design tasks in a more comprehensive way than ever before.

Markku Kanerva, MSc (Nav Arch)
Director, Business Development
Deltamarin Ltd

June 2001

Practical tools for improving ship safety

At the recent Cruise & Ferry 2001 conference*, a paper by Harri Kulovaara, Dracos Vassalos, Markku Kanerva and Janne Luukkonen discussed two new engineering approaches dealing with ship safety, developed and tested during the last 15 months. The paper addressed safety as a global issue (total safety assessment - TSA), also the timely issue of passenger evacuation. In both cases, the theoretical background, developed methodology, and practical results are presented. The TSA concept has been developed at Deltamarin and the EVI program at the University of Strathclyde in close collaboration with two shipping companies, Royal Caribbean International (RCI) and Color Line.

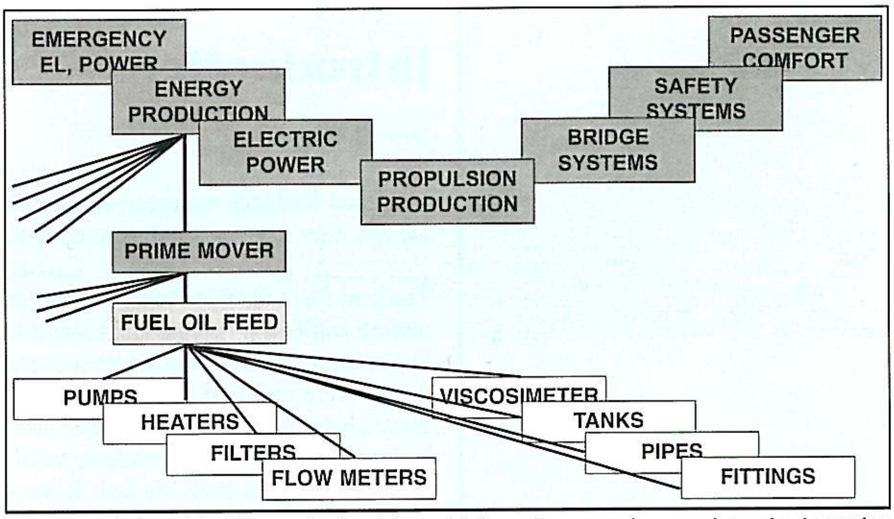


Fig 1. Description of the ship service breakdown database. Seven services are determined covering all functions aboard. The model shows which components are needed for producing different services.

DESPITE fast development during the last decade of new safety and redundancy rules and regulations, accidents unfortunately continue to happen. The rapid development of marine technology, prototype ships, growth in ship size, and ageing fleets demand pro-active methods for preventing failures, incidents and accidents. So far, the development of new rules has mostly taken place in reaction, in other words as lessons are learned.

Most accidents are caused by human errors. A major number occur because the systems and equipment are not ergonomically designed and do not function logically. In the future, much attention should be paid to securing easy use of systems and equipment, with the design of functions being self-explanatory.

Incidents and delays are also caused by technical failures of components and systems. This type of disturbance induces considerable and unnecessary expense. The number of these incidents can be decreased by dedicated maintenance of components, by building redundancy into systems, re-arranging components, and by protecting hot surfaces in engineroom spaces. There are numerous ways of increasing safety onboard. What has been missing, however, is a systematic, comprehensive, and practical method for establishing the most effective ways for increasing safety and service reliability.

In recent years, a lot of discussion has taken place around the formal safety assessment (FSA) concept. This technique consists of different types of commonly used tools of reliability technology; for example, failure mode and effect analysis (FMEA) and fault-tree analysis (FTA) are basic means of inventing new rules by FSA.

It can be used effectively for producing generally applicable new rules for different ship types; however, it is not applicable for optimising the safety of individual ships. FSA is a theoretical approach and gives no practical tools for defining how the safety and service reliability of an individual ship can be improved.

Every ship is an individual, requiring special solutions and arrangements. Different machinery spaces have their own risky areas when, for example, thinking of fire risks or consequences of mechanical or electrical failures. Bridge systems have their own special features, with different layouts, equipment and makers.

Safety systems are characterised by their own capabilities and operating methods. All these issues have an effect on safety and service reliability of a specific ship, and should be considered as such. Generally applied rules developed reactively or by FSA will only give indirect and limited guidance in establishing this kind of special risk.

Commonly applied methods in reliability technology mostly concentrate on analysis of documentation. Analysis of the design is an important part within the process of identifying rational solutions for increasing safety of a particular ship; however, this is not sufficient. A ship designed to fulfil the highest safety and service reliability expectations may fail due to defects in implementation.

Usually, this is caused by a tight building schedule, insufficient surveillance during the building procedure, or lack of understanding in the installation phase or missing procedures. Effective surveillance demands the use of customised tools to assist the documentation management and to provide guidance for surveyors by highlighting the relevant safety and reliability issues.

During the lifetime of a ship, many modifications are carried out - mainly by the crew - which affect also safety and reliability. Safety awareness and culture become critical issues.

Incidents during recent decades have made owners suspicious about the adequacy of safety levels reached by present methods. Too many close-call situations have been seen, and many owners are now willing to invest in boosting the safety and service reliability of their fleet to a higher standard. But the question is how to find the most risky areas, arrangements, and systems, also the most cost-effective ways to improve ship safety.

Background to the work

Deltamarin has developed, in co-operation with two owners - Color Line and Royal Caribbean International - a practical method for increasing ship safety. This pioneering method is called total safety assessment (TSA). Both owners had experience from earlier theoretical safety assessment projects. Based on this experience, emphasis was put on three main objectives: the new approach should be systematical and comprehensive, and especially it must give practical results in analysing a ship and in finding out the most cost-effective ways to improve safety and service reliability.

This feature was seen as important for securing the identification of all risky issues onboard. A new method based on FSA was developed to fulfill these objectives. If the safety assessment process is to be efficient, the effort required to accomplish the study should be minimised. This target was reached by developing a working procedure that can be repeated from one case to another. Database and software were developed for ensuring systematic document management and an

* *Improving ship safety with practical tools*, by Harri Kulovaara, MSc (Nav Arch), senior vice-president, marine operations, Royal Caribbean International Inc, and Professor Dracos Vassalos,The Ship Stability Research Centre, Department of Ship and Marine Technology, University of Strathclyde, Markku Kanerva, MSc (Nav Arch), director, business development, and Janne Luukkonen, MSc (Nav Arch), product manager, R&D department, both from Deltamarin Ltd. Presented at the Cruise & Ferry 2001 conference, held at Olympia, London, May 8-10, 2001, organised by Lloyd's List Events, 67/69 Paul Street, London EC2A 4LQ, UK.

efficient identification process of risky issues.

The new method must identify all single mechanical or electrical failures, or operational errors leading to a situation where a ship is incapable of fulfilling its mission. The assessment method is to identify all fire-risk issues in machinery spaces and in all other high fire-risk areas and spaces. Hot surfaces and components handling oil must be located and rational proposals for preventing fires must be found.

The redundancy of machinery and systems has to be analysed in case of fire aboard, as well as proposals for ensuring operability of essential functions during a compartment fire. It is essential to survey fire integrity of compartments to prevent escalation of fire, as well as the sufficiency and location of fire-fighting systems and equipment. The operational reliability and proposals for securing the functioning of fire indications and fire alarm systems must be checked.

In case of grounding or collision, a ship should maintain its watertight integrity and should not capsize or sink. The method is to identify possible leakage and flooding risks in watertight bulkheads and watertight decks and systems. In the case of grounding, a ship should maintain take-me-home propulsion capability - even if several compartments are flooded. The method should suggest rational advice and proposals for managing this type of hazardous situation.

Results given by an assessment must be easily implemented. Experience gained from previous safety assessments have convinced the authors of the importance of self-explaining results. This feature was seen as one of the key characteristics. The report must include practical proposals for increasing ship safety and operational reliability, and these must also be set into priority order.

This has to be determined by using computational estimation. The purpose of this is to determine the highest risk probabilities and the most cost-effective proposals; in other words, actions that will do most to increase safety and service reliability in relation to risk and cost. This enables priorities in action implementation to be set out.

Total safety assessment and recent experience

The total safety assessment method must be a comprehensive one to cover a complete ship and all of its vital functions, but in addition, it must as well cover the whole process through design, engineering, document control, and survey. Drawbacks of theoretical methods should be avoided. Incident statistics are missing for modern vessels, especially for modern cruise liners and ferries equipped with the latest technology and systems.

An auditing guide was developed, supported by a database. This guide consists of two databases: 'Ship service breakdown' and 'Evaluation criteria', and carries a surveyor through the work and through the whole process. It also assists in data handling and management, and includes an on-the-spot fast reporting system.

The ship service breakdown database contains all essential ship functions and components. This novel model can be implemented for all types of ships and ensures that all functions and spaces are surveyed during an assessment. It speeds up work by giving a detailed list of spaces, systems, and components to be surveyed during the process.

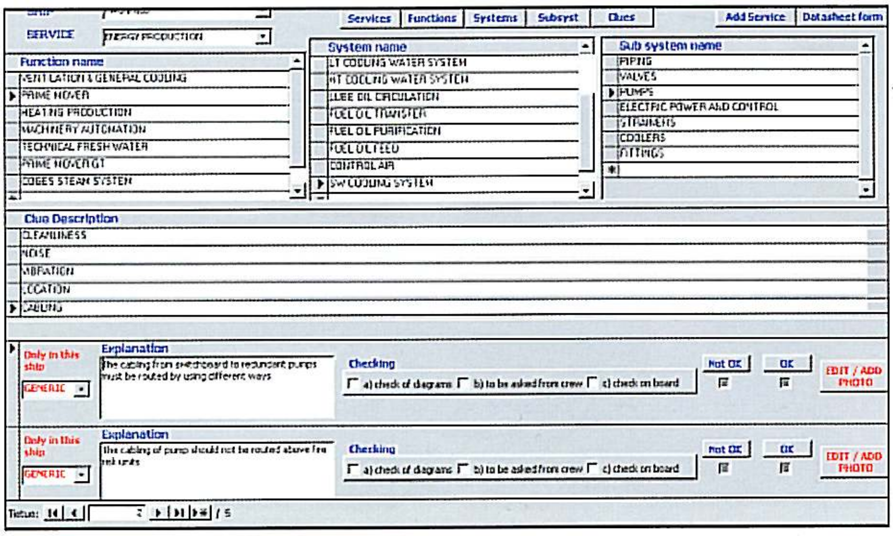


Fig 2. An overall view of the auditing guide. The application contains two databases and gives the surveyor information as to where to pay attention during the document control stage and ship audit. It also assists in reporting by enabling direct printing of identified defects and action proposals.

The ship service breakdown contains four different levels (Fig 1); these are: services, functions, systems, and sub-systems. Service level is the highest level and sub-system the lowest. Services contains seven different sections: energy production, emergency electric power, electric power, bridge systems, safety systems, propulsion production, and passenger comfort.

Energy production contains electric power and heat production. Emergency electric power production and distribution are included under emergency electric power. Electric power distribution and consumers are within electric power. Bridge systems contain navigation communication, safety and other bridge systems. Safety systems contain issues related to management of different types of hazardous situations aboard such as fire or flooding events.

Passenger comfort contains functions needed for passengers and crew, such as heating, air-conditioning, water, toilet and similar systems. These are considered to be important ones, especially in cruise liners and ferries; however, due to a modular structure and the link to the ship specification system, the ship service breakdown can be easily adopted or widened for any other approach or ship type. The service level is divided in accordance with functions and systems into smaller entities, and the sub-system level contains components such as pumps, fire detectors, and process sensors and breakers.

Evaluation criteria are developed to ensure a systematic, comprehensive, and efficient approach. A criterion is determined for each sub-system included in the ship service breakdown database. By checking all the items described in the criteria database for each component shown in the service breakdown, all essential and important risks are certain to be identified. At present, the evaluation criteria database includes more than 4000 items for checking.

Experience from modern cruise liners and ferries has been fed into the database. Experience has been gathered from designers, surveyors, crew members, and superintendents. Important and valuable statistics are being gathered. A lot of near misses as well as actual incidents are reported for equipment, sub-systems, systems, and spaces. The size of this database grows continuously through new commissions.

The assessment method itself contains three different phases: document control, ship audit and reporting. The auditing guide follows through all the phases.

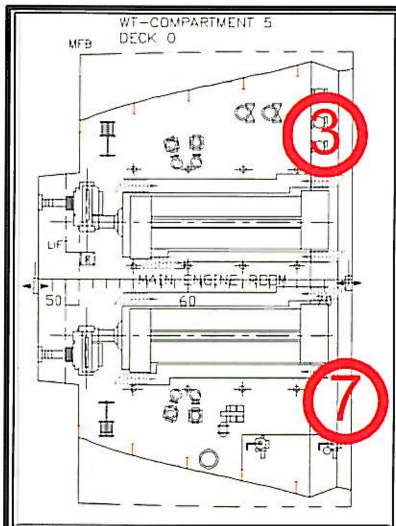
Document control

The purpose of document control is to identify any possible defects in the design. Defects in machinery systems, for example, are lack of redundancy in case of mechanical or electrical failure, and especially in case of fire or flooding. Document control will also prepare surveyors for the audit and enables effective utilisation of the ship visit. The auditing guide takes surveyors through the document control stage, giving clear advice as to where particular attention should be paid and supporting the personal experience of each surveyor. Fig 2 presents a typical view of the guide.

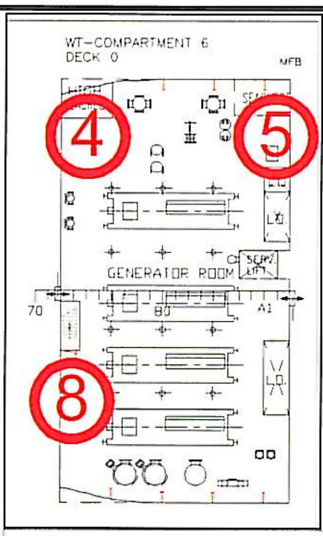
Reliability block diagram analysis assists in determining the sufficiency of system redundancy. Diagrams are commonly used tools in reliability technology. The authors' companies have also developed the method to be efficient in a ship environment by preparing topographical diagrams, showing the actual location of component systems, especially in relation to fire and watertight compartmentation. Fig 3 presents a typical system diagram, whereas Fig 4 shows a block diagram of the same system in topographical format. These diagrams show the consequences of a single failure event in process; is it possible to prevent the consequences or is the system designed without redundancy? The defects identified during the document control stage are stored into a TSA database and are double-checked during the ship audit. From the database these

WT - integrity

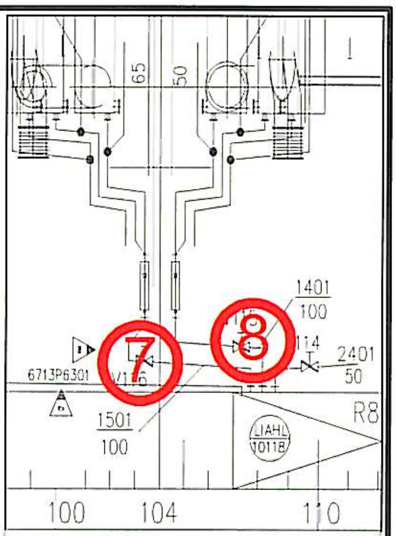
Issue in question	Pic. id	Failure event description	The worst possible final event	Recommended proposal for preventing failure event	Priority factor P_F
Ventilation duct for ME room routed via generator room.	1,2,3,4	In case of collision event into generator room the ventilation pipeline may break and water can flood to ME room. However the probability of such collision that would not cause failure of bulkhead but only ventilation duct is estimated to be extremely small and actions are not seen to be needed. (In generator room the duct is WT.)	Flooding of two compartments.	Both sides of the air channel must be build WT	0
Cable penetration through WT-bulkhead.	1,2,5	In case of flooding event the water will flood to the other side of the bulkhead.	Flooding of three compartments.	Installation a WT penetration	8
Hotwell feeding water pipelines (DN150) are connecting the ME rooms together when thinking of flooding situations.	1,2,6,7,8	In case of collision event the water will flood through the pipeline to the other side of the bulkhead through the hotwell tank that is not WT. The closing valves are located under floor plate level. Accessibility of the valves is poor.	Flooding of three compartments.	The bulkhead valves should be remotely operable or atleast operable from floorplate level	43
Hose penetration through WT-bulkhead.	1,2,9			Using of steel pipe in place of hose.	



Picture 1



Picture 2



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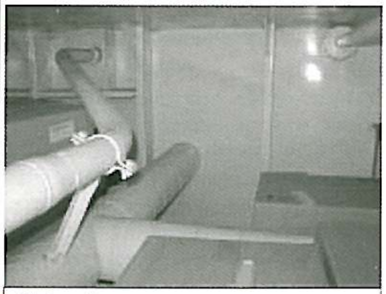
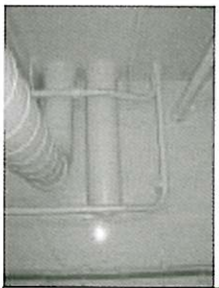
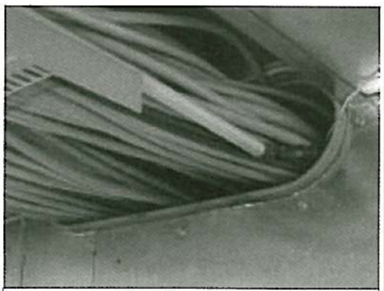
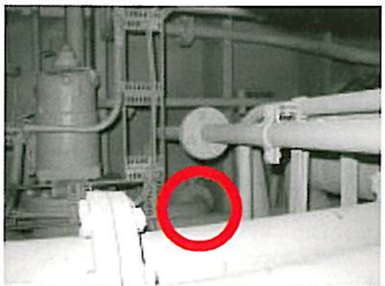

Picture 3


Picture 4

Ventilation duct for ME room routed via fore generator room. However because of watertightness of pipeline in forward generator room and location of pipeline beside the bulkhead (collision event) no actions are seen to be needed.

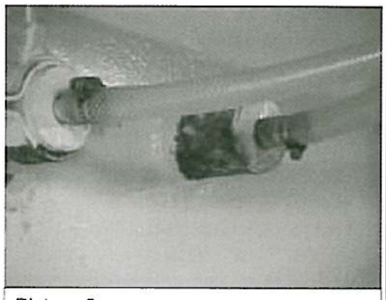

Picture 5

Cable penetration through A-60 wall. Cables are routed to cable trunk. A-60 penetration should be installed.


Picture 7


Picture 8

Machinery space rooms are connected to each other with DN100 pipelines (closing valves are all the time open). In case of comp. flooding or leak. of drain tank water will flood to both mach. rooms as long as closing valves are closed. However valves are not easily accessible and not oper. from floorplate level.


Picture 9

WT-bulkhead penetration with hose connection. Steel pipe should be used

Fig 4a. An example of the reporting method used to identify safety risks.

defects are automatically moved to the final report.

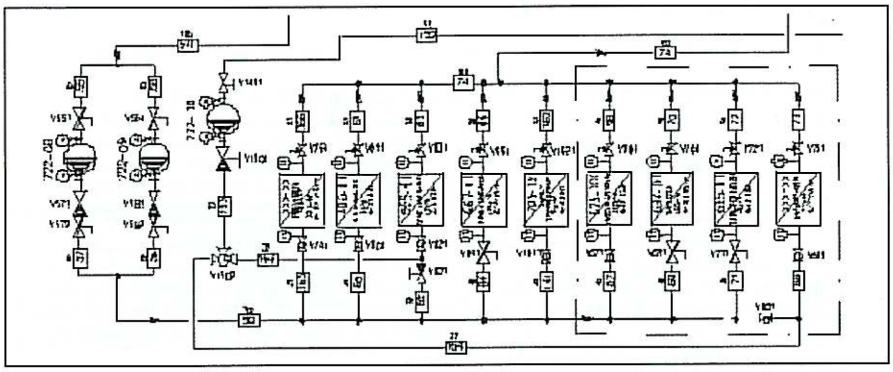


Fig 3. Above: Layout of a fresh water cooling system, in which many components are cooled. Two pumps feed water to heat exchangers.

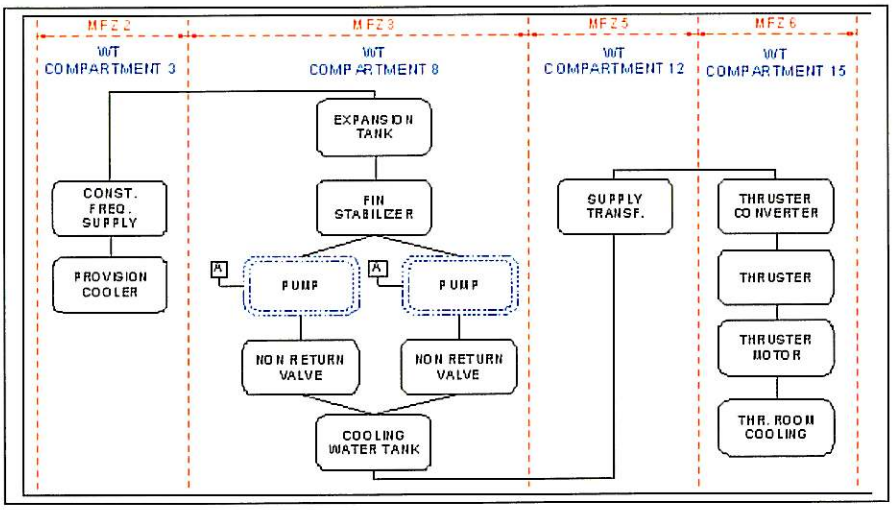


Fig 4. A reliability block diagram analysis of the system in Fig 3. The diagram shows that many heat exchangers are located in different compartments.

Ship audit

The purpose of the ship audit is to survey the implementation of safety and service reliability designs, and to identify risks that cannot be found during document control. If a ship has sailed for several years, there may have been system modifications, which cannot be seen in the drawings. System and space modifications usually have a major effect on ship safety and/or service reliability, and must be carefully checked during the audit.

Defects found will be discussed with the crew. These discussions usually have a very positive influence, and crew commitment becomes more concrete through better understanding. In future, it will also be easier for the crew to identify possible risks, and thus design and accomplish rational safety and reliability-improving actions. The auditing guide plays an important role in this. It also assists surveyors to ensure that all essential components and spaces will be surveyed and all-important items will be identified and data stored for reporting.

The auditing guide will give advice where to pay attention when considering components to be surveyed. Items to be checked can, for example, be installation, condition, material, location, protection, penetration, hangers, vibration, and other similar features that may affect safety and reliability of a system or space. All identified safety and reliability risks are photographed, and these photos are included in the report.

Reporting

Much attention has been paid to ensuring the report to be self-explanatory. The report can be used directly as a list of actions to be accomplished. All the actions increasing safety and service reliability are described, both verbally and visually, by diagrams, drawings, and photographs, so that the defect can easily be localised and identified.

The report is composed of system reports, according to the ship service breakdown. Each system report contains a table and associated defect visualisation. In the tables, defects found, possible consequences, severity of the risk, possible actions, and recommended action(s) are all described.

The recommended actions are determined by using computational estimation. For each action, a priority factor (PF) is calculated; this describes the importance of the action. The purpose of this factor is to assist the owner/builder to choose the most cost-effective actions. Cost-effectiveness means increase in safety and reliability by accomplishment of the action in relation to cost, also taking into account the probability of an incident.

The first projects have shown that this method gives practical and valuable results. Defects and items for possible improvement have been identified. Safety and service reliability really can be increased. Identified items can be subdivided into minor and major ones. Typically, minor ones are easy to accomplish. Major ones can further be subdivided into safety-related and reliability-related.

Fire, flooding, also mechanical and electrical failures have been identified and the awareness of crews increased. Crews have directly repaired some of the identified defects on the spot. The computational estimation of the priority order of recommended actions has assisted owners to choose actions to be accomplished.

The method has been applied up till now on existing vessels. As a spin-off, a spare part assessment method has been developed. Questions such as, which spare parts, how many, which systems, where stored, and how quickly they can be received, are addressed by the method.

Examples of defects identified

The importance of identified risks alternates considerably. The most important are defects in watertight bulkheads causing flooding through the bulkhead, or missing insulation in primary fire zone bulkheads or decks.

Weak points in safety systems are also quite usual. For example, electric power for sprinkler system pumps serving a complete ship is routed from the emergency and main switchboards using the same cable trays and non-fire-resistant cable. A local fire in the engineroom may cause malfunction of the whole sprinkler system.

In case of grounding, the bilge system is needed for emptying compartments; however, the bilge main line may not have any closing valves, which could cause progressive flooding. This event will also prevent direct suction from compartments.

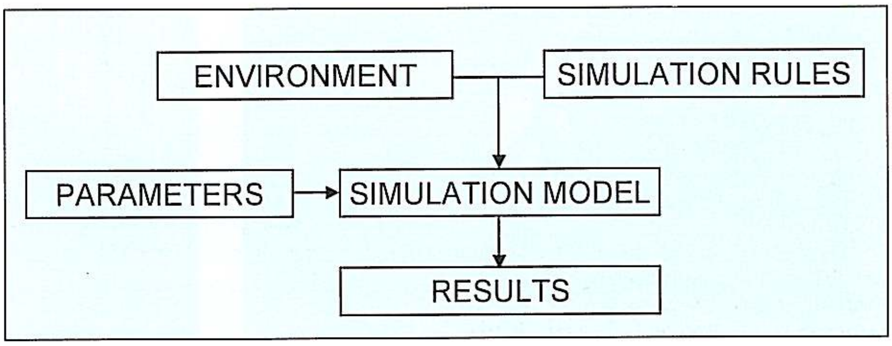
Lack of redundancy is quite usual in propulsion systems of passenger ro-ro ferries, but a single mechanical or electrical failure may cause unexpected loss of all propulsion. In many cases, this can be avoided by implementation of low-cost actions. An example of the reporting method is shown as Fig 4a.

Although work so far has concentrated on existing vessels, the technique is now being developed for newbuilding projects as well. The method will be used in preparation of a ship specification, so that the essential issues affecting safety and service reliability will be systematically included. The method will cover the design and engineering phase as well as construction and outfitting up to commissioning and sea trials.

The systematic and comprehensive method will ensure that necessary - and only necessary - items and issues are addressed in the specification. Non-essential, sometimes costly, investments can be avoided when not really required for improving safety or service reliability. On the other hand, the intended safety and service reliability features are properly taken care of through the whole shipbuilding process. Even the last installation phase by subcontractors' subcontractors can be properly addressed.

Simulations and safety design

Markku Kanerva and Markku Miinala, both from Deltamarin, discuss the valuable benefits of performing simulations for many aspects of modern ship design and operation, especially if carried out at the project stage.



A diagram illustrating the simplified principle of simulation: by combining simulation, environment, and rules, a simulation model can be generated. By modifying parameters, different cases can be simulated.

IN shipbuilding, simulations have so far meant almost solely navigation simulators, but new simulator programs have today added a new dimension to this science. One of the most important new simulations is that related to safety, but other ship function simulations are also possible. When shipyard production processes are simulated, the emerging concept of digital manufacturing will finally materialise in the shipbuilding industry.

For the first time in shipbuilding history, 3D computer models and simulation tools make it possible to simulate, check, and verify almost every function onboard. This is especially important for 'money making' and/or complicated functions, and an attractive benefit is that several options can be checked easily, with exact comparisons giving an opportunity for real optimisation.

The main purpose of ship function simulations is to optimise and improve processes on board, also to detect bottlenecks and other problem areas. When simulation is carried out at a very early stage, ie, at the project design stage, the full benefit of a simulation can be achieved.

A simple example of a ship function simulation is luggage handling on a cruise liner. This operation is typically a problem, especially on today's giant vessels, where more than 3000 passengers can be on board, and the process is complex enough to benefit from a simulation. The results can be used to optimise the number of service lifts, to define the correct capacity and size of luggage-handling areas and luggage trolleys, and to design the best possible luggage-handling strategy for the vessel in question.

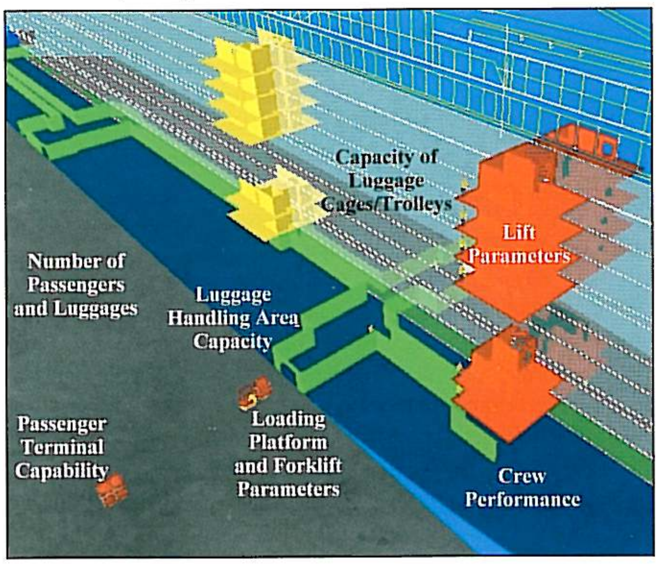
Other typical ship function simulations are loading on ro-ro ships, passenger flows, galley operations and even anchor handling. All these can be examined without the need for awkward plastic models. Some simulations are a combination of both continuous and event-based simulator programs: for example, in a ro-ro loading simulation, the truck driving times to stowage positions are discovered by using a continuous simulator, and based on this information a loading process can be optimised.

Safety simulations

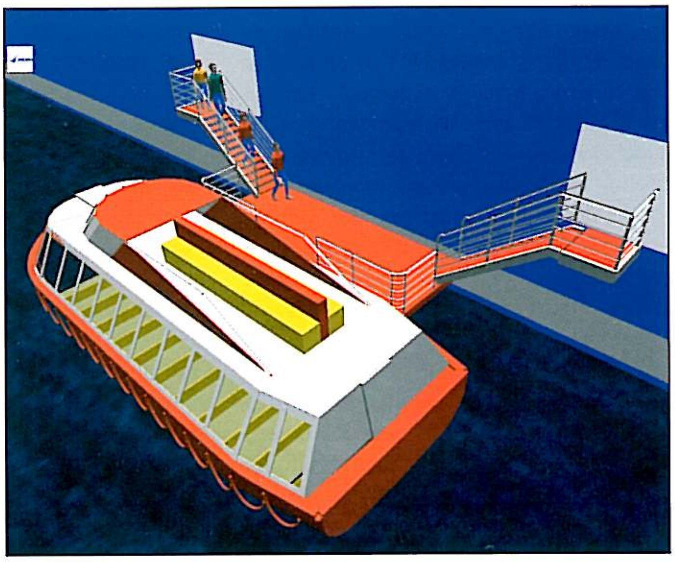
Use of a simulation is a practical and safe way to illustrate and analyse extreme situations onboard vessels. Easy modification of parameters allows fast testing of the relation between, for example, smoke and passenger evacuation time.

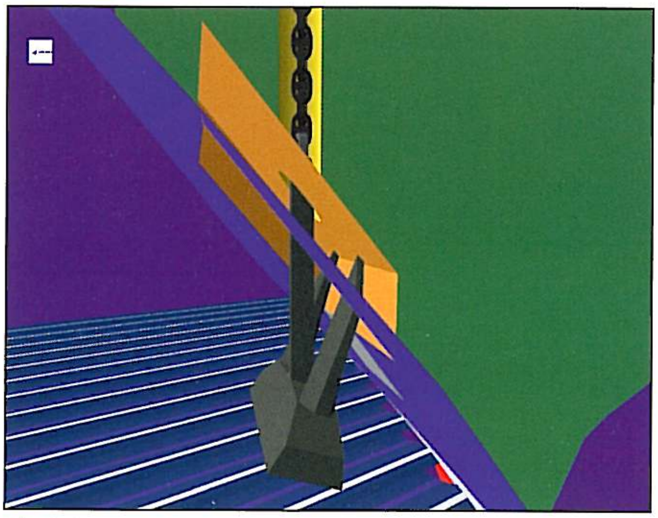
The SOLAS regulation II-2/28-1.3 requires that escape routes of ro-ro passenger ships constructed during or after July 1999 should be evaluated by an evacuation analysis early in the design process. Deltamarin has an efficient simulation tool, which allows evacuation analysis according to these requirements, and this has also been extended to include human behaviour and various evacuation conditions. The

A typical environment for a luggage-handling simulation. Some of the required parameters are shown here. If required, the simulation could also include passenger terminal functions.

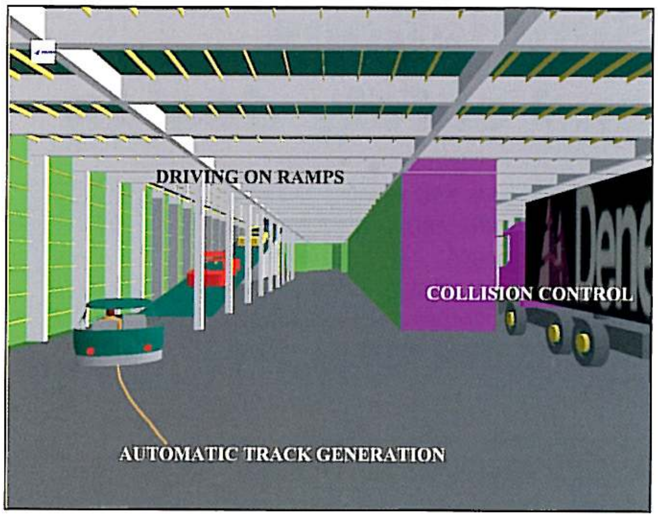


An example of a tender loading simulation. The effect of having one or two access platforms can also be compared.

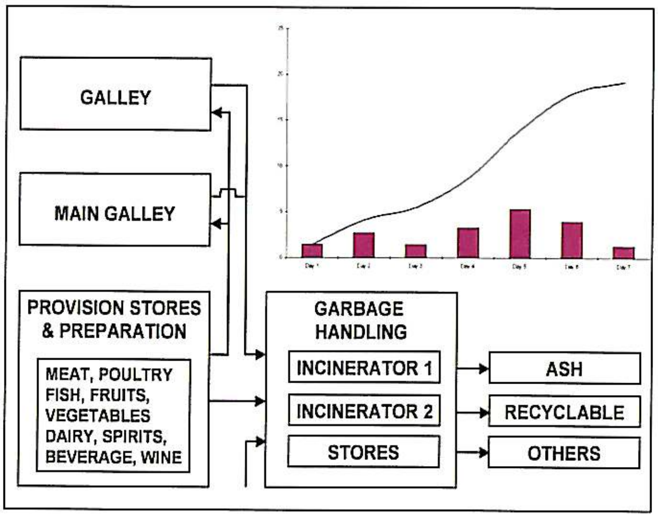




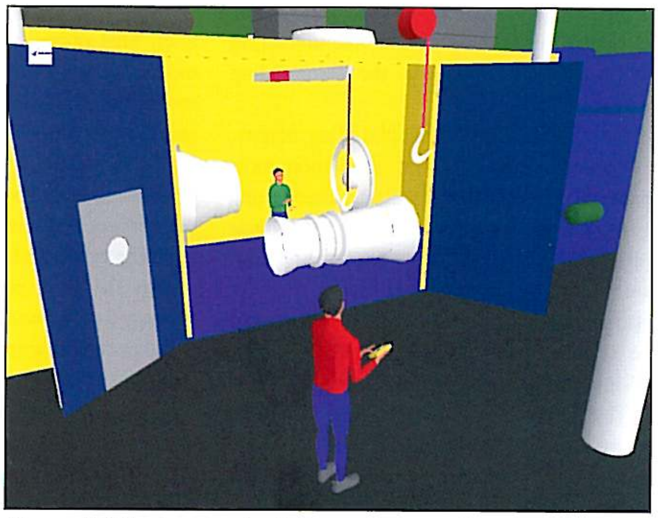
Simulations can even be used for the anchor-handling process. The program can be run several times with a random initial position of the anchor, and thus the 'success rate' can be verified.



An example of a vehicle loading simulation for a ro-ro ferry. All kinds of ramps and lifts can be accurately simulated with exact performance parameters. The speed of vehicles can be varied to suit individual situations.



Dealing with garbage on a large cruise liner or ferry is a major problem for many owners. This diagram illustrates the process flow prepared for a garbage-handling simulation.



The possibilities for using simulation are almost endless. This illustration shows a simulated gas turbine maintenance operation, but exhaust flow and optimisation of a cooling water system are other candidates for examination.

evacuation simulation tool has been developed in co-operation with Strathclyde University in the UK.

Some real situations have pointed out the significance of human behaviour in a distress situation: for example, 15% of passengers will be unable to act at all and 60% will not act without instructions from the crew. A simulation has to take into account ship heeling and movements, blackout and smoke-in-corridor situations, as well as panicking passengers; the role of the crew and passengers returning to their cabins to collect their luggage must also be considered. In addition, passenger age, intoxication, and mobility impairment has to be included.

Simulation can include combinations of human behaviour in several conditions, random location of passengers, all passengers gathered into the same area, and several 'what-if' cases. With an evacuation simulation, it is also possible to simulate situations with casualties.

The most valuable benefit of an evacuation simulation is the more realistic results, the most interesting being the total time required for evacuation in different conditions. With a simulation critical design, behaviour and environmental parameters can be found and bottlenecks detected, which makes it an excellent design tool for safety improvements.

One use for an evacuation simulation is crew training: crew can test different alternatives and can, in advance, find the most critical areas in a distress situation. An evacuation simulation can also be used as an onboard tool: a simulation can be run before each departure, based on actual number of passengers and the correct occupancy of cabins. In this way, it is possible to practise a possible evacuation situation.

Deltamarin has carried out several evacuation analyses for passenger/vehicle ferries, according to the current SOLAS regulations. Also, the first passenger evacuation simulations with human behaviour and various evacuation conditions have been made for a Royal Caribbean International cruise ship.

Today, ship design based on a product model (discussed in more detail elsewhere in this publication) enables new possibilities in safety analysis. A vessel's technical safety against accidents can be analysed: for example, the consequences of a fire or flooding can be easily evaluated during the design phase or in case an accident happens. Similarly, emergency instructions for crew can be incorporated into the product model. Also, new class notations related to redundancy and safety can be verified using product model information.

Combined diesel and gas turbine: the alternative option

At this year's Marine Propulsion Conference, held on March 22-23 in London and organised by *The Motor Ship* journal, Jari Nurmi, head of the R&D department at Deltamarin, discussed new generations of propulsion plant for tomorrow's ships. In particular, he examined the CODLAG concept and analysed the main differences to diesel-electric and COGES concepts, with particular reference to cruise liners and ro-pax ferries. However, good potential for such combined-cycle plant is also seen in future LNG tankers.

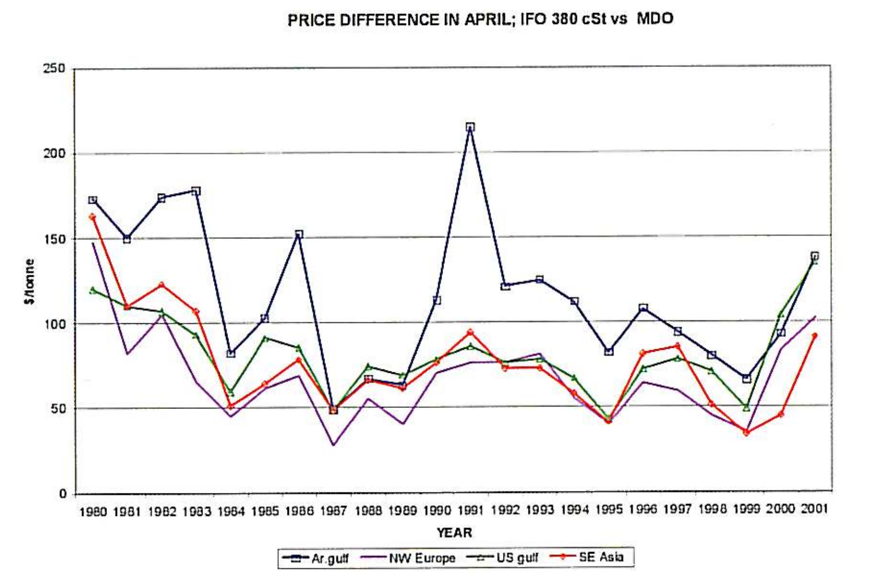


Fig 1. Price difference history between heavy fuel and marine diesel oil. The main disadvantage of a gas turbine is the need to burn high-quality fuel (marine gas oil), which, at present, is much more expensive than heavy fuel. The principal differences have been in the range of US$60/tonne to US$80/tonne. Marine gas oil is typically some US$5-US$15 more expensive than marine diesel oil. The 2001 value is for February.

TEN years ago, only diesel engines were considered as a viable primary power source on cruise ships, but today, there are several cruise liners completed or on order with gas turbine machinery. A great step was taken when COGES (Combined gas turbine and steam-turbine electric) machinery was specified for the *Millennium* and *Radiance* classes for RCI. The prototype was completed last year by Chantiers de l'Atlantique.

COGES options as such, related features and design criteria are extensively described in the paper 'The Royal Caribbean *Millennium* class cruise ships - from studies to virtual reality', prepared by Deltamarin and presented at *The Motor Ship* Conference in 1999, also in The *Naval Architect* February 1997, page 15. Since then, gas turbines have secured a significant share of the cruise ship machinery market.

Major changes such as this seem to create a strong counter-action; here, diesel engine manufacturers have made extra efforts to boost their products. Consequently, diesel development has been rapid and a synergy of diesel and gas turbine concepts are today being applied. Thus, around half of the cruise ships currently on order with gas turbines have hybrid machinery named as CODLAG (Combined diesel and gas turbine electric). Here, the larger amount of the power is produced by diesel engines, with the gas turbine mainly used as a booster for short-period peak-load requirements.

Gas turbine potential

Several trends can be seen in ship development. Power levels are increasing on most ship types, either due to higher speed requirements or larger vessels, and compact, especially low height, power plants are needed. Electric propulsion systems have shown their efficiency potential, and pod propulsion has come to stay. Freedom to position power plant/propulsion systems is another key feature in new ship concepts.

The main advantage of gas turbines is their modest space requirements. Due to low weight and a small number of ancillaries, a gas turbine can be located almost anywhere on a ship. Although a simple-cycle solution is always most compact, installation of exhaust-gas boilers (as required for a COGES concept) means more limited possibilities.

COGES is, however, a must in most cases in order to achieve low fuel consumption, since the gas turbine fuel itself (marine gas oil) is more expensive than heavy fuel. There are also installations where gas turbines burn heavier distillates in order to reduce the fuel bill.

Robust, industrial-type gas turbines have a lower burning temperature and hence lower efficiency than aero-derivative types – applied on the *Millennium* class, but capability to burn lower quality fuel, even some heavy distillates, compensates for this difference. Lower exhaust temperatures by around 100°C on industrial-type turbines increase the cost of a steam cycle if COGES is applied, and thus COGEN (only heat recovery, no steam turbine) can, in some cases, be an even more feasible choice with these engines. Preparing a case study is always worthwhile.

The only drawback for gas turbines, when compared with diesel machinery, is a restriction on the burning of heavy distillates. Nevertheless, gas turbine-based machinery should be considered as a viable optional concept when at least some of the following main criteria are fulfilled:

- Gas turbines are more compact than diesel engines; the space-saving potential can also be utilised effectively in ship design work. This is an absolute priority on cruise ships and could be the key issue for future high-speed, full-displacement ferries.
- Low weight must give some benefits. This issue is important, especially on high-speed ferries.
- Gas turbines supply large quantities of easily recoverable heat, but there must also be a use for that energy – clearly, there is a big requirement for heat energy on cruise liners.
- Low exhaust emission levels must be of great value. This may be critical on coastal operations.

Key issues today are how to arrange a power plant and what should be the prime mover for the generators. This calls for novel thinking over the whole vessel design, and new applications such as 'all engines aft' COGES or CODLAG concepts, where remarkable amounts of installed power can be relocated from traditional engineroom spaces. Both these options also give a real additional safety value for a ship due to physically separated engine spaces.

Examples show that a small engineroom can be turned to profitability, eg, more cargo capacity or more cabins, and the increased earning potential can cover higher fuel costs. The cost difference compared with heavy-fuel-burning diesel installations is evident. Fig 1 shows fuel price trends since 1980.

A gas turbine option is also worth studying if the use of heavy fuel is a problem for environmental, maintenance, or other reasons, and simultaneously when there is a need for high power. In that case, the gas turbine in a COGES or ICR (intercooled and recuperative) configuration can have equal fuel costs to a diesel-powered ship. However, it should be noted that leading diesel engine designers have made tremendous strides towards achieving lower emissions.

Attractive gas-turbine-based options

Machinery properties depend heavily on the selected gas turbine concept and cannot be considered as general for every ship. What is true for a gas turbine itself is not necessarily valid for a complete plant. As an example; gas turbine fuel consumption is very sensitive to load variations in an individual unit, but as part of a combined cycle, the situation is opposite. Thus the gas turbine must not be evaluated as single power source but as a one component of a total machinery concept, or even more widely, as part of a complete ship concept.

The complete energy (mechanical and heat) profile of a ship is decisive, and the machinery must match this profile. The most interesting gas turbine solutions for commercial ships are:

Direct gas turbine mechanical machinery

Here, the gas turbine is mechanically connected through a reduction gear to the propeller or waterjet. This simple-cycle solution (no waste heat recovery) is attractive in cases where high power, low weight, and small volume are of utmost importance, and fuel economy is only a secondary aspect - this means that there is no suitable diesel engine available for the purpose. Applications are viable on fast ferries, especially catamarans, due to the limited space for machinery.

CODLAG; combined diesel-electric and gas turbine machinery

With CODLAG, the gas turbine is arranged to supply booster power. The principal theme, as shown on Fig 2, is to use diesel engines (diesel-mechanical or diesel-electric) during normal operation, and gas turbine power for short transits or in environmentally-sensitive areas. This machinery is especially applicable for use on cruise ships, or other vessels when there are clearly two different operation profiles.

Since the gas turbine operation is not continuous, it is not feasible to apply any kind of heat recovery system. Principal advantages of this concept are: compactness, good fuel economy at normal operation, and attractive first-cost for the machinery. A disadvantage is that the machinery can operate efficiently only on a limited operational profile; off the design profile, efficiency will suffer. There is always a risk of a situation, where diesel power is not sufficient and the simple-cycle gas turbine must be run at low load. Another disadvantage is that two different types of power source call for two different sets of auxiliary equipment.

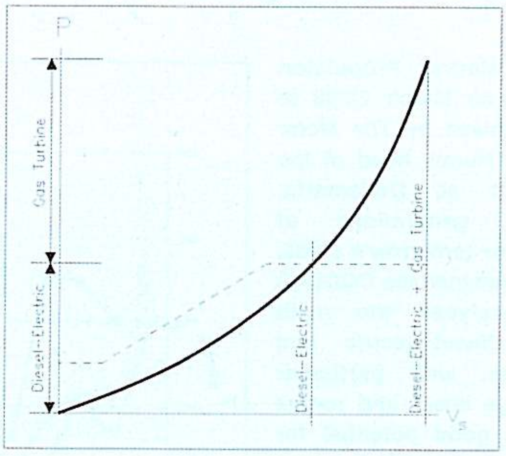


Fig 2. Principle of the CODLAG concept.

COGES; combined-cycle gas + steam turbine electric machinery

This solution is based on electric propulsion and alternators driven by both gas turbines and steam turbine(s). Gas turbines are directly connected to the alternators. Heat-recovery boilers are fitted in the gas turbine exhaust lines and the resulting superheated steam (at approximately 30bar) is led to a steam turbo-alternator.

This solution changes completely the properties of a simple-cycle turbine; whereas gas turbine efficiency decreases at low load, the steam turbine recovers the lost power. The result is a constant fuel consumption curve over a wide operational range.

Heat for ship's services is taken directly from the steam turbine extraction (condensing-type turbine) or at the steam turbine exhaust

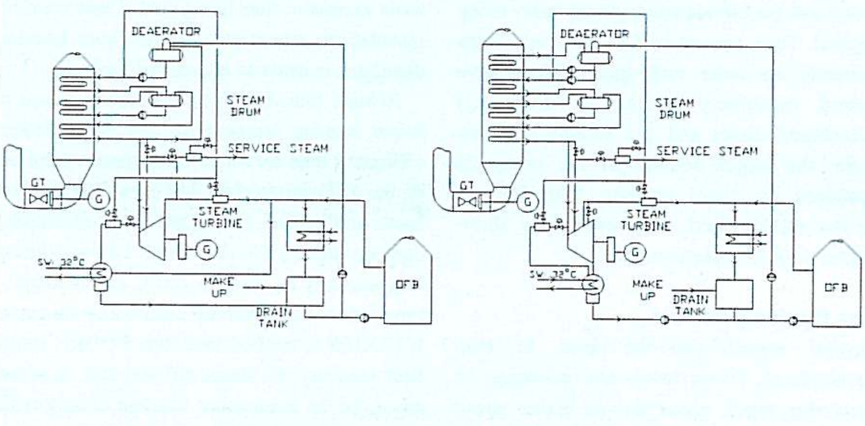


Fig 3. Two applications of the COGES principle: a less expensive back-pressure plant (left) and a high-efficiency full condensing plant (right). Back-pressure types are to be preferred when heat consumption for ship processes is high, as on cruise ships.

(back-pressure turbine), and thus there is normally no need to fire-up auxiliary boilers. This is an important aspect when calculating total fuel consumption and overall emissions (engines plus boilers).

Consumption can be lower for the COGES ship than for a diesel ship. The key item is fuel consumption for auxiliary boilers as well as vessel operational profile. However, much attention must be paid to the choice of steam-cycle details, such as boilers, condensers, and type of cycle (condensing or back pressure), in order to specify an economically optimum plant. Basic alternatives are shown on Fig 3.Giant cruise liners have high heat demands, and thus the impact of boiler fuel is significant. Use of heat energy in general should receive higher attention on large cruise ship installations due to ever-increasing heat demand - mainly for fresh water production. Compact and simple machinery as well as low fuel consumption are the main advantages, but the sensitivity to fuel price changes remains.

Ship types for gas turbine propulsion

Some ship types can be considered clear candidates for gas turbine propulsion. The most interesting ones are:

- Cruise liners, where the small machinery volume can be translated into additional cabins, and the heat consumption is high. On large cruise ships, this difference compared with a diesel-electric vessel can be from 20 up to 100 passenger cabins on the same hull dimensions, and depending on the arrangement philosophy.
  Compact machinery means a small number of prime movers and only few ancillary systems. It can be roughly stated that gas turbine plant can manage with only 50% of those ancillaries needed on diesel-based machinery. Compact size and modular construction also means less installation man-hours and calendar time.

- New generations of large fast ferries are calling for extremely high power outputs, which are difficult to achieve with diesel engines, also pod propulsion has shown to give powering benefits on these ships. Thus, there is a demand for compact machinery for alternator drives. Such vessels operate in coastal waters and thus marine diesel oil can be a significant environmental issue.

- LNG tankers, due to an ability to burn both cargo boil-off and liquid fuel at better efficiency than a traditional steam turbine plant

- On fast container ships, the criteria is very similar to large fast ferries; compact machinery can allow additional containers, including refrigerated boxes, to be loaded,

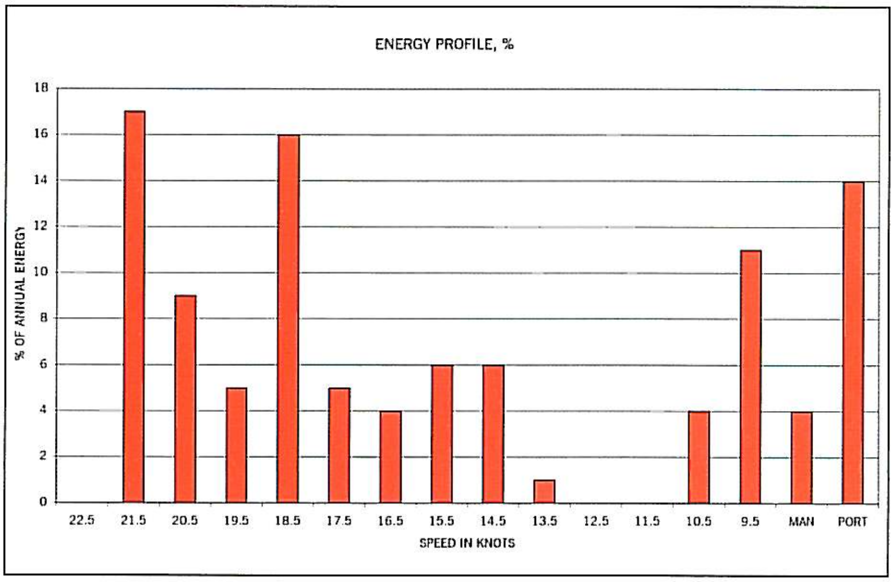


Fig 4. A typical cruise ship speed profile. Around 75% of the energy (power x time) is consumed at below 20knots.

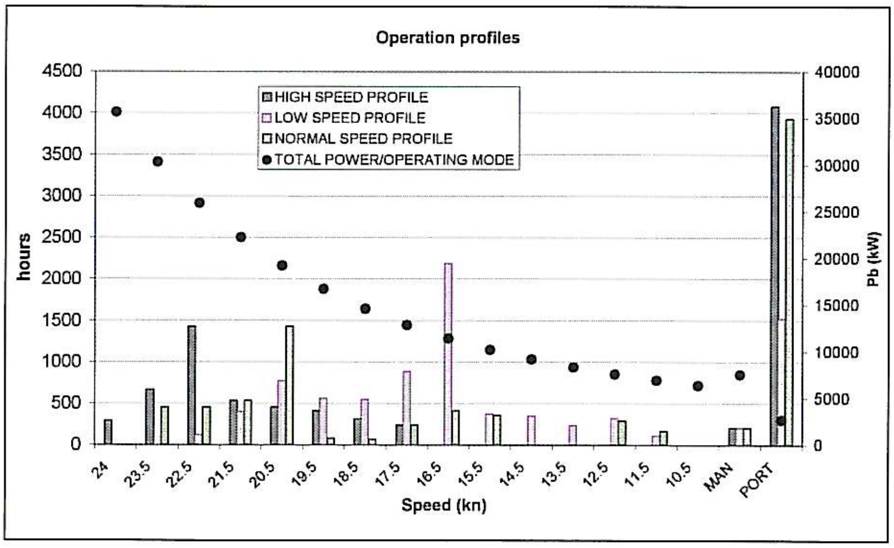


Fig 5. Operation profiles and power demand as a function of vessel speed. Low- and high-speed profiles are applied on the sensitivity analysis. The high-speed profile is more applicable above 22.5knots, and the low-speed profile below 18.5knots.

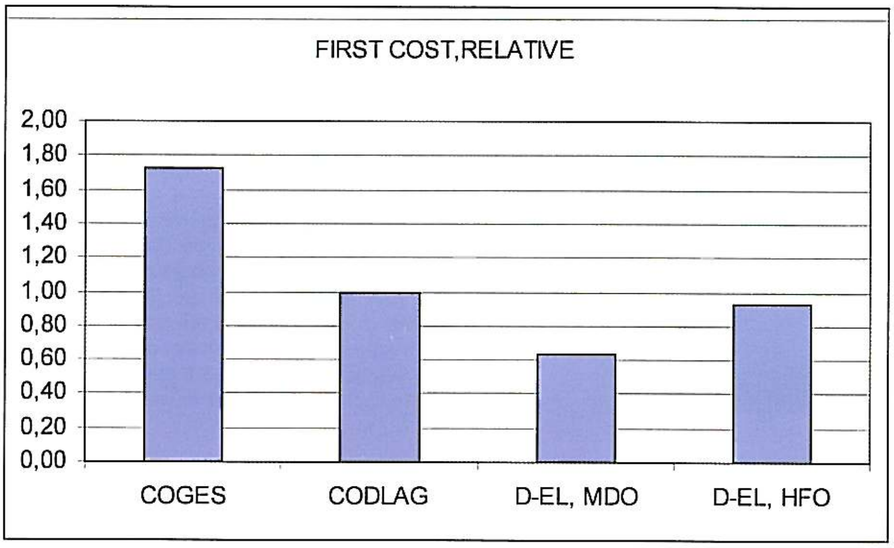


Fig 6. Relative first costs for machinery main components. The COGES figure would be somewhat lower if installation costs were to be included, but an equal price level can be achieved only when the installed power is in the range of 55MW-65MW.

while coastal operation also brings the gas turbine into the frame.

Cruise ship applications - ship of more than 80,000gt

When selecting gas turbine-based machinery for a large cruise ship (more than 80,000gt), it should be considered that:

- Machinery is based on electric propulsion (as is almost standard today)
- Typical power demand varies from 8MW-9 MW (in port) and around 50MW (at sea)
- Hotel services need a lot of heat for fresh water production. Heat demand (steam) is typically some 25tonnes/h-28tonnes/h.
- The operational profile is not constant and includes several power levels.The machinery choice has to be based on an annual energy (power x time) profile, Fig 4 being a typical example. Fuel consumption is important, and so a simple-cycle principle should be considered only as a booster solution. An 80,000gt cruise ship with a 60MW machinery plant consumes some 43,000tonnes fuel annually using COGES machinery. Due to a very high heat consumption on these ships, a back-pressure steam plant is more feasible than the clearly more complicated and expensive full condensing plant.

For a cruise liner with approximately 42MW of installed power, the plant can be based on one of three machinery concepts: COGES, CODLAG, or diesel-electric. From a space demand and redundancy point of view, an optimum COGES plant should be based on twin engines. Since power demand on this ship size is still rather low related to available gas turbine candidates, the plant could easily become 'over-dimensioned'. Fig 5 indicates the total power demand.

Design criteria for the CODLAG configuration in this case would be such that the diesel engines could meet the profile up to at least 20.5knots speed, equalling 60% of total energy consumption. At higher speeds, the gas turbine is also coupled in. The same 20.5knots can be reached with a single gas turbine and steam turbine on COGES option. The 6MW-8MW higher installed power on the twin-engine COGES option is clearly seen, as regards first costs, in Fig 6.

Already, at 60MW installed power, the cost difference between the options would be marginal. A diesel-electric power plant and a CODLAG configuration have an equal price level at a fairly wide power range. This is mainly due to absence of a steam turbine.

While the rating of CODLAG machinery has a good match with the operation profile, fuel economy is approximately equal to a diesel plant, as shown in Fig 7. However, the COGES option is suffering here from the low

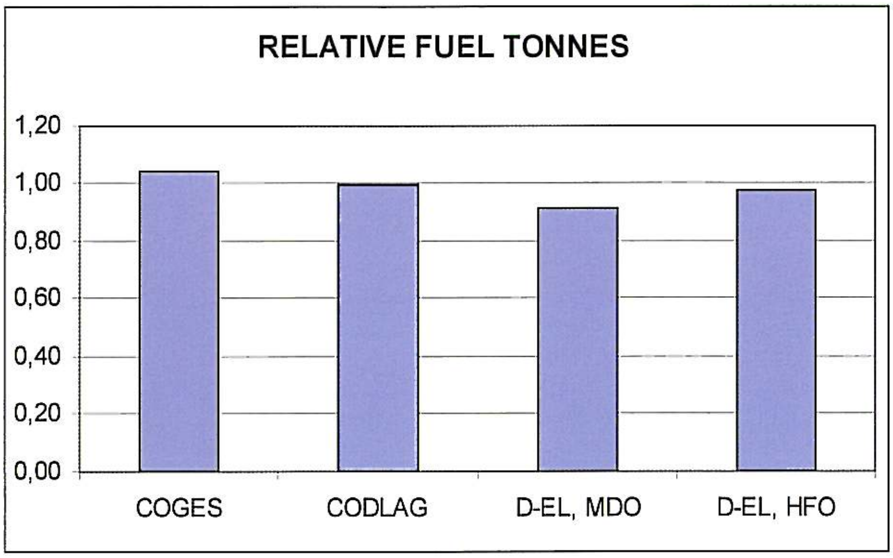


Fig 7. CODLAG is equal to diesel and lower than COGES in fuel consumption for typical cruise ship operations. However, the overall differences are marginal.

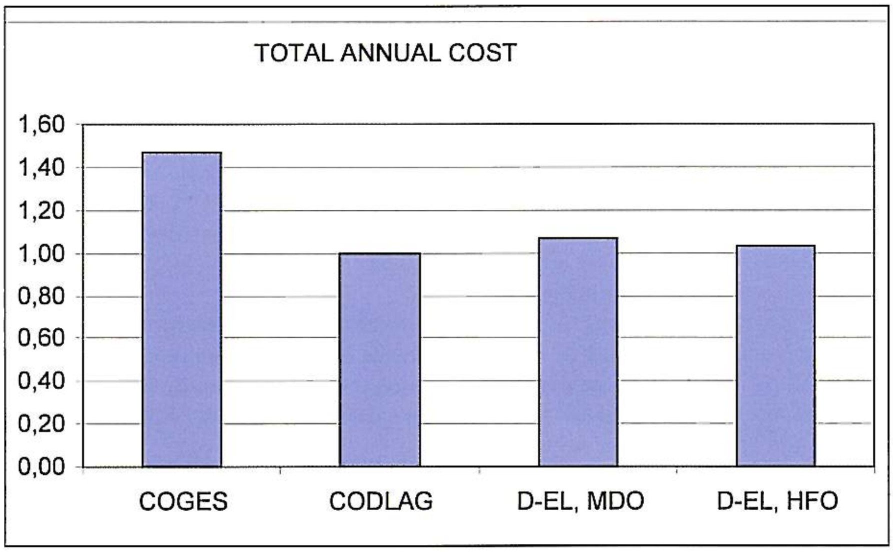


Fig 8. Relative total annual costs (6% over 10 years), with first cost of machinery, fuel, and lubricating oil included. It is also assumed that selective catalytic reduction (SCR) units are installed and run on the diesel options. It is also assumed that heavy fuel can be burned when the SCR units are in operation.

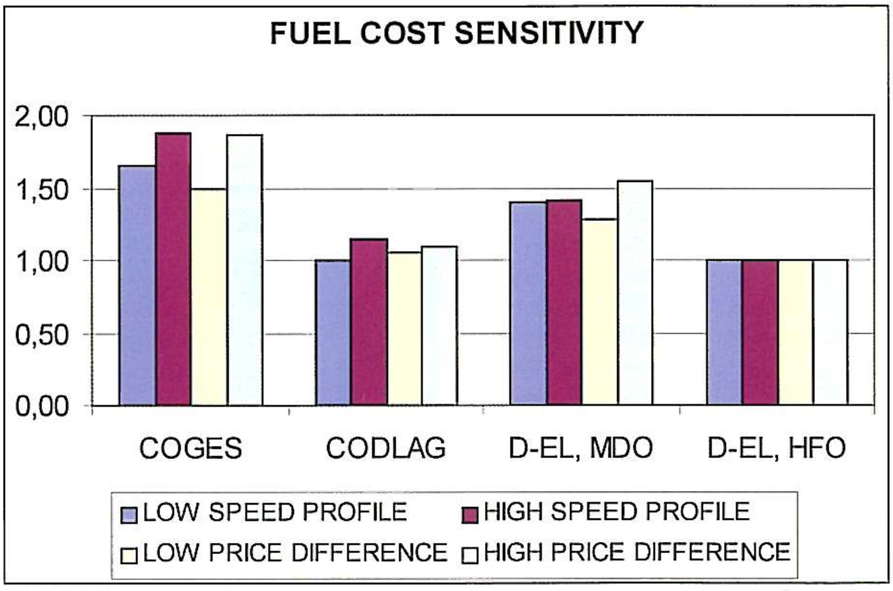


Fig 9. The analysis shows clearly the sensitivity of CODLAG machinery - not necessarily to fuel price but certainly to operational profile changes.

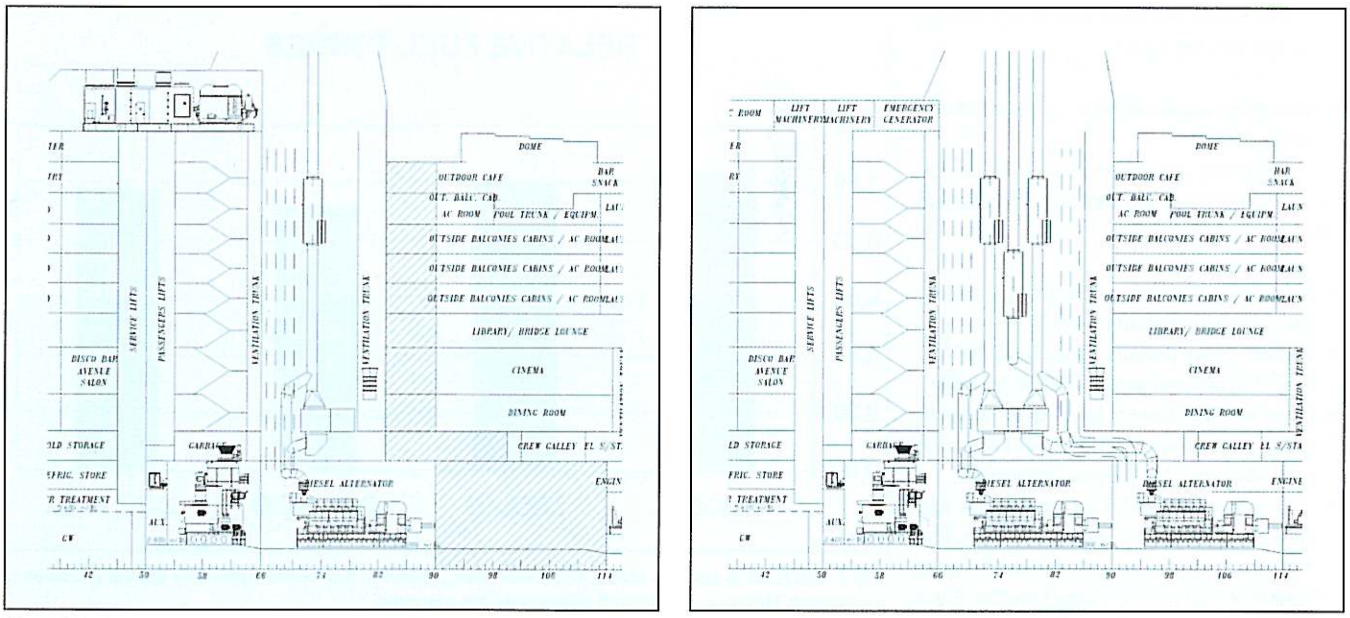


Fig 10. Typical arrangements of the machinery for CODLAG and diesel-electric cruise ships. The proposed location of the gas turbine (at the base of the funnel) allows low and compact exhaust and air intake arrangements. Weight difference between these two machinery concepts is 300tonnes, the CODLAG being lighter. The diesel-electric ship has six engines while three are sufficient on a CODLAG version.

power demand - not only on mechanical power but also on heat demand for this ship size.

Should the calculation be carried out at equal NOx level and selective catalytic reduction (SCR) catalyst units installed for the diesel engines, the relative total annual cost (over 10 years at 6%) is shown in Fig 8.

Since gas turbine economy is strongly depending on fuel cost as well as operating profile, it is worthwhile carrying out a sensitivity analysis. Fig 9 gives an idea of the relative fuel cost when changing the speed profile and when varying fuel price.

The operation profile is as given on Fig 5. Each profile has the same sailing distance. The 'high-speed profile' contains more transition voyages at high speed (22.5knots–24knots) and respectively more time in port. Correspondingly, the 'low-speed profile' includes more cruising at sea at speeds of 12.5knots to 18.5knots and less time spent in port.

The price for heavy fuel is kept constant at US$140/tonne. The marine diesel oil price of US$210/tonne equals the long-term average difference of US$70/tonne. Marine gas oil is US$10/tonne more expensive than diesel oil. In the 'low price difference' case, marine diesel oil is only US$50/tonne more expensive than heavy fuel and US$5/tonne cheaper than marine gas oil. At the 'high-price difference' level, gas oil is US$15/tonne more expensive than diesel oil, and the gap between heavy fuel and diesel oil is US$90/tonne.

The feasibility of a gas turbine installation is always related to ship layout advantages. Fig 10 shows one solution for a 60,000gt vessel where the low-weight gas turbine generator for a CODLAG installation is arranged at the base of the funnel. The benefit in space for a CODLAG concept compared with a diesel one is around 800m². How this area is utilised depends case by case on the project and its arrangement; nevertheless, as a theoretical statistical figure, some 45% of the area could be utilised for cabins, equalling 15-20 cabins in this case.

Gas turbines in ro-pax ferries

Criteria of machinery choice for a large, high-speed, ro-pax ferry are totally different to those for a cruise ship. The main differences are:

- No need for heat; little energy from the waste heat can be utilised for ship processes. Heat should be used for mechanical power production.
- Complex profile; many short port calls and frequent start / stop of engines
- Cyclic operation, changing power profile
- Low power demand in port, high at sea
- Limited machinery spaces - especially engine casing and engine room height and width. COGES is difficult to apply.

The following case represents a 200m length bp ro-pax ferry concept, capable of reaching 30knots, and with approximately 50MW of propulsion power. Heat demand on this vessel is very low, and thus exhaust-gas heat energy from the gas turbine cannot be effectively used.

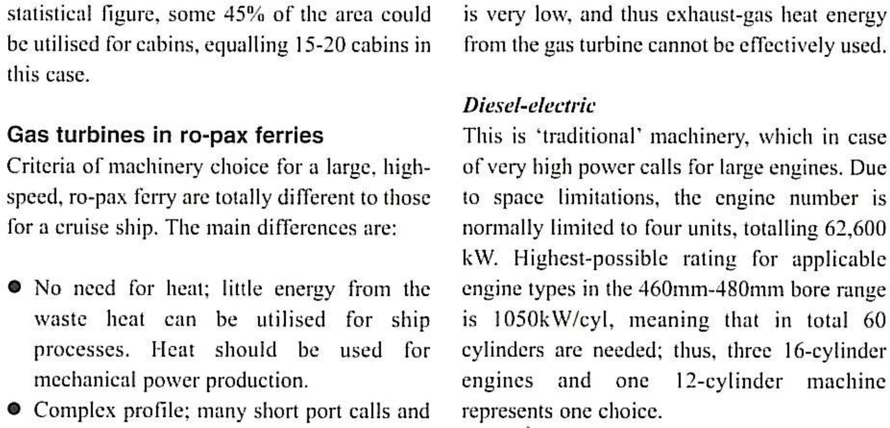
Diesel-electric

This is 'traditional' machinery, which in case of very high power calls for large engines. Due to space limitations, the engine number is normally limited to four units, totalling 62,600 kW. Highest-possible rating for applicable engine types in the 460mm-480mm bore range is 1050kW/cyl, meaning that in total 60 cylinders are needed; thus, three 16-cylinder engines and one 12-cylinder machine represents one choice.

Since port load is only some 2000kW, the engine load will be very low - around 16% for the 12-cylinder engine in port. This calls for special arrangements if heavy fuel is to be used.

In addition, four large Vee-form engines are slightly difficult to locate; in particular,

Fig 11. Principle of the CODLAG gas turbine booster.



maintenance access and exhaust-gas piping can be problematic and calls for special attention. One alternative would be to place all machinery in side casings.

CODLAG

The idea of applying a booster gas turbine (Fig 11) is to decrease the size of the diesel engines. If the maximum power level is required seldom, the higher fuel consumption and cost for the gas turbine is not an issue.

The diesel engine requirement is similar to the diesel-electric option, giving 1050kW/cylinder. The gas turbine is rated for 21,000kW at normal rating and 23,000kW at overload rating. This gas turbine power means that the vessel can manage speeds of around 27knots with diesel engines only. The overload rating of the gas turbine can be considered as 'sea-margin power', ie, part of the sea margin is handled by overloading the gas turbine and part by having a higher installed diesel power.

The effect of a booster gas turbine is that approximately 24 diesel engine cylinders can be removed. This means that instead of four 16-cylinder and 12-cylinder engines, only four nine-cylinder machines would be required – and these would be a simpler in-line type.

A 9-cylinder engine would have an acceptable load of 22% when in harbour. If the vessel operates for a long period at speeds above 27knots, the gas turbine increases operational costs of the vessel, but in case the demand for high power/high speed is limited, this is a good alternative, saving both weight and space.

COGES

The COGES alternative is based on 23,000kW gas turbines and one 10,000kW steam turbine, running in a combined-cycle operation. Depending on harbour time, an additional diesel-powered harbour alternator could be considered.

Machinery weight

The three machinery alternatives have clear weight differences: the all-diesel alternative is the heaviest and the COGES the lightest, with

Diesel Electric

ITEM	NO	WEIGHT	TOTAL
16 cyl 46 engine	4	225	900
20 MVA generator	4	56	224
engine foundation	4	6	24
			0
			0
			0
			1148

Diesel Elecric + Booster gas turbine

ITEM	NO	WEIGHT	TOTAL
9 cyl 46 engine	4	137	548
11 MVA generator	4	34	136
LM2500 genset	1	87	87
engine foundation	4	6	24
System reduction			-10
			0
			785

COGES

ITEM	NO	WEIGHT	TOTAL
LM2500 genset	2	87	174
10 MW ST genset	1	45	45
ST condenser	1	10	10
HRSG	2	106	212
Steam tanks	3	15	45
System reduction	-1	50	-50
			436

Table 1. Weight comparison of machinery alternatives. 'System reduction' is weight saving due to a lower number of ancillaries and piping on gas turbine alternatives.

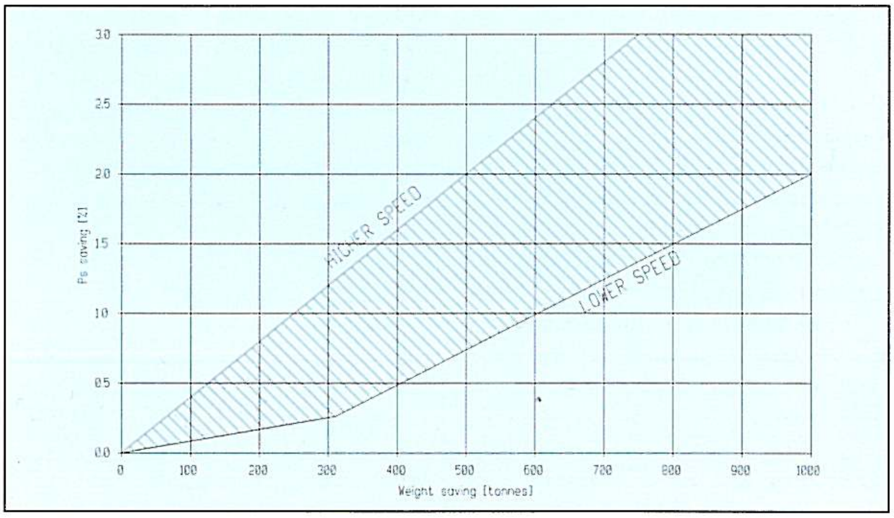


Fig 12. Estimation of propulsion power decrease versus weight saving. This graph is based on a displacement of around 20,000tonnes and a length bp of 200m. Based on the figures, 400tonnes of weight saving equals only 1% in propulsion power; alternatively, 2% in displacement change equals 1% in propulsion power for this size of ship.

Fig 13. Fuel consumption of the ship, depending on machinery alternative. The consumption with a full-condensing steam turbine COGES arrangement is well in line with a diesel system, but the CODLAG starts to suffer when the simple-cycle gas turbine is started.

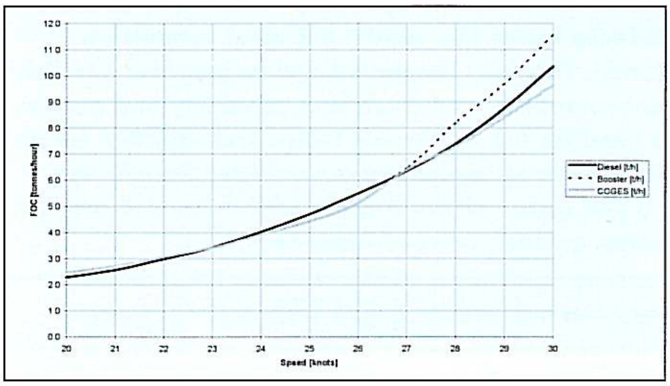
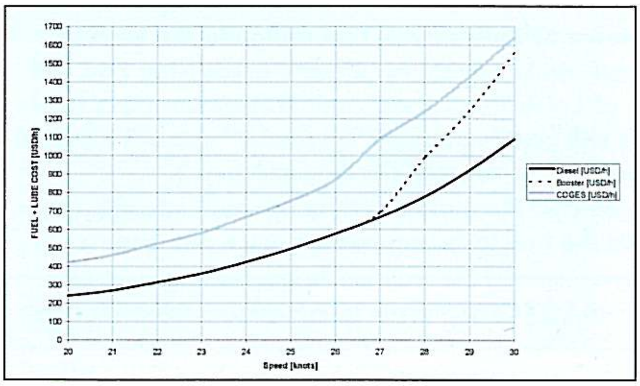


Fig 14. Fuel and lubricating oil costs for machinery options; the cost of lubricating oil does not significantly alter the situation. This graph does not include any costs for emission control; also, the obviously lower propulsion and auxiliary power demand for gas turbine options is ignored in this connection.



the booster alternative being a compromise of these two. Table 1 gives an idea of the weight difference, using a comparison based on a power demand of 56MW.

On a fast vessel, the weight saving (Fig 12) can be utilised by:

- Decreasing displacement and thus power demand.
- Increasing deadweight and keeping the displacement the same.

Cost

At this power level, the difference in first cost between the options is marginal and focus is on fuel side. Fig 13 indicates the fuel consumption of the ship, depending on the machinery alternative.

Corresponding fuel and lubricating-oil costs as a function of speed are shown in Fig 14, and based on prices of US$100/tonne for diesel engines and US$170/tonne for gas turbines. Based on these figures, the booster alternative is clearly more expensive to operate at high speeds than the diesel alternative - fuel cost is approximately 50% higher at speeds of 30knots. Approximately 2% reduction could be considered for a CODLAG plant if the lower weight is taken into consideration.

Conclusion for ro-pax ferries

The all-diesel version has the lowest fuel cost but the large space demand and high unit power can make this alternative the most difficult to apply. If operation at high speeds (above 27knots-28knots) is limited, the higher fuel cost of a booster alternative is not significant in the total economic picture. For this alternative, a smaller diesel engine unit size can be introduced, when comparing with an all-diesel alternative. However, the gas turbine power has to be well matched to the operational profile, and in case consistently high power is needed, a CODLAG option is not the right choice.

The COGES alternative is interesting, but more expensive fuel means high fuel costs. At full speed, the difference is around 50% when compared with a diesel-electric plant. Where very strict emission limits are a factor, the cost difference between COGES and other options would be close; also, this option has the lowest space demand, which obviously means some benefit in most cases. However, the arrangement of the boilers and steam-cycle equipment is at least challenging and requires some new thinking.

It could be concluded that the high-powered future ro-pax ship should be based on simple-cycle engines rather than a COGES plant. However, fuel consumption is so important that gas turbines could be considered only for booster use while the main power output is based on diesel machinery.

Summary and future prospects

It is evident that shipowners are becoming more aware of gas turbine options. At present, a COGES solution is the most fuel-efficient commercial gas turbine version, but the ICR cycle (as proposed by Rolls-Royce for its WR-21 turbine) would give even better economy. However, this model still suffers from the lack of marine references - it is still on test (principally for naval use) at the French Navy's plant at Indret, near Nantes. The most promising gas turbine concept for cruise liners includes two gas turbine-powered gensets and one steam turbine-driven set within a COGES layout. Pluses and minuses for COGES can therefore be summarised as:

+ Significant space saving
+ Significant weight saving
+ Low emission levels
+ Simplicity.

- Fuel cost

CODLAG can be readily introduced as an efficient 'mixed machinery' possibility if the operation profile includes a clear 'booster' speed function. CODLAG makes it possible to develop a machinery arrangement which is actually a conventional diesel-electric during normal operation, with the gas turbine connected only for short time. Like COGES, this concept has also both benefits and disadvantages:

+ Some space saving
+ Some weight saving
+ Fuel cost.

- Speed profile sensitivity
- Complexity

A major drawback is that the simplicity of gas turbine-based machinery is lost due to two different engine types with related ancillaries, spares, maintenance routines, and operational features. An evaluation can also be made for diesel machinery. When comparing this with a gas turbine, the list is as follows:

+ Fuel consumption

- Space demand
- Weight
- Complexity of auxiliaries

Gas turbines should be considered mainly as high-unit power suppliers. At low output - less than 10MW - both purchase cost and low efficiency, together with high maintenance cost - are clear drawbacks. Correspondingly, COGES feasibility is highest on large cruise ships with at least 60MW installed power. On small ships, such plant becomes overpowered and thus expensive when regarding available engine options. CODLAG is a potential intermediate alternative if the greater complexity is accepted.

On ro-pax ferries, the main issue will be how far diesel engines can cover the power demand. Medium-speed alternator engines of 460mm-480mm bore are, space-wise, on the upper limit, and today, these machines can develop around 67MW in 4x 16-cylinder formats.

Eighteen-cylinder engines are possible but more difficult to apply due to the large free moments. There are already projects being considered which would need more than 60MW propulsion power - well over 75MW - and thus CODLAG will become a real option since fuel economy, space and weight are the main issues on such ships.

Diesel and gas turbine combinations are also feasible options on some other ship types, the most interesting being LNG tankers. Diesel + COGES clearly has a higher efficiency than steam turbines and proven capability to handle the boil-off.

Importance of the heat factor

Energy management must be very carefully considered at a cruise ship design phase. This is a major issue needing much more attention than is currently given to it today, especially since waste heat recovery potential on modern cruise ships is already far from the demand. Heat has become a valuable energy, with both fresh water and cooling demand increasing from project to project.

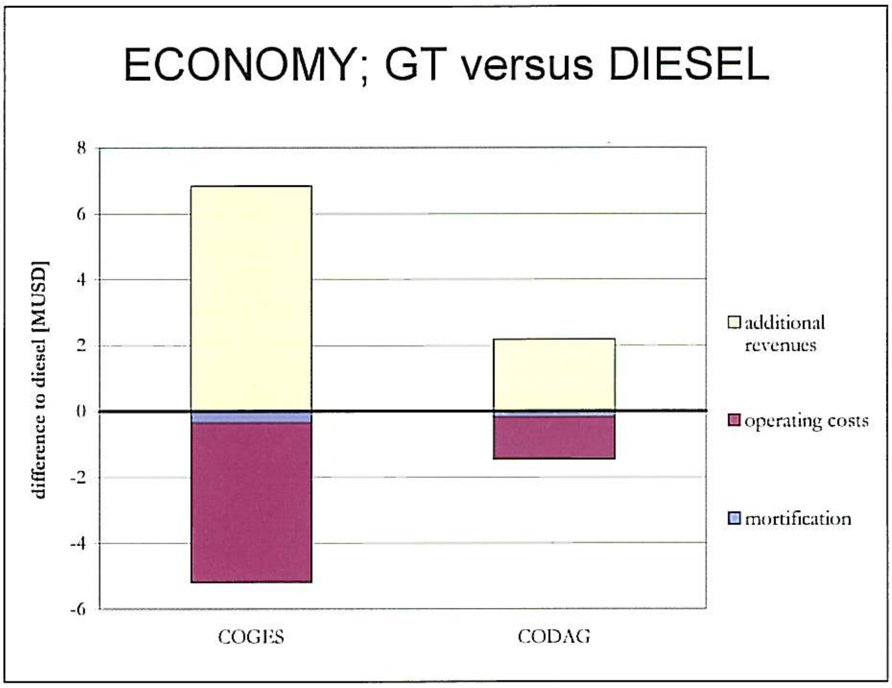
Today, water is generated by using heat, and cold air and water are produced by using electricity. Since both energy types have to be produced by fuel and are linked with the main power plant, it is important to focus on total energy efficiency and not just on energy for propulsion. The result may be that the traditional method is no longer the optimum one.

Just as an example, 30 times more energy is used when water is produced by using heat (in an evaporator) instead of electricity (the reverse-osmosis process). Correspondingly, it is six times more efficient to use electricity (in compressors) than heat (absorption chiller) for cooling.

Only a careful evaluation of all energy flows, not just mechanical ones, allows judgement on how these different options should be mixed when targeting optimum production and use of energy. Thus, these factors will certainly play a significant role when selecting machinery for the super-efficient next-generation vessels.

TIMPs: offering great benefits but some risks

Total integrated machinery packages, or TIMPs, as they are colloquially known, are a relatively new concept, which offer tremendous advantages for owner, yard and supplier, believes Deltamarin's Jari Nurmi. However, there are some risks attached.



The choice of machinery package is influenced by economic factors. This bar chart reflects the differences between gas turbine and diesel-based systems.

MOST leading names in the marine industry are working towards the total integrated machinery package (TIMP); however, it is quite clear that the three parties involved – shipowner, yard, and supplier – not only need to have a totally clear understanding of what is involved, but also incentives to follow this path. Failure to realise these twin goals could involve a high level of risk for all; for both owner and shipyard, delay in delivery is the most obvious - there are many stories worldwide of completion being delayed by subcontractors' failure to deliver vital components on time.

Additionally, suppliers may not deliver what has been expected. For the supplier himself, there is also a risk of too high costs and increased liability, but this could be overshadowed by vistas of increased sales volumes. Most importantly, a supplier needs to grasp an owner's view of a project and a particular yard's way of working.

Three essential features needed for the smooth running of any project involving TIMPs – especially so in shipbuilding, where the size and complexity can be enormous – are: modern software, efficient project management, and good co-ordination. These are also linked to the new subject of knowledge management, which is discussed in a separate article in this publication.

Some companies are already involved in supplying outfitting packages, as Leo Lagström outlines in the accompanying article, but for large-scale machinery systems, the concept is still in its infancy. For TIMPs to work efficiently, suppliers may have to rely more heavily on subcontractors – with possibly unfortunate results, as the recent saga of the bearings on new podded propulsion units has revealed.

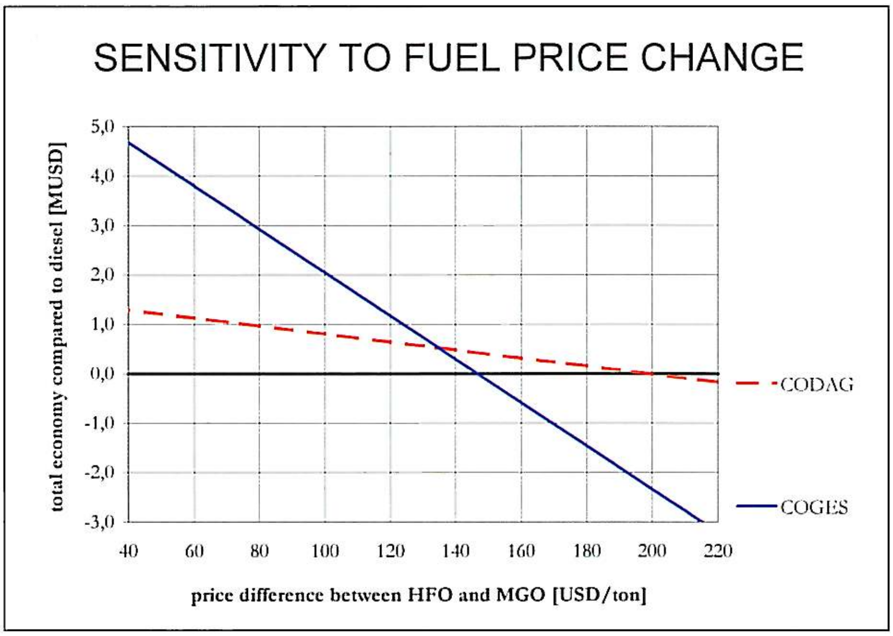
On the positive side, incentives for an owner can be summarised as:

- Integrated system responsibility
- Single source interface
- Single source for maintenance and life cycle support
- Enhanced training
- Increased safety
- Reduced operating costs.

Incentives for a yard include:

- Integrated system responsibility
- Single source supplier
- Shorter lead and installation times
- Lower overall costs
- Lower overheads.

continued



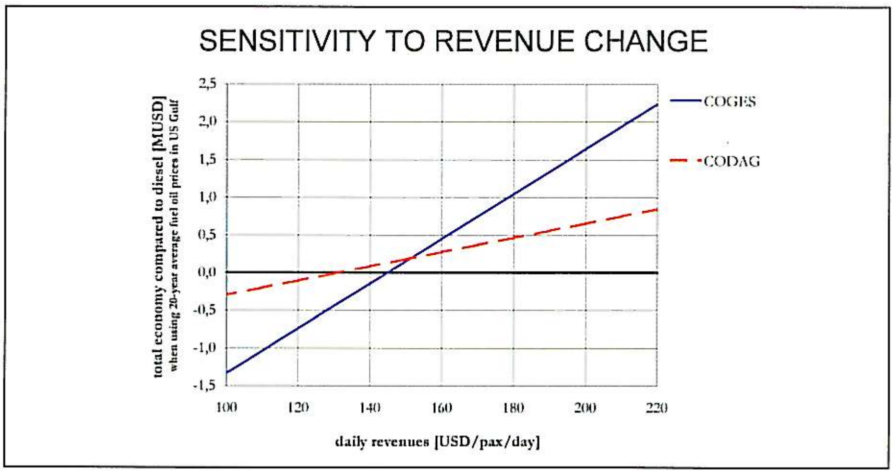
Propulsion machinery is equally sensitive to changes in fuel prices, as shown here for heavy fuel and marine gas oil.

For a supplier, the incentives could be most attractive; these mainly relate to increased volumes, increased market, increased after-sales volume, and improved margins. Despite the considerable risks for all parties, it does appear that the TIMP concept is one in which the industry should be actively investing – for the benefit of all.

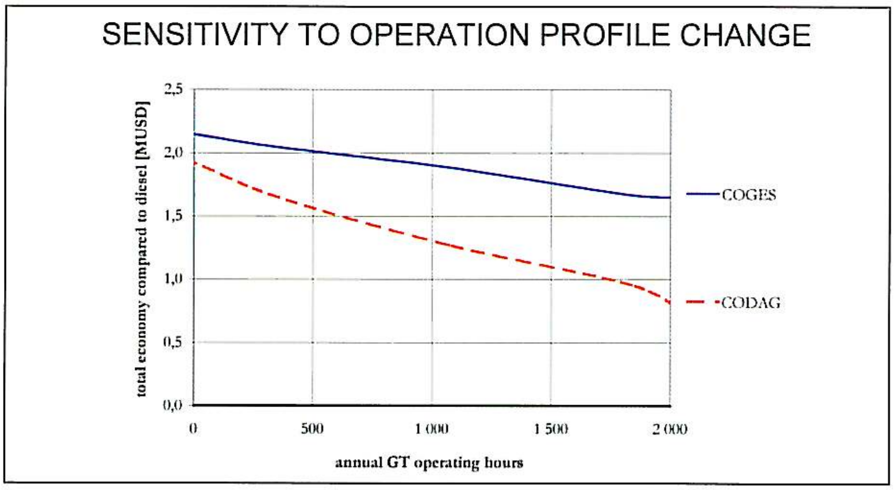
For its part, Deltamarin has approached this subject from three directions. The company has carried out several complete machinery space design and engineering tasks for different shipyards, including basic and detailed design, procurement handling, production planning, and site supervision.

At the same time, it has introduced new layout configurations, such as diesel-electric machinery and pod-propulsion for ro-ro passenger ferries, diesel-electric machinery for chemical tankers, and combined gas- and steam-turbine machinery for cruise liners, just to mention a few. The company has also introduced several new products to the market.

This background gives a perfect position for helping all three parties – owners, suppliers, and shipyards – to find an optimum route to the package philosophy. This should combine modularisation, standardisation, plus efficient co-ordination and definitions to suit the best role for each party.



Sensivity to operating revenues on a cruise liner or ferry is illustrated here.



Finally, changes in a ship's operating profile can also influence overall economy.

Modular packages offer great potential

TODAY, modern shipyards are making extensive use of labour-saving methods, such as prefabricated units, standardised modules, and even modular designs. Basic ship configuration and lay-out designs supporting this philosophy are therefore preferred by yards.

Typical areas where the modular concept has been successfully implemented are:

- Prefabricated passenger and crew cabins
- Prefabricated pipe packages
- Shower/toilet units
- Podded propulsion packages
- Ancillary machinery modules.

Detailed studies, says Deltamarin's Leo Lagström, have shown that installation time onboard can be reduced by between 10% and 50%, compared with workshop installation hours. On top of reduced costs, the quality of work carried out in a workshop is better and more consistent. In addition, the scheduling of deliveries and other logistic processes is simplified.

Some shipyards have even gone one step further by outsourcing all outfitting, insulation, heating/ventilation/air conditioning (HVAC), electrical, and interior work for complete areas. In this case, one area usually equates to a main fire zone (40m- 48m length).

In both concepts - modular packages and turnkey subcontracting - the benefits for owners, yards, and suppliers are evident:

Owners	Yards	Suppliers
Better application reliability	Shorter lead times	Improved edge over competitors
Less weight – reduced running costs	Fewer design hours needed	Modular concepts can be implemented
Better control of ship life-cycle costs	Reduced material costs	Better control of delivery information
Simulated layouts give operator-friendly solutions	Reduced installation time	Pre-planned and optimised delivery process.
Space savings through optimised layouts	Better control of building schedules	
	Fewer failures during testing and sea trials.	

Despite all these potential benefits, the necessary parameters, when planning an optimal building process, still have to be integrated into the concept phase, and all functionality has to be carefully evaluated. Unfortunately, in many projects, this still is not the case, due to a lack of large organisations with the necessary skills in ship concept design, supplier applications, and ship construction techniques. This means that progress in what is otherwise a favourable trend for all parties is being held back.

Passenger evacuation in a virtual environment and performance-based evaluation

As part of their Cruise & Ferry 2001 conference presentation, Harri Kulovaara, Dracos Vassalos, Markku Kanerva, and Janne Luukkonen outlined the fascinating topic of modelling passenger flows during an emergency.

A CONCISE outline of the novel EVI (evacuability index) simulation programme developed by the Ship Stability Research Centre at the University of Strathclyde in association with Deltamarin, is given in the accompanying article, but some more details are given here. Unlike earlier models, EVI has been developed from the outset for application to passenger ships, including the largest cruise liners and ro-pax ferries, in a marine environment.

A number of catalysts have brought passenger evacuation to the forefront of European shipbuilding priorities, triggering a need for the development of tools and procedures in support of performance-based design for evacuation to ensure cost-effective treatment of this important issue. Ro-ro ferry accidents have brought about the realisation that ship and cargo survival might have to be addressed separately from passenger survival, in that these vessels can capsize very rapidly, when damaged, thus not allowing sufficient time for evacuating passengers and crew. Accidents have also shown that lifesaving appliances (LSA) do not always fulfil the latter objective, particularly so in heavy weather conditions [Ref 1].

An amendment to SOLAS 74 requires ro-ro passenger ships constructed on or after July 1,1999, to have escape routes evaluated by an evacuation analysis early in the design process. This derives from the recommendation of the Panel of Experts (the IMO working group set up after the *Estonia* disaster), suggesting that ro-ro vessels will carry only as many passengers as can be demonstrated to be evacuated within, typically, one hour.

After investing for decades in ship's hardware for purposes of increased returns, it has been recognised that marked ship safety improvement necessitates investment in people. This is paramount when addressing the very survival of passengers, in that the consequence of accidents involving large loss of life could drive shippers out of business, as the *Estonia* tragedy has amply demonstrated.

Such consequences are bound to reach intolerable levels when addressing new concepts such as cruise liners carrying well over 5000 passengers. Moreover, the impracticality of evacuating such a large number of passengers exercises the minds of all concerned, in that they all appreciate the potential of a disaster waiting to happen.

There is a clear shift from rule-based and deterministic to performance-based and probabilistic approaches in the shipping industry, necessitating a fresh approach to problem-solving and state-of-the-art tool development with emphasis clearly on cost-effectiveness as key measures to increasing competitiveness in European shipbuilding.

Derived from the above, there is an immediate need to address the capability of the whole passenger evacuation system pertaining to mustering routes and procedures, life-saving appliances, also decision support and management. In turn, this leads to the necessity to focus on the development of evacuation analysis and simulation tools for the prediction of evacuation performance, thus allowing for a meaningful evolution of passenger ship designs with enhanced evacuation performance (minimum time for safe evacuation of passengers and crew).

Successful mustering and evacuation can avert disaster as last lines of defence even after the safety measures linked to structural reliability and enhanced ship survivability have failed. In this respect, the development of tools in the form of computer simulation models for the prediction of evacuation scenarios, evacuation time and probability of success in different conditions must be addressed as a top priority. The same tools could also be used to aid decision-making onboard the ship, thus tackling the same problem as an operational rather than a design issue.

Mathematical modelling

The mathematical modelling used in the development of the evacuation simulator is explained in detail in Ref 2. The main strength of this modelling derives from an ability to utilise high- and low-level planning interchangeably (EVI is believed to be the only middle-range model currently available for passenger evacuation analysis) and to account for human behaviour realistically by adopting multi-agent modelling techniques.

Moreover, EVI treats space as continuous, unlike other models that treat the ship area as a mosaic of square grids - a quantifying of space, which represents a problematic as well as an unnecessary deviation from reality. These features, coupled to minimal geometric modelling techniques, allows for very high computational efficiency, thus rendering the software suitable for routine application to passenger evacuation analysis.

Environment model

Modelling the environment is one of the most important aspects of multi-agent modelling. Generally, this consists of three aspects - geometry, topology, and domain semantics. The perception model for the agents will be able to use the information in these three abstractions at different levels of the decision processes. A whole ship layout is segmented into Euclidian convex regions with local co-ordinate systems and a structure of a linear space, directly connected if they have a common gate.

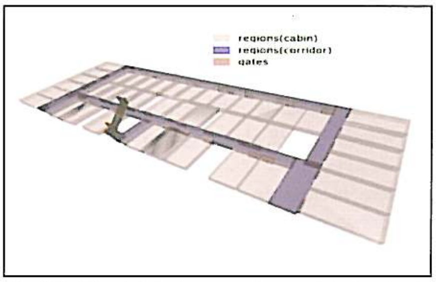


Fig 5. Minimal virtual-geometry model of a deck.

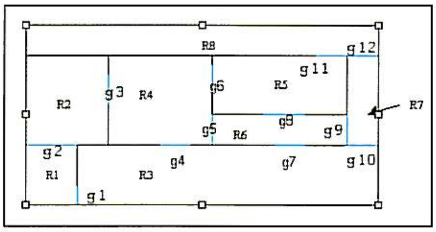


Fig 6. An example layout of regions and gates.

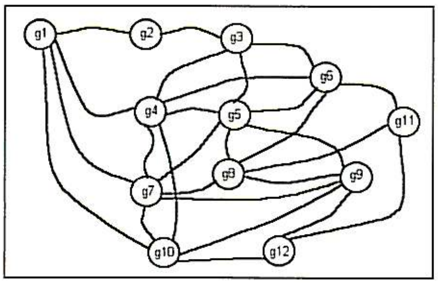


Fig 7. A gates graph corresponding to Fig 6.

For all computation and analysis purposes, this connection can be represented by a graph. In ship layout terms, regions are defined as cabins, corridors, public areas (or subsets of these), each with its own co-ordinate system and connectivity, defined by gates (these may be actual or artificial doors). Figs 5-7 illustrate schematically these ideas.

The path of the agents leading to an embarkation station is determined by searching the connectivity graph. Currently, the length of the path is taken as the criterion of optimality for network flow. A minimal description of the ship layout will enable designers to modify the layout easily (add a new corridor or a staircase in virtually no time, without having to draft details using an elaborate CAD tool). Hence, evacuation performance can be obtained faster, thereby making simulation an ideal design tool.

The contrary can be also easily achieved – by simply blocking areas, regions or whole fire zones, the effect of these changes can be examined, and therefore the sensitivity of each part of the vessel on evacuation capability.

Furthermore, the availability of 2.5D and 3D models allows for real-time visualisation, in which the complete geometric details of a ship and human agents will be utilised to give rise to an extremely realistic representation. As an alternative, the code can also be executed separately, allowing much faster evaluation of a simulation and leaving visualisation as a post-processing alternative.

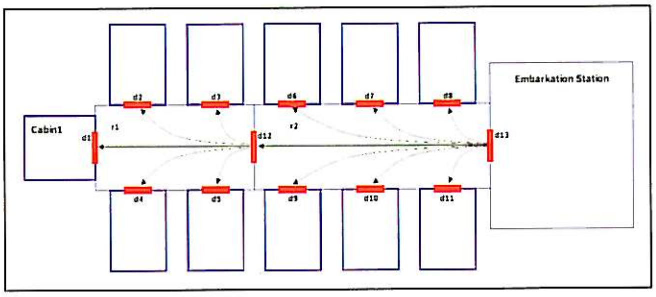


Fig 8. A simple illustration of path-planning. Re-planning during evacuation is also possible if, for example, there is a dense crowd 'blocking' the path or a blackout in the presence of fire or smoke.

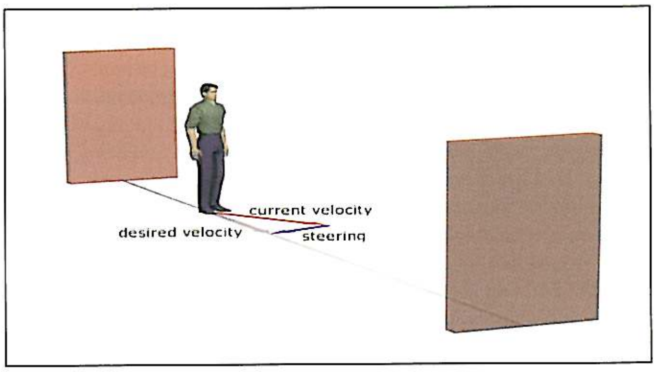


Fig 9. Pursuit of a static target.

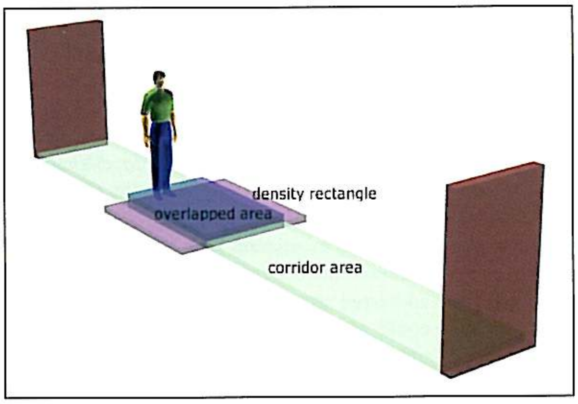


Fig 10. The concept of local density.

High- and low-level planning

High level – path planning and graph search

Since increasing complexity involving thousands of doors and regions is likely, it is very important to have an efficient path-planning process. The path-planning algorithm adopted is illustrated in Fig 8, explaining how only the distance information from each door to the embarkation station needs to be left with the door's identification. When an agent is located in a region, the distance information from each door of the region can be obtained, thus allowing the agent to simply head to the shortest path leading to the destination area.

Low level – steering of agents

Pursuit of a static target acts to steer the agent towards a specified position in global space. This behaviour adjusts the agent so that velocity is radially aligned towards the target. The 'desired velocity' is a vector in the direction from the agent to the target representing global 'flow speed', adjusted on the basis of local density, as explained in the following. The steering vector is the difference between this desired velocity and the agent's current velocity, as shown in Fig 5.

In the absence of any obstacle and other evacuees, every agent will 'flow' along the evacuation direction field (passing through the gates unobstructed), hence heuristics are used to avoid collision with neighbouring agents and obstacles along an evacuation path.

Modelling human behaviour

To cater for the plethora of behavioural parameters that are likely to affect the evolution and outcome of an evacuation scenario, there is a need to adopt a framework that allows for as many behavioural parameters as deemed appropriate to be considered. The framework adopted in the development of EVI treats passengers as intelligent agents with attributes modelled as an array of 'genes'. These, for example, determine the behaviour of a mother searching for her child before abandoning the ship, the father taking a leadership role in a crisis, the child following parents, members of a family forming a group, and so on.

'Genes' may be active or inert depending on circumstance, time and domain semantics. For example, if the current leader of a group becomes incapacitated, a new leader (someone with the right 'gene') would take this role. Hard data has largely been obtained from open literature. An overview of the behavioural parameters currently being considered is provided in Ref 3.

Speed of advance is the compounded outcome of all that is going on onboard a ship in an emergency at sea during evacuation. As the IMO Interim Guidelines state, the speed of an agent is determined by the density of the crowd in a region. In general, crowd density is non-uniform and it may strongly depend on the size of the area considered.

If the crowd is concentrated near a gate in a large region, the remaining part of which is empty, division of the number of occupants by the total area of the region may give a small value of density which clearly fails to capture the situation. To overcome this drawback, the concept of 'local density' is used as shown in Fig 10, in which the local density in a region in front of the agent (a rectangle of 2.14m x 2.14m) is computed and the IMO speed values assigned in accordance with this local density value. This makes the scheme conformant with IMO without sacrificing realism.

Additionally, when long queues form, the effect on speed of advance is calculated on the basis of the queue length. Dependence of speed on other parameters is modelled by using multiplication factors that are functions of relevant parameters, the total product being treated as a mobility index.

In EVI, results from MEPdesign research [Ref 1] are adapted to mustering and evacuation scenarios. The way of approaching this topic is to relate the reduction in speed to the roll angle. To this end, a maximum roll angle of 20deg is assumed, at which the speed reduction becomes 100%. The reduction in other angles follows a relationship derived on a basis of a scheme in which the weighted average of the roll angle values experienced in the immediate past (over a few roll cycles) is used.

Modelling uncertainty - human behaviour parameters

The psychological and physiological attributes of humans are non-deterministic quantities. Even in a contrived experiment, one can hardly reproduce human actions/reactions, even if all of the conditions remain the same. This inherent unpredictability of human behaviour, especially under unusual and stressful circumstances, rules out the possibility of a deterministic program to model evacuation correctly.

For this reason, human behaviour has to be modelled with some built-in uncertainty. To this end, every parameter is modelled as a random variable with a predefined distribution. This is to eliminate the occurrence of unrealistic behaviour - for example, everybody of the same age reacting exactly at the same time to an alarm call.

Monte Carlo method

The inherent uncertainty in human behaviour will give rise to a reasonable amount of variation in the result of simulation in different instances of execution. Thus, some statistical aggregate quantities evaluated over several simulation runs (forming a cumulative probability distribution as shown in Fig 11) have to be defined; these must have the property of approaching a limit as the number of ensembles grows indefinitely.

The term 'evacuability' is defined as the probability of an environment being completely evacuated no later than an elapsed given time after the alarm sounds, in a given state of the environment and a given state of initial distribution of people onboard. With this formalism, a sound rule may be proposed, eg, Evacuability (60 min, entire ship (worst anticipated conditions, worst passenger distribution) > 0.99.

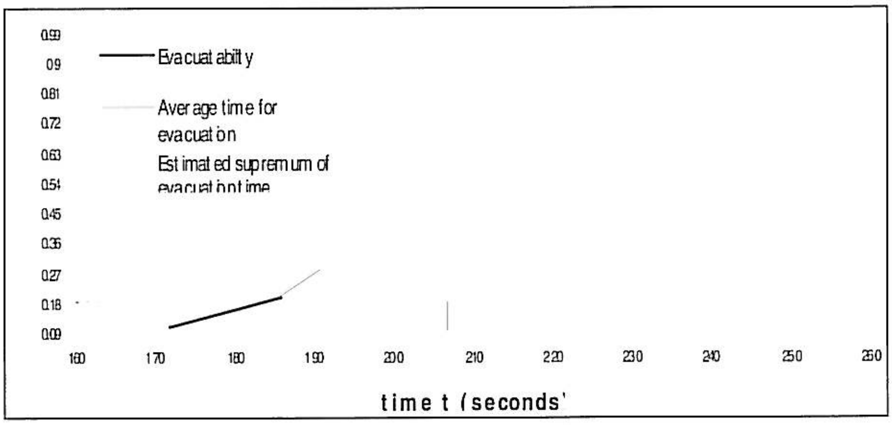


Fig 11. A typical 'evacuability' graph using the Monte Carlo method.

Design for ease of evacuation

If all the constraints were analytic and all the variables continuous, a rigorous way of solving the evacuation problem would involve minimising a contrived grand objective function which includes all the constraints (with properly weighted penalties corresponding to their violations) and the pure objectives. But since the adjustable parameter space also contains topological parameters that are inherently discrete valued (the number of staircases between two decks, number of cross-ways connecting the corridors, number of corridors, and so on), the main alternative is to undertake a sensitivity analysis.

In this respect, microscopic simulation reveals a lot more technical information about the scenario (in addition to the information on evacuation time), which may be of great value in the design process, including the following:

- The time history of queue size at the gates of interest (the ones to be designed). Queue length history directly reflects bottlenecks in the simulation quantitatively, without requiring someone to watch the animation to identify these, and thus does not rule out the possibility of some automation in the design for ease of evacuation.

  It may appear that bottlenecks are always problems; however, it could be argued that the narrow design of a gate may prevent an intermediate region (for which the said gate mostly plays an inlet) from being overcrowded beyond the extent that hinders guided evacuation or beyond what some other constraints permit, and this may be a plausible design alternative.

- The time history of the total number of crossings through each gate of interest. If the width values for the doors are set to large numbers, then the allowable efflux rate for the doors will be large enough to allow any number of people through and will not cause any queuing. Under this contrived situation, the maximum value of (or may be a modal value of) the slope of the gate crossings' history curve will indicate the value of efflux rate (and thereby the width) required to prevent queuing.
- The history of total occupancy of each region of interest. The peak value reflected in a region's occupancy history must not exceed the total capacity of the room (as determined by the area of the room multiplied by the maximum allowable crowd packing density).

Run-time simulator

EVI's user interface includes a number of pages, addressing the ship environment, behavioural issues, and the running of the simulators. By way of illustration, the main page is shown in Fig 12, and details are as follows:

The main page: Adjustable loading condition (of passengers and crew); choice of which deck to include in the simulation; time-of-day; sea states; simulation mode.

The behaviour page: Choice of behaviour to be included (both for crew and passengers).

The region/gate page: Add/edit/remove regions; block door/area/staircase/decks/fire zones.

The platform/playback: Choice of simulation visualisation mode: playback, save or combination.

The run-time chart/Visualisation: Chart showing progress during evacuation.

Case studies

To demonstrate the use of the run-time simulator, three evacuation cases are considered here for a large cruise liner. Information on passenger distribution was received from the owner based on counts from 43 voyages completed by the vessel during the year 2000 and from demographic details through the Cruise Lines International Association. All cases use 3492 passengers.

The simulation runs continued until 99% of the evacuees had reached the assembly station, the obvious reason being that in some cases (such as passengers becoming lost), a very small number of passengers could have a very large effect on the evacuation time. The simulations were run for the full vessel - with passengers in their cabins for the first case and with the 'true' passenger distributions in the remaining two.

Case 1: This case is based on IMO Interim Guidelines, [Ref 4]. This is a standard day-case with passenger distribution according to the liner's escape plans.

Case 2: This case simulates an evacuation situation, taking place during the morning and based on the cruising daily programme. The special condition during the simulation is a blocked stairway between decks 6 and 10 in fire zone 5. As a consequence of this, people onboard are forced to find an alternative route to the assembly station.

Case 3: This case imitates 'senior' cruising at evening time. Around 90% of the passengers are over 60 years old and the rest are over 50. During the simulation, the heeling angle increases steadily from zero to 10deg over a period of 10 minutes.

Results

Results of some real mustering exercises for large passenger ships [Ref 5] indicate that the time it takes to assemble all passengers before embarkation varies from 7 minutes to 28 minutes. The great variance was due to the difference in passenger preparation. Some vessels also recorded the time taken to empty the assembly stations at the end of a passenger drill – that is, the time it takes for passengers to depart the assembly stations and for the stairways to empty of other than routeing traffic. The time to empty the assembly stations consistently turned out to be between 7 minutes and 9 minutes.

Members of the International Council of Cruise Lines (ICCL) have identified five incidents since 1984, in which passengers were sent to assembly stations without advance notice as a result of a collision, grounding, or fire. The time for mustering all passengers and crew, including a full sweep of the ship for injured, stragglers, disabled, or uninformed, ranged from 17 minutes to 28 minutes.

In one instance, where the ship had taken on a 5deg list, the assembly time was increased to 25 minutes. Two of the incidents occurred in the late night/early morning timeframe when many or most passengers were in bed.

Results from the case studies considered are shown in Figs 13-15, together with results

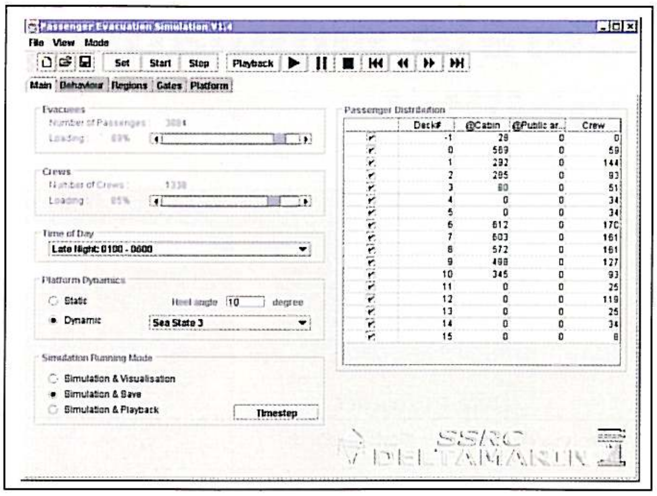


Fig 12. EVI – The main page. This is one of a number of pages providing details for the run-time simulator.

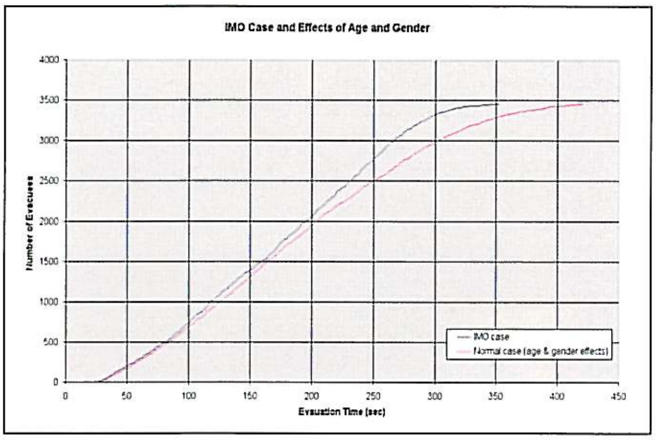


Fig 13. Case 1 – Basic IMO and normal cases. This shows a 20% increase in time due to gender and age. Both normal and IMO cases, however, suggest times for evacuation towards the lower end of the data provided in Ref 2.

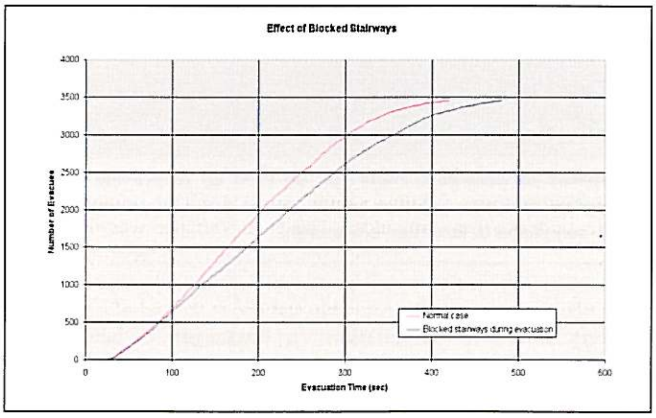


Fig 14. Case 2 – Blocked stairways in fire zone 5. In addition, when passengers arrive on the deck where the assembly station is (a short period later than a normal case) they still have to queue before arriving at their destination.

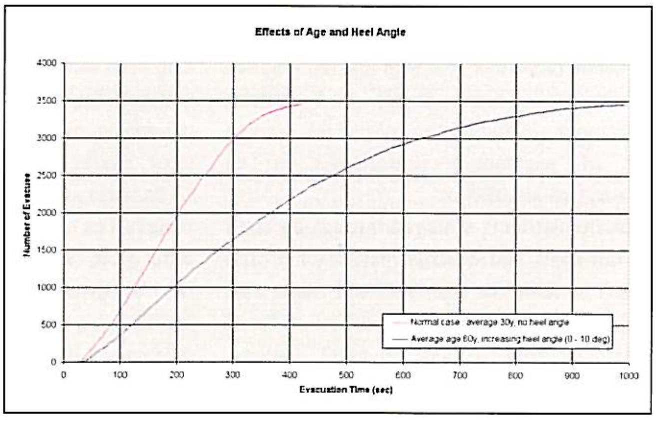


Fig 15. Case 5 – Effects of age and heel angle. The effect of this is to more than double the evacuation time. For comparison purposes, the opposite extreme is also simulated, referring to a mustering scenario where all the passengers are young (thus, faster walking speeds and shorter reaction times).

from a 'normal' case for comparison purposes, the latter referring to a standard case of EVI, including uncertainties relating to age and gender effects.

Fig 14 illustrates that the effect of blockage on the evacuation time is not as noticeable as one might expect (considering the loss of means of escape routes). The reason for this is that the distance passengers have to travel to reach an alternative stairway (most choose staircase in fire zone 7) is not that much further than their original choice and does not take long to travel. This is, of course, directly related to the layout of the vessel.

Conclusion

A state-of-the-art passenger (ship) evacuation simulation model has been developed offering wide-ranging capability to model realistically the most complex of scenarios. Its structure takes advantage of middle-range multi-agent techniques to simulate realistically human behaviour whilst accounting for the ship-sea environment and the inherent uncertainty in all the prevalent parameters.

Design-for-ease-of-evacuation and evacuability studies could be readily undertaken, rendering EVI a valuable design tool. Work at IMO is currently addressing the problem of evacuation of large passenger ships as a matter of priority. In this respect, it has been demonstrated that EVI can deal with the sheer size of the problem at hand - from computer modelling and simulation viewpoints. Efforts must now be directed towards verification and validation through benchmarking, and through acquiring 'real' and experimental data.

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EVI: a new tool for accurate simulation and analysis of 'evacuability'

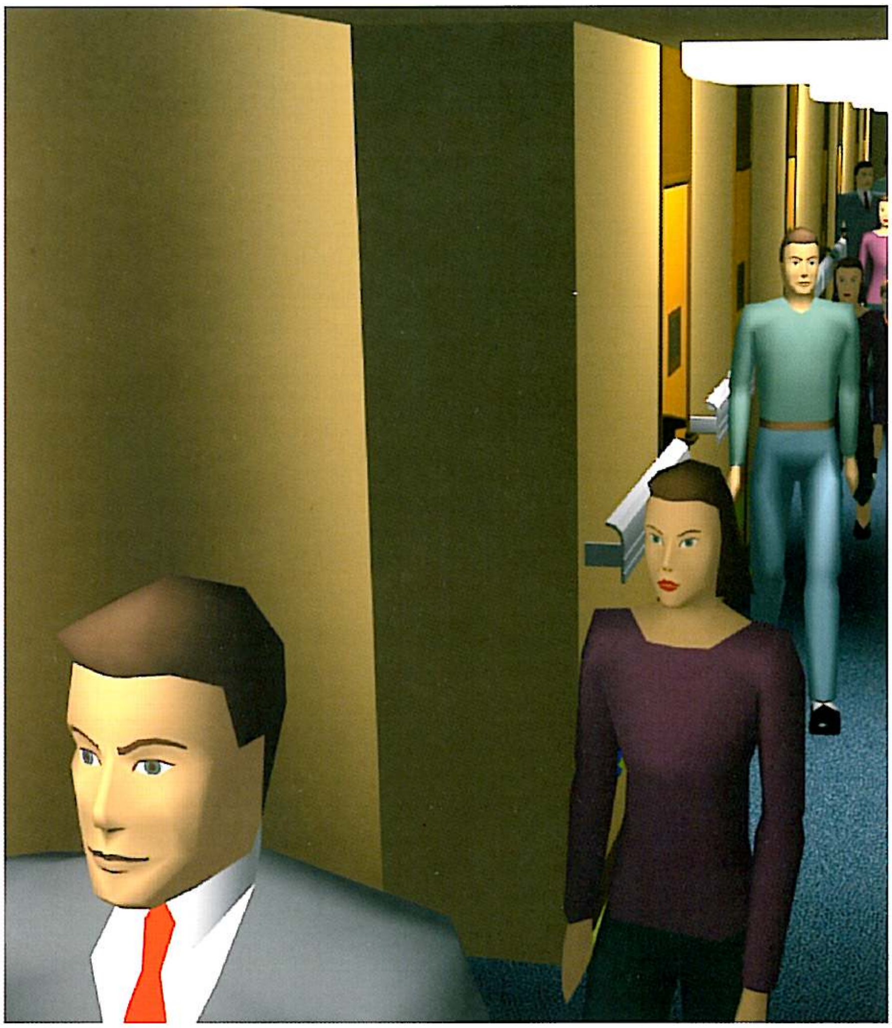
A MOST useful real-time interactive model, developed by the Ship Stability Research Centre at the University of Strathclyde in collaboration with Deltamarin, has now matured to the point where it can be used routinely to provide state-of-the-art simulation of effective evacuation performance. This follows successful trials with the virtual-reality software - code-named EVI (an acronym for 'evacuability index') - on analysing procedures for a number of vessels, including large cruise liners and ro-pax ferries, with some owner feedback resulting in a number of practical refinements.

The term 'evacuability' covers a wide range of capabilities for EVI, including evaluation of evacuation time, potential bottlenecks, accommodation module layout, and sensitivity analyses to assist with the inclusion of design features to aid easy evacuation. In addition, 'what if' scenarios can be built for training purposes, effective planning procedures and decision-support strategies can be devised to manage a crisis, and videos can be used to familiarise passengers with a ship's environment - especially important in modern-generation giant cruise liners.

EVI is based on multi-agent modelling techniques, seen as the most appropriate for passenger evacuation simulation, and on a multi-level planning structure. A combination of high-level planning (eg, path selection or a decision to use an alternative exit when a slow-moving queue forms) and low-level planning (eg, obstacle avoidance and direction detection) can be injected, together with modelling of uncertainty in all parameters that could affect evacuation times.

These aspects, plus an ability to playback recordings as video, make it possible to model realistically the most complex of scenarios, including flooding and fire. EVI is termed 'mesoscopic' (middle) to emphasise that in evacuation analysis, both macroscopic (the flow model advocated by IMO in its interim guidelines) and microscopic (human behaviour) models are necessary for an analysis of mustering and evacuation to be meaningful.

EVI is available in the form of a computer program that can be customised to a particular ship. Semantic, topographical, and geometric information are all required, the last varying from the very simplistic (allowing rapid calculations for high-level planning) to a 3D virtual environment that replicates an actual ship, with an efficiently tailored user interface and run-time simulator (RTS). The RTS allows, with a minimum of training, almost any evacuation scenario to be set up while accounting for the dynamic behaviour of a ship in a realistic sea environment (sea state) and human behaviour (including the role of the crew) - all of paramount importance in an evacuation simulation.



By using EVI, virtual-reality replicas of individual ships can be built up to provide accurate evacuation simulations. A complete analysis, together with a report and customised run-time simulator (RTS), can normally be completed in less than one month.

A simulation is achieved through an array of variables that describe passenger profile (such as numbers, age, sex, and those with impaired mobility) and distribution for a particular time of day or night - again, essential knowledge before attempting a simulation. Passenger behavioural characteristics also need to be included (such as treating passengers as intelligent human beings with the ability to perceive/decide/act), and each needs a number of 'genes' inserted that shape individual behaviour. The number and location of crew members and the sea state also need to be input.

Typically, EVI can simulate 5000 passengers mustering on a 15-deck vessel in very nearly real time - a feat which Deltamarin and the University of Strathclyde believe has yet to be accomplished by any other group working in this area. Using this new equipment, a full evacuation analysis, including a comprehensive report and a customised RTS, can normally be completed in less than one month.

Achieving an optimum 'green' ship through minimal exhaust emissions

At a conference three years ago on diesel-electric propulsion (April 1998, Helsinki, organised by the Norwegian Society of Chartered Engineers), Jari Nurmi, from Deltamarin, discussed in his paper 'Environmental Aspects – Fuel Emissions', how often the preliminary targets for machinery are set too high. Owners often want an ultimate from the start without having a clear idea about the impacts each solution has on a ship's overall economy. This may lead to a situation where many of the primary targets have to be abandoned due to cost pressure while the project is proceeding. Although written three years ago, this text is still highly relevant to new ships today, although costs may have altered slightly.

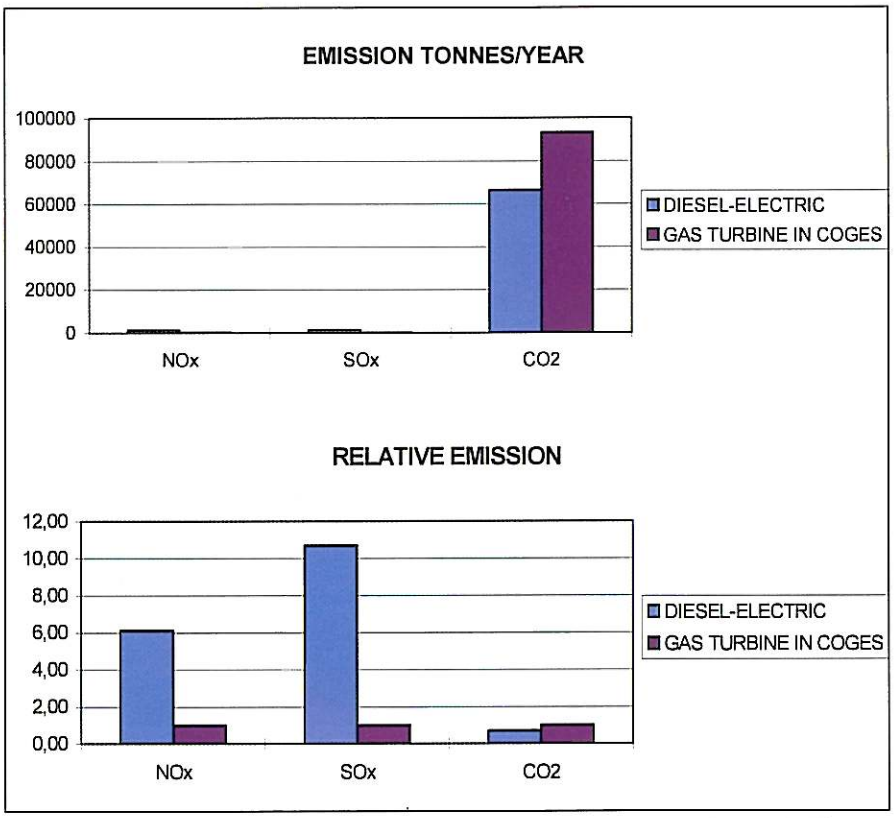


Fig 1. Exhaust emissions from one cruise ship. The figures would be different if the global impact, including emissions from refineries and oil transport, are also included. Is a ship with high NOx and low CO_2 a 'green' ship?

'GREEN-SHIP' issues are closely tied to both machinery and fuel type; does heavy fuel, low-sulphur heavy fuel, or even marine diesel give best economy for the actual operation pattern of a particular vessel? This article aims to show how different fuel emission reduction methods should be compared and what aspects must be considered in such an evaluation.

Diesel-electric machinery has been proved to be an attractive and efficient choice not only for passenger ships but lately also for several tanker types; however, the configuration and arrangement of such a power plant is a decisive factor affecting the feasibility of electric propulsion. Profitability of any ship concept mainly depends on how the better freedom in power plant and component allocation can be utilised when creating ideas for new ship designs.

One major difficulty for a shipowner in any 'green-ship' discussions has been how to compare the possible NOx and SOx abatement methods to each other if an emission limit or cost penalty would be applied on his vessel. In most cases, the straightforward comparison will not give the right answer due to the fact that the basis is not the same for all options. Comparing selective catalytic reduction (SCR) with water-based methods leads to false conclusions just because the end result is different; the methods are not comparable at all. Another issue, directly related to emissions, is the choice of fuel type; what should be considered and what are the impacts for the ship economy.

A frequent question on this complex matter is: what would be the real cost impact from the different emission limits and which are the issues to be considered when designing machinery for a green ship?

Engine exhaust emissions

Most of the world fleet is continuously operating relatively near the shoreline. Thus, there is little doubt that ship emissions have an impact on acidification, air pollution in cities, and global warming. Environmental discussion has reacted correspondingly, and today great attention is paid to exhaust emissions when selecting a machinery concept.

Emissions from propulsion machinery and alternators are CO_2, SOx, NOx, HC, and particulate matter, with the main concern being for NOx, SOx, and CO_2. The situation becomes problematic when taking into account that these emissions have different development methods, and hence different abatement methods have to be applied for each of these components.

Definition of a 'green' ship itself is an open question. Which are the emissions to be considered in the definition: is it NOx, SOx, CO_2, or even particulates. Can we call a ship with very low NOx and SOx values but high CO_2 emission a green ship? Fig 1 gives some idea of the dilemma.

This is only one of the open questions which is actually really relevant when considering machinery choice and the possibilities for emission abatement. Other issues are:

- What impact does the engine type have on emissions?
- What methods are possible to achieve lower emissions?
- What is the cost?
- How does one compare these methods?
- What fuel should be burned?

Reducing exhaust emissions

Carbon dioxide (CO_2)

CO_2 is a greenhouse gas having a global warming effect and is thus subject to wide interest. CO_2 emission is related to carbon content of the fuel and in a stochiometric burning process all carbon is turned to CO_2 in reaction with oxygen. In reality, the burning is not as efficient and some of the carbon is unburned and emitted as carbon monoxide, CO. As the carbon content of liquid fuels is quite constant, 85%-86% of weight, the emission can be directly related to volume of fuel used, despite the fact that there are slight fuel-type-dependent differences; every tonne of fuel creates about 3.1tonnes-3.2tonnes of CO_2. The difference in fuel heat value and corresponding impact on fuel demand must be considered in evaluations.

Thus, the only effective method of reducing CO_2 emissions is to reduce fuel consumption by applying higher efficiency engines or propulsors. A 15% saving in propulsion power demand with podded propulsion would reduce CO_2 emissions by around 15%. The question of CO_2 is really relevant in respect of selection of engine type; in particular, gas turbines have extremely low NOx and SOx emissions but high CO_2 due to high simple-cycle fuel consumption.

Nitrogen oxides (NOx)

NOx is one reason for acid rain and ozone depletion. NOx has, according to DNV, 20 times greater relative impact on global climatic change than CO_2, hence NOx has received more attention in ship emission discussions than CO_2.

The most common nitrogen oxides in exhaust gases are NO and NO_2, which are denoted NOx. NOx builds up by reaction between nitrogen and oxygen of combustion air (thermal NOx), by reaction between exhaust-gas hydrocarbon and combustion air oxygen (prompt NOx) and by reaction between nitrogen bindings in fuel (fuel NOx).

Thermal NOx is decisive for total emission, and all the abatement methods are targeted to reduce that component. High temperature and free oxygen molecules are prerequisites for thermal NOx. At temperatures above 1500ºC, NOx rises very sharply and thus methods such as retarded injection or water in burning or in fuel reduce those peak temperatures, at the same time lowering NOx emission.

Since NOx is dependent on the combustion process, it is also related to engine type. Low-speed engines with a slow burning process and a high air/fuel ratio have the highest emissions due to the long time that the oxygen is allowed to react with nitrogen. On the other hand, constant-flow engines such as gas turbines have no temperature peak; hence these engines have low NOx emissions. Fig 2 shows average NOx emission levels for three engine types.

NOx reduction can be carried out either by modifying the combustion process, or by fitting separate exhaust gas catalysers (SCR). The main question is: what is the feasible method at each emission level.

Applied, commercially available methods at present for marine NOx reduction are:

- Retarded injection
- Direct water injection
- Water-fuel emulsification
- SCR-catalyst with urea (or ammonia on cargo ships) as agent.

Quite often these methods are compared against each other by just calculating the first cost and running cost; however, this would lead to false conclusions. The vital variable to be considered is the cleaning capability. Whereas a SCR unit can reduce the NOx level on a medium-speed engine typically down to 2g/kWh, a water-based method is applicable only down to a minimum NOx limit of around 6g/kWh for a medium-speed engine and 10g/kWh for a slow-speed type. Thus, the systems are not comparable with each other, and judgement must be carried out at certain emission level. Fig 3 shows the situation; if the future NOx limit becomes lower than 6g/kWh (or 10g/kWh for a slow-speed engine) the emission abatement cost double and will have a real impact on overall economy.

NOx abatement also affects ship systems. If a water-based method is selected, fresh water production must be expanded, in most cases. A 14MW engine installation may need 30tonnes of fresh water daily for NOx reduction alone. This is well over normal demand on a typical cargo ship and must be considered as an additional cost.

If SCR is selected, then the catalyser is just one of the many components of the system to be considered. A SCR plan has an average volume of $1m^3$/MW and a weight of 1kg/kW for a medium-speed engine. Additionally, dedicated urea storage tanks, pumps, and injection and control systems must be also provided. Fig 4 gives an idea of a SCR installation on two different ship and engine types.

Urea consumption is around 20g/kWh for a medium-speed engine and 30g/kWh for a low-speed engine when the target NOx value is 2g/kWh. Thus, urea costs can easily rise to up to one quarter of fuel cost, as shown on Fig 5.

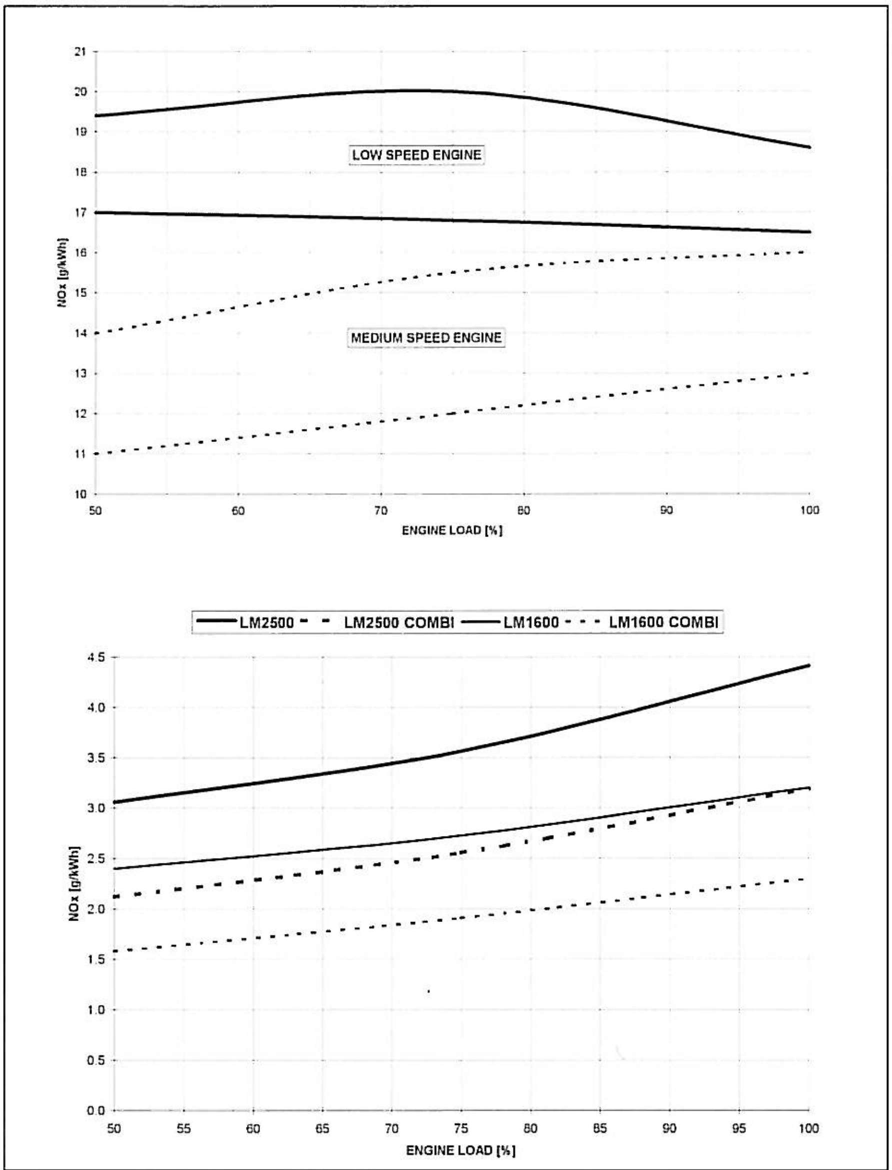


Fig 2. NOx emission curves for slow –speed and medium-speed diesel engines, and for gas turbines. In the diesel-engine graph the top curves are for a standard engine and the lower ones for a low-NOx version.

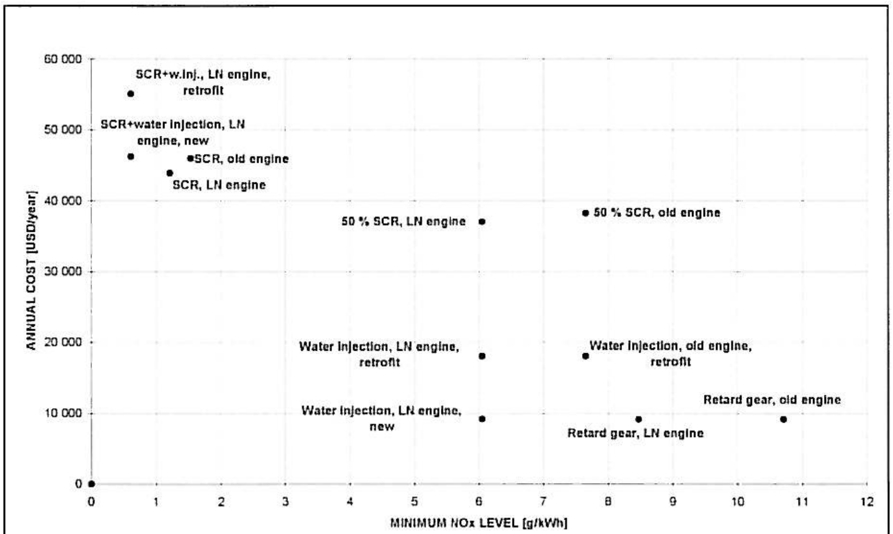


Fig 3. Annual cost of a 1500kW auxiliary engine on cargo ship, which is only used in harbour. A SCR system for a 14MW main engine in continuous use can easily create a US$1million/year additional cost for the owner. This value can be reflected in an annual fuel bill of US$2million. Below 6g/kWh, SCR is the only commercially viable option for medium-speed engines.

The SCR concept also needs also a certain minimum temperature to operate correctly; this depends on the sulphur content of fuel, according to Table 2. Too low a temperature and a high sulphur content increase also the probability for catalyst blocking by ammonium sulphate.

The temperature issue must be especially considered when evaluating engine choice for diesel-electric ships, since constant-speed engines have decreasing exhaust temperatures at decreasing load. This may in some cases lead to too low temperatures for effective SCR operation and thus later modifications to the turbocharging system.

Sulphur in fuel	0.5%	1%	1.5%-2%	2.5%-3%
Minimum catalyst inlet temperature	320ºC	325ºC	330ºC	335ºC

Table 2. Example of recommended minimum exhaust gas temperature in the catalyst inlet, depending on fuel sulphur content. It must be noted that even though exhaust-gas temperature rises in an SCR unit, the temperature is cooled down to some 5ºC-10ºC before the catalyst depending on the distance from it. This, together with exhaust-gas temperature features of modern diesel engines, can lead to situations where the SCR does not operate correctly at low engine load.

It could be concluded that the choice of NOx abatement system must be initiated from a requested NOx level. A good starting point is the well-known IMO curve, which actually indicates the NOx level of a modern low-NOx diesel engine and thus shows where no additional cost penalty can be expected.

In case of a reduction up to 50% of that level, meaning a minimum emission level of 6g/kWh for medium-speed engines and 10g/kWh for slow-speed models, being sufficient for a ship's lifetime, then the best solution would be one of the water-based systems. This can be either direct-water injection to the cylinders or burning a water-fuel emulsion; the choice depends on engine make.

If even the strictest proposals are implemented, then the only possible choice is based on an SCR application as far as diesel engines are considered, while gas turbines can be equipped with low-NOx burners.

Fig 6 shows the cost structure when the alternative methods are applied on a 1.5MW engine. It should be noted that the kW cost of a SCR unit steeply decreases from 1MW to a 5MW engine output; for example, the kW price of a SCR unit for a 2MW engine is twice that of a 5MW engine. Thus, larger engines and low engine numbers give a lower SCR cost than a high number of small engines at the same power level.

Sulphur oxides (SOx)

Like NOx, the environmental consequence of SOx is acid rain and ozone depletion. Concerning SOx emissions, there is actually only one feasible method to apply: reduction of the sulphur content in marine fuel. Because all sulphur in fuel remains in exhaust gas, 1kg of sulphur in fuel equals 2kg of SO_2 in exhaust gas. This means a daily SO_2 emission of around 3tonnes on a diesel plant operating at 14MW average power and burning typical 2.5% sulphur-content fuel.

Low-sulphur fuel is already available on selected markets, and there are no technical

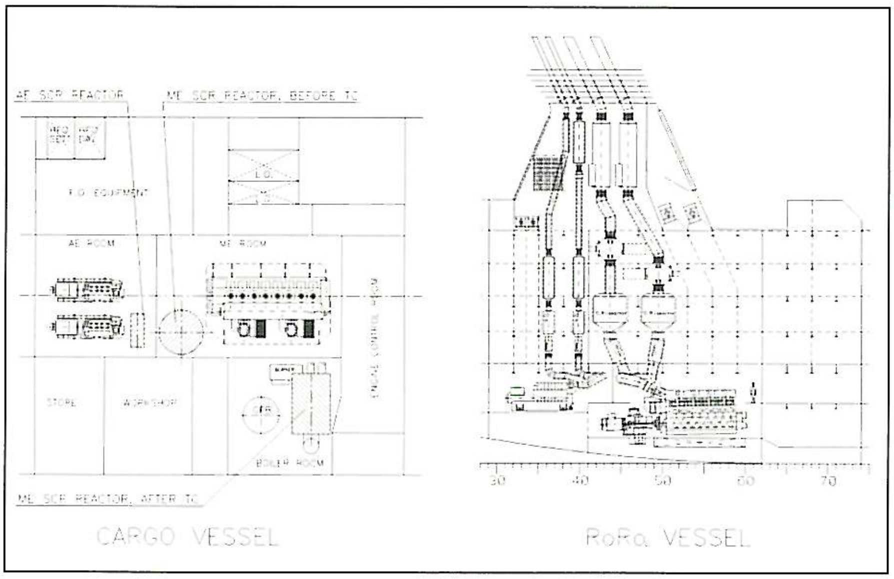


Fig 4. Installation of a SCR plant on two different ships: a cargo ship with slow-speed main machinery and a ro-ro ship with medium-speed engines. Items to be considered when designing an arrangement include a urea injection chamber before the SCR unit and exhaust-gas boiler after it. Space must be also be provided for dedicated urea storage tanks.

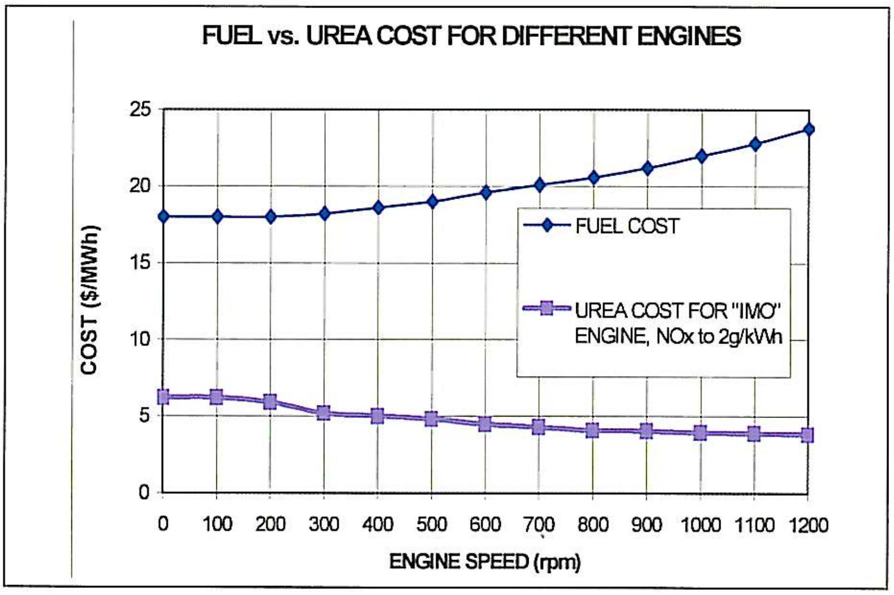


Fig 5. Urea cost vs fuel cost on different engine types. RPM indicates nominal engine speed.

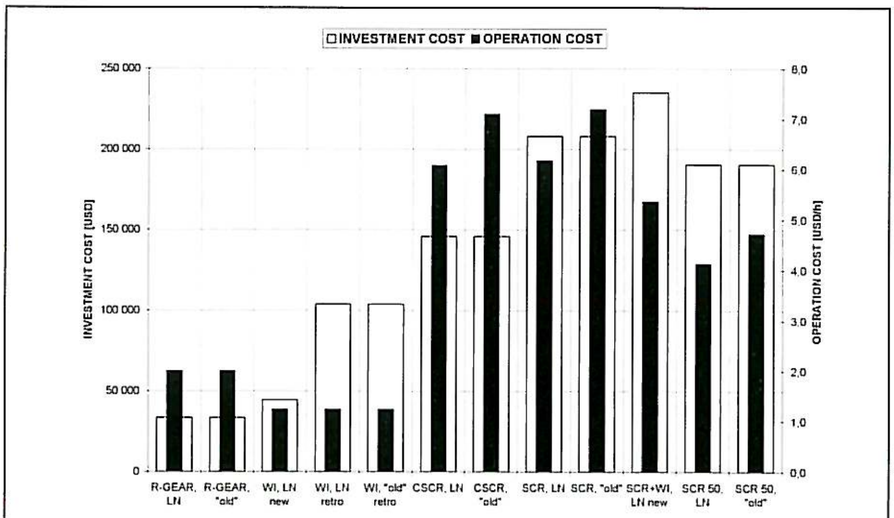


Fig 6. Investment and operation cost for NOx-reduction methods on a 1.5MW medium-speed engine. R=retard, old=existing engine needing modifications, LN=low-NOx engine, SCR=selective catalytic reduction, WI= water injection, SCR 50=a SCR unit rated for 50% capability.

problems regarding pollution prevention through use of this. It is possible and feasible to de-sulphurise residual oil at the refinery, but it requires much energy and investment, meaning a higher fuel price.

Figures such as US$15-US$30/tonne are stipulated as estimates when changing from a typical heavy fuel with 2.9% sulphur content to 1% sulphur content. More important global questions centre on what to do with the even lower quality end-product burned on ships today and when will low-sulphur fuel be commonly available - current supplies are very limited. SOx emission is negligible on gas turbines, since they cannot burn the lowest-grade fuels, and high-quality, almost sulphur-free fuel has to be specified, anyway.

Could marine diesel oil be a common future fuel?

Availability of marine diesel oil is not a problem but the price is! This fuel would be perfect for 'green' ships; benefits include less CO_2 emissions due to lower fuel consumption, SCR units function better due to no risk of blocking by ammonium sulphite, low SOx emissions due to low sulphur content, and no risk of too low an exhaust temperature.

Low fuel cost is always a primary criterion. Fuel price itself is decisive in this respect and the estimation should be based on long-term fuel prices rather than a spot price. The long-term world-wide price gap between heavy fuel and marine diesel oil has varied from US$60 to US$80/tonne.

One interesting question recently raised in several discussions with owners has been whether it could be possible for a diesel-oil-burning ship to have better total economy than a heavy-fuel one. Could the benefits of using diesel oil cover the gap in fuel price, or alternatively, at which fuel price gap is the economic equilibrium reached when designing a vessel for diesel oil use from the very beginning - and by considering all impacts that fuel type will have on total economy? Additionally, it is often useful to know which emission penalty would justify burning diesel instead of heavy fuel.

Fuel type has several impacts. Maintenance costs easily equal some 15%-20% of fuel cost. Maintenance of an engine itself is decisive when evaluating maintenance costs of all machinery; some 80% of the cost is accumulated from the diesel engine and therefore fuel type and quality play major roles. It is calculated that some 30%-40% can be reduced from scheduled maintenance costs by burning marine diesel oil instead of heavy fuel. This can generate almost US$10,000/year on a 14MW machinery plant. Diesel-electric machinery is not as sensitive to fuel quality as diesel-mechanical; there the reduction potential is only 20%, but this is still a remarkable amount.

More interesting is the relation between spare parts consumption and cylinder size. Some engine makers use the definition 'wear rate' when comparing spare part consumption on different engine types. The empirical equation of wear rate for a heavy-fuel engine is: number of cylinders x cylinder diameter x mean effective pressure x piston speed. This gives a handy guideline when comparing different engine types and indicates approximately 20%-30% higher maintenance cost for a 320mm bore engine than for a 400mm-500mm bore model. Therefore, on a heavy fuel engine, it is feasible to select larger-bore machinery and a low cylinder number – which, in practice, is almost always done.

However, the equation does not apply so clearly for diesel oil use; cylinder numbers and diameters have less impact on maintenance costs, and this shifts the economical importance from maintenance and repair towards engine purchase cost. The price of a 320mm engine is only 70% of an equally-powered 500mm engine, thus giving a totally new cost aspect to machinery choice.

With diesel-electric propulsion, this difference is even larger due to smaller-bore engines having higher revolutions, to give an additional reduction in generator price. The conclusion is clear; the marine-diesel-oil-burning ship should have smaller cylinder-diameter engines than a heavy-fuel ship, and should benefit from the lower first cost of the engine.

This means that already at around 15MW power level, the difference in engine-generator price can vary up to US$1 million, even without making ultimate choices or changing the make of an engine. Engine cylinder size is clearly a dominating cost factor to be considered in fuel choice due to the extra cost of ancillaries, piping, tanks, and heating when a 15MW engine for heavy-fuel use is only around US$0.4 million, according to Fig 7.

It is possible to carry out a calculation for determining the most feasible fuel quality for a certain ship and a certain operating pattern. However, this calls for an effective simulation model, which can take into account a huge amount of different variables, which are depending on fuel type and must therefore be included in any calculation. Table 3 shows the most important variables for evaluation.

By running the above variables on a simulation program it can be estimated when it is more feasible for an owner to choose diesel-oil-burning machinery instead of a heavy-fuel type.

continued

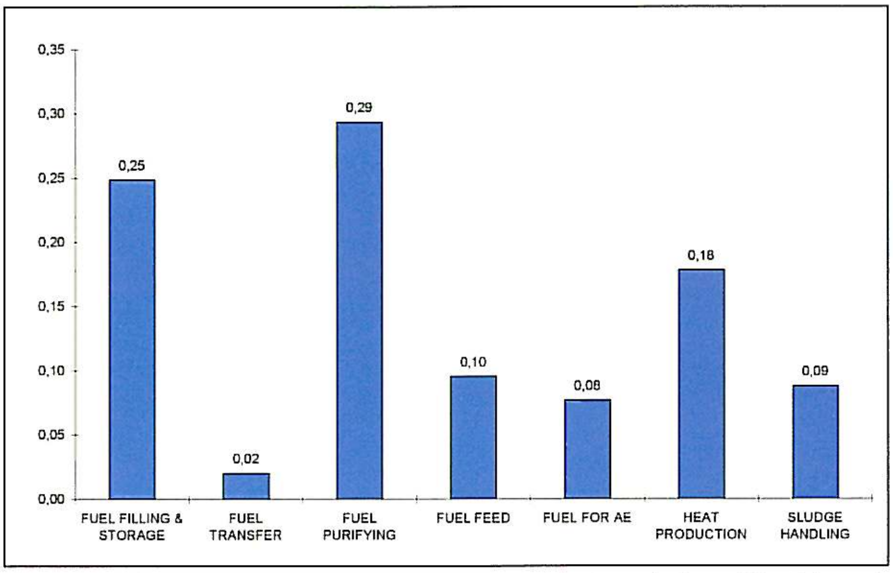


Fig 7. Distribution of cost differences when providing 15MW for heavy fuel capability. This graph does not include the possibility of using smaller-cylinder engines for diesel-oil ships. Approximately 29% of the cost comes from the fuel purifying system. The total difference in ancillary systems in this case was US$400,000.

Investment data	Operation data
engine type	operation profile
machinery configuration	engine efficiency
fuel filling system	power demand
fuel storage system	fuel analysis & price
fuel transfer system	lubrication oil analysis & price
fuel purification	emissions
fuel feed	emission fees
heating system	heat demand
sludge system	maintenance and spares
Economy	**Output of the calculation**
interest rate	purchase cost
investment method	fuel cost
calculation period	lubrication cost
inflation	emission cost
taxation	heating cost
	maintenance cost
	total economy

Table 3. List of main variables and calculation results to be considered when selecting fuel for certain operating patterns.

Case study: a ro-ro ferry

The following case example involving a ro-ro ferry gives some idea of what kind of results can be expected:

Mode	*propulsion*	*auxiliary*
At sea	12,500kW	800kW
Manoeuvring	4000kW	1500kW
In port	nil	1000kW

It was decided that the ship will have electric propulsion but the operating profile was not fixed. The ship will operate between a profile of 60% at sea or 60% in port. Thus, the calculation is carried out for two extreme cases, and then all other profiles will be in between the range.

Mode	*at sea*	*manoeuvring*	*in port*
1	2760*	700*	5300*
2	5300*	700*	2760*

* = *annual operating hours*

The result of the simulation is shown in Fig 8.

The following conclusions can be drawn from the graph:

Case 1. Only first-cost differences in ancillary systems are included:

- If the vessel spends 60% in port, marine diesel oil can be almost US$44/tonne more expensive than heavy fuel
- The more the vessel is at sea, the lower the price gap should be. In a 60% sea mode, the gap between diesel fuel and heavy fuel is allowed to be only US$28/tonne, which does not meet the long-term average
- Marine diesel oil is hardly justified for the ship, considering the long-term fuel price history.

However, if the vessel is really designed for marine diesel oil by considering also smaller-bore engines, eg, 320mm bore engines instead of 480mm bore models, the result is quite different:

Case 2. The power plant is based on 320mm engines instead of 480mm engines:

- At 60% in port condition, the allowed marine diesel oil price is US$70/tonne higher than heavy fuel
- At 60% at sea mode, the price of marine diesel oil can be US$45/tonne higher than heavy fuel
- Burning marine diesel oil can be justified, especially for Profile 1 and if any sulphur penalty or limit for the operation area is, or will be, applied in the future.

Thus, running on marine diesel oil can be justified by considering the long-term price difference between heavy fuel and marine diesel oil. However, local specialities in fuel availability and cost structure, as well as political and environmental trends, must be always checked and valued to a higher degree than just the world-wide average figures.

The result of the case study is quite clear:

- The less the ship operates at sea, the more feasible it is to design the ship for diesel oil
- The diesel-oil ship should be based on smaller-bore engines than a heavy-fuel one.

If an owner selects heavy fuel, the next choice for a 'green' ship will be made between standard fuel and a low-sulphur variety. For example, for the study-case vessel at a fuel price of US$100/tonne, an average US$340,000 annual sulphur emission penalty can be allowed before reaching break-even cost for low-sulphur fuel costing US$120/tonne.

This US$340,000 could be reflected in a Swedish emission penalty of US$0.12/gt for ships burning high-sulphur fuel (S > 0.5% for passenger ships and S>1.0% for cargo ships). That would give a sulphur emission penalty of around US$56,000/year for a 26,000gt ferry.

Low-sulphur fuel, if available, is normally some US$15-US$30/tonne more expensive than standard fuel. If that figure is reflected in the result above, it can be also concluded that use of low-sulphur heavy fuel is difficult to justify from economic reasons, and that the main choice has to be made between standard heavy fuel and diesel oil, especially on a diesel-electric ship.

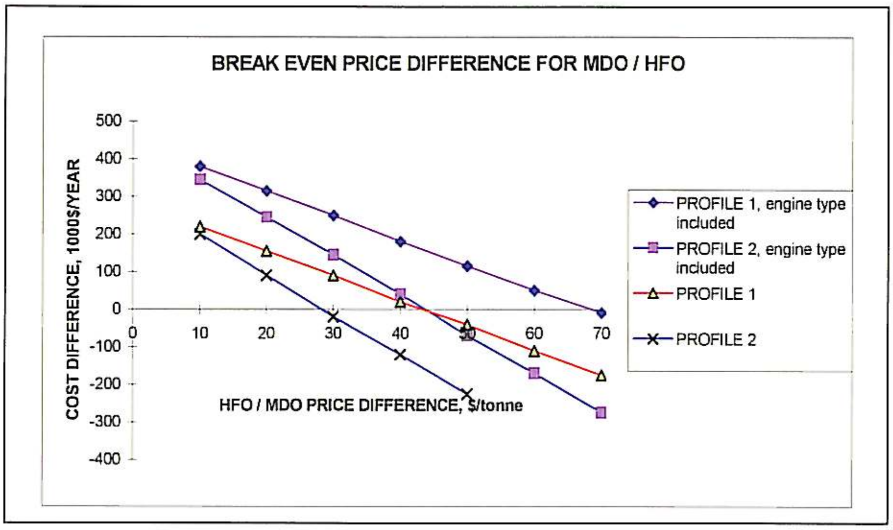


Fig 8. Results of the simulation. This graph shows the price difference between heavy fuel and marine diesel oil at break-even economy condition. Profile 1 = 60% in port, Profile 2 = 60% at sea.

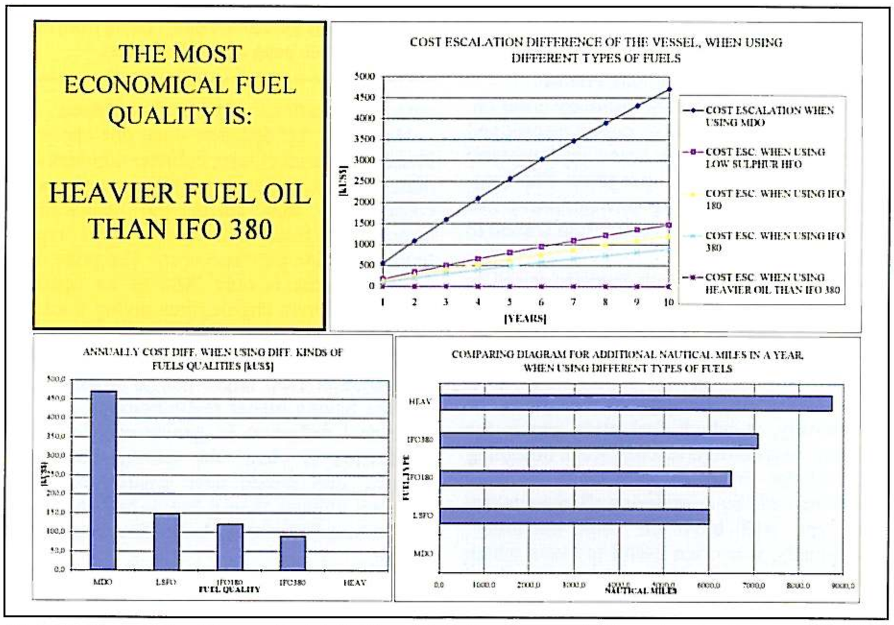


Fig 9. Typical printout from a fuel-definition calculation for one tanker, showing the most feasible fuel for the ship and operation pattern. Additionally, annual cost differences and cost escalations for each fuel, also differences in annual sailing distance when the cost is turned to seamiles, are shown. The following fuel prices are applied: US$198/tonne for marine diesel oil, US$130/tonne for low-sulphur intermediate fuel (IFO380), US$120/tonne for IFO180, US$114/tonne for IFO380 and US$99/tonne for heavier fuel. A sulphur penalty, according to Swedish regulations, is included.

Tool for the evaluations

A comprehensive economy simulation of machinery and fuel type for common operating patterns should always be carried out prior to making any final choice of machinery concept. For this purpose, an effective and extensive simulation program tailored for each ship and owner is an efficient tool.

Results of these calculations can be presented in many forms based on each actual need. Fig 9 gives an idea of one typical printout when the simulation is applied to a cargo ship operation. This example was carried out for a tanker with a 14MW main engine and having 12 annual calls at a Swedish port.

The result shows that for this ship and operation pattern, the heaviest possible fuel would give the best economic result. Differences to other fuel types are also clearly seen in the cost escalation, annual cost, and difference in annual sailing distance.

Risk-based design: an integrated tool for complete ship life cycles

TRADITIONALLY, ship safety has been dealt with by adherence to rules and regulations, and is thus treated as a constraint in the design process. With technology and user requirements developing faster than knowledge can be assimilated and best practice produced, this approach to safety assurance is expected to be largely ineffective. Adopting an integrated approach that links safety performance prediction, risk assessment, and design is therefore necessary, so that safety can be treated as a life-cycle issue and optimal design solutions attained.

Risk-based design adopts an integrated and holistic approach that includes risk analysis in the design process. Risk analysis pools together not only developments in consequence-analysis tools concerning collision, grounding, major flooding, cargo shift, extreme load effects, fire, and passenger evacuation but also design measures/parameters, systems design and approaches to preventing and mitigating risks. Cost-effectiveness of safety-enhancing design features or measures is used as a basis to achieve optimum balance between costs and safety whilst rendering risks as low as reasonably practical.

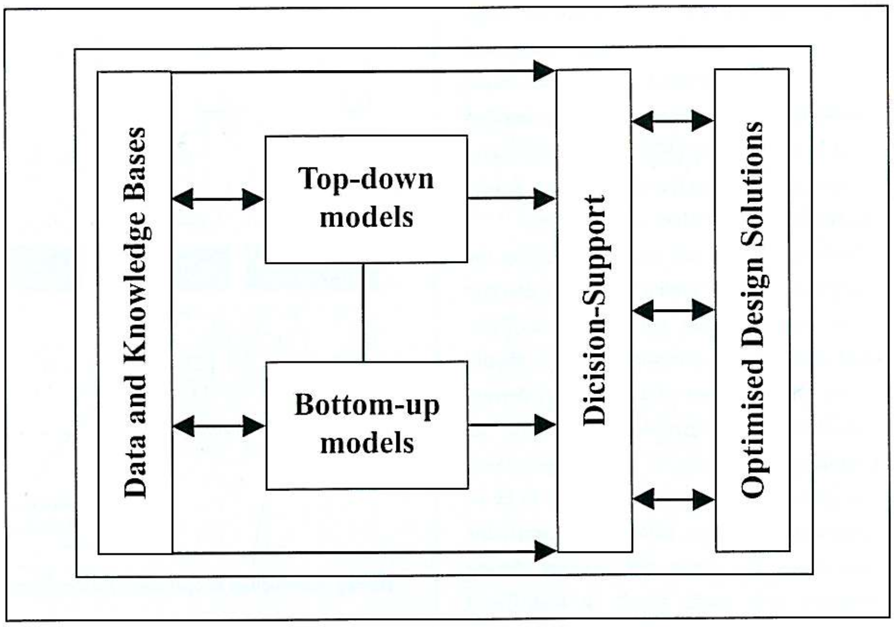


Fig 1. The overall framework of a risk-based design approach.

Fig 1 illustrates the overall framework of the risk-based design approach. Through the interfacing of top-down (consequence analysis) and bottom-up (frequency prediction) models, rational decision-support for achieving the best designs is possible. This can be assisted, where appropriate, by comprehensive data and knowledge bases which relate to incident statistics, also design/operational measures applicable to risk prevention and mitigation. These factors could have trade-offs among various design and safety indicators. Various systems of a vessel can be analysed using classical risk-analysis techniques, such as fault-tree analysis (FTA) and failure modes and effect analysis (FMEA).

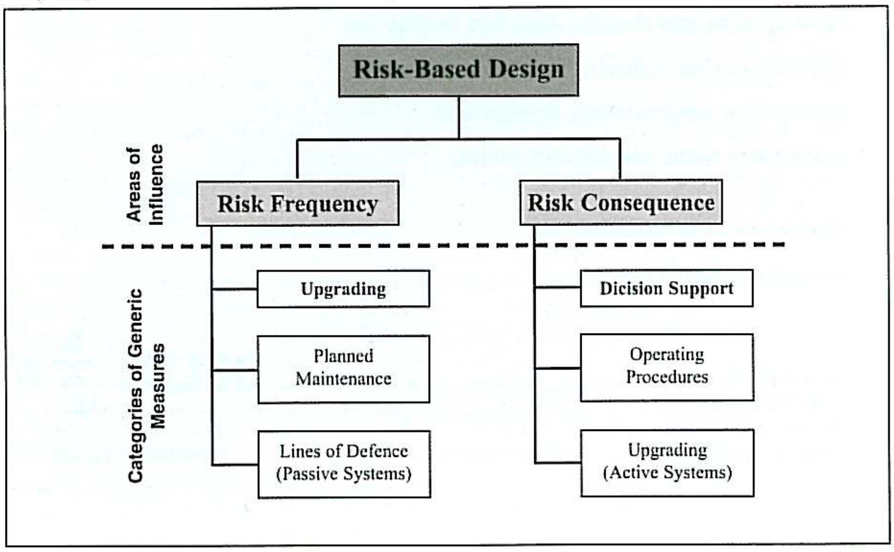
An operational procedure that is applied onboard can also be considered as a ship system and analysed using the same techniques. Human factors and interaction can additionally be modelled within this analysis. Bottom-up models are concerned with the quantification of system representations. When a bottom level cause is considered as an initiating one, the respective representation is yielding a frequency (likelihood) of the top-level event occurring.

Starting from the top event, outcomes (consequences) and their severity are established, utilising the top-down models. The analysis starts with the construction of representations of chains of events, which lead to potential outcomes following an accident. This is being performed in a generic manner, using event tree analysis (ETA). Following this, the task is to establish the branch probabilities of the event trees. This can be achieved in a number of ways, using available statistical data, expert judgement, or first-principles consequence analysis tools.

The overall frequency of a top-level event can be broken down into expected frequencies of the final outcomes of this event happening. According to the severity of each of the individual outcomes (number of implied fatalities and/or injuries, extent of environmental pollution, and implied property loss - including such matters as damage repair, insurance costs, and business interruption), the outcomes can be classified and appropriate actions taken.

Fig 2 shows a breakdown of the generic

Fig 2. A breakdown of the generic categories of measures, which can be taken to reduce the frequency of an accident or limit its consequences.



categories, both technical and operational, of the measures that can be taken to either reduce the frequency of an accident occurring (prevention) or lessen its consequences (mitigation). When considering implementing various safety-enhancing measures (risk control options - RCOs), their costs and benefits can be evaluated and checked using established criteria; for example, the implied cost to avert a fatality (ICAF). This idea could be extended to considering genuine design features for risk reduction or mitigation.

Decision support can assist in selecting the best option available whilst taking into account interaction with other ship functions. Risk-based design, as a life-cycle process, should involve all the phases of a vessel, ie, design, production and operation, as well as facilitating the transfer of knowledge among these phases. The latter is considered to be of paramount importance, since it is evidently the main cause for many deficiencies during operation and could result in significant improvements for the whole process. These interactions are illustrated in Fig 3.

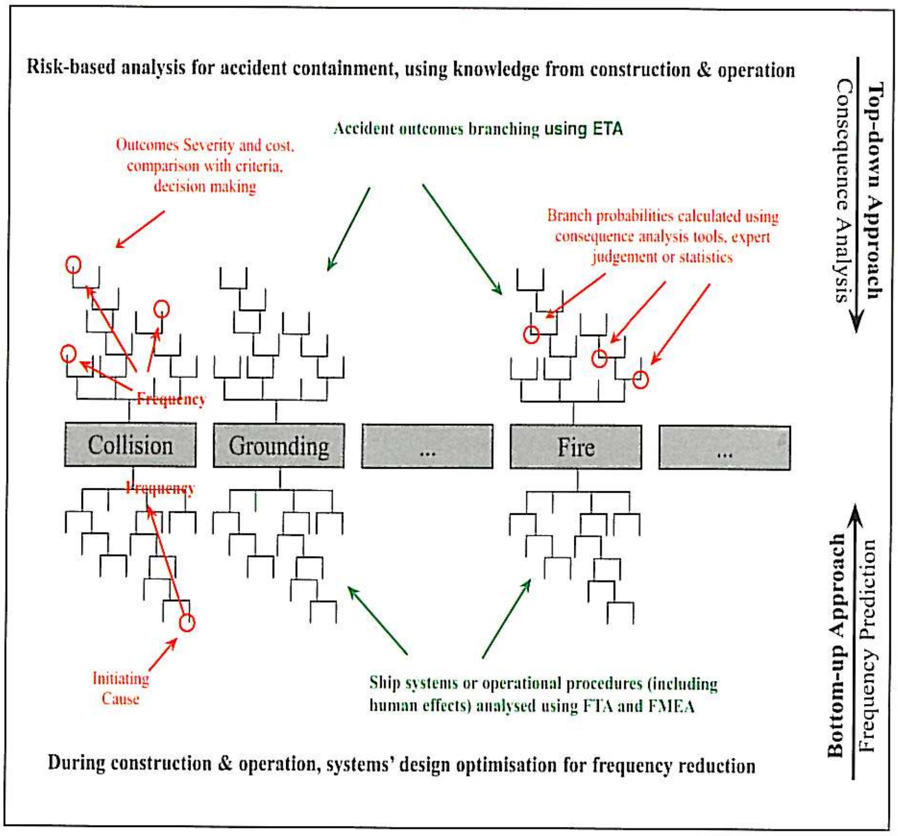
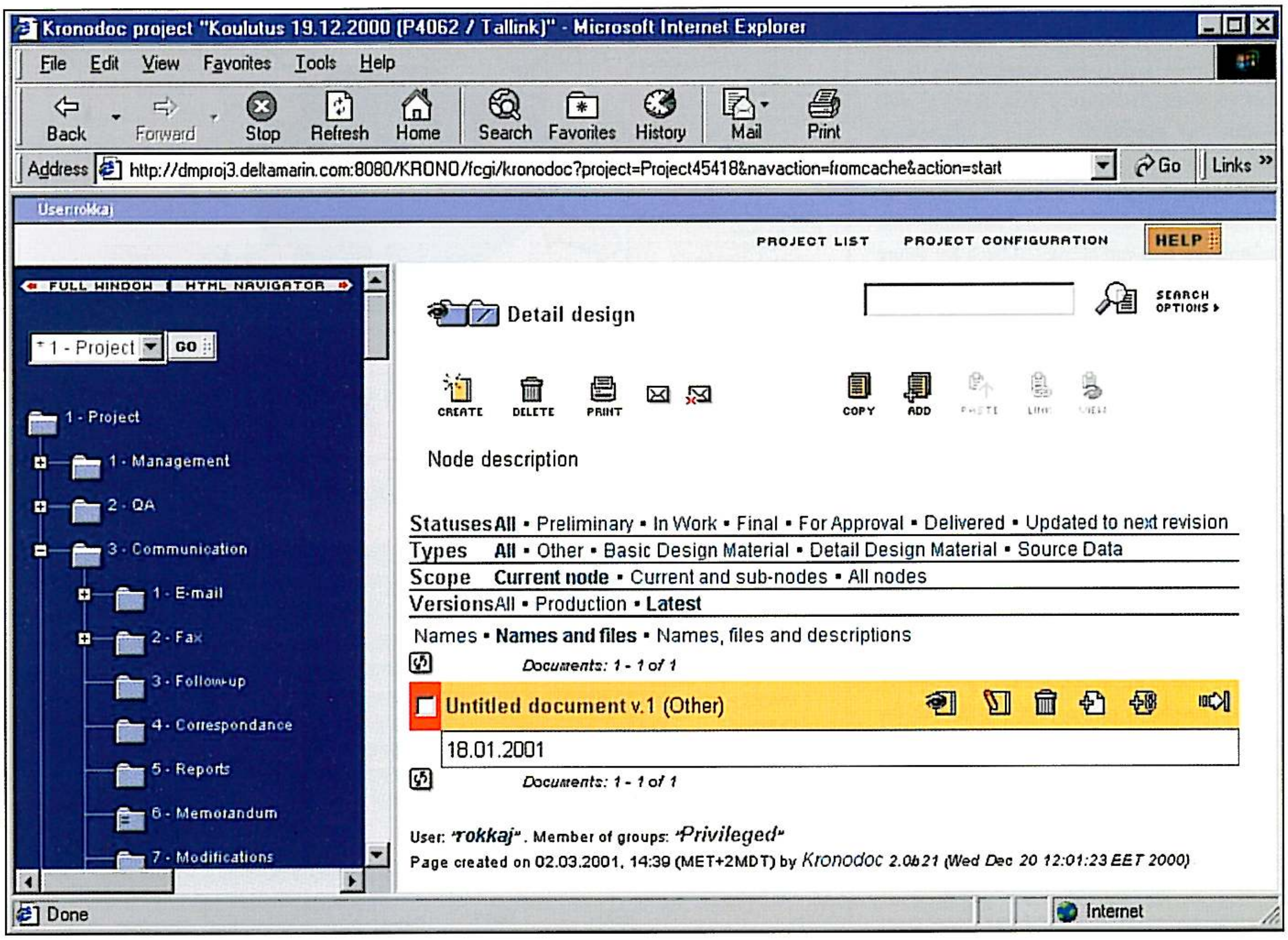


Fig 3. Risk-based design should involve all phases of a ship; this diagram shows these interactions.

Knowledge management - new technology for efficient ship construction and operation



The Delta-Doris concept is a scalable web-based information management tool for extended enterprise collaborative projects.

MASTERMINDING any shipbuilding project is a complex process of juggling many diverse aspects, and in the case of a large cruise liner or ferry, the task is of gargantuan proportions. To try and ease this problem, also the many associate ones that can easily arise from a non-disciplined approach to project management with consequent need for hasty 'firefighting' action, Deltamarin has taken a licence out on a software program known as Delta-Doris. This is part of the Kronodoc suite developed for the CERN multi-national industry consortium but has been adapted for marine use. Similar systems using other software are understood to be in existence for the land construction industry in both Finland and the UK, but Deltamarin is believed to be the first to use such software for marine purposes.

The objective is to smooth the complete ship construction process, but equally important, to provide a complete Knowledge Management tool for use once the ship has gone to sea and throughout its life. Deltamarin hopes that there will also be some spin-off benefit for improving its own process control in the many prestigious projects with which the consultancy is currently involved. At the same time, it is vital that the concept should be suitable for the many small subcontractors who are always involved in a huge cruise liner or ferry project - not just for a giant shipyard, owner, and class society.

The system is entirely based on the Internet worldwide web (using Internet Explorer and Netscape Navigator), so that an owner in one country, a consultant in another, shipyard in another, and subcontractor in a fourth country can all keep in real-time contact. Deltamarin feels particularly confident in its expertise here, since in 1994 it became the first Finnish company to set up a direct ISDN link, to Germany. The company has been assisted in development work by the Croatian company Brodoplan, based in Rijeka; this company is 49% owned by Deltamarin and is mainly composed of staff from the former Brodoprojekt national consultancy.

The problems of controlling a large marine project in a disciplined way are extremely challenging, as the accompanying diagram 'Information Flow Modelling' illustrates. Nevertheless, there are many incentives raised by numerous problems, which can result, for example, from a lack of whole-ship knowledge that is often displayed by major-system subcontractors, especially (on cruise liners and ferries) interior architects. It is astonishing to note that shipyards and consultancies can sometimes, because of indisciplined change management procedures, spend twice as many manhours in making corrections and alterations as were taken up in generating an original design!

Perhaps even more overriding is the knowledge that the short lead times required for ship projects today make reduced manhours highly desirable. Other problems include different views on a project's objectives and poor response to sudden changes. The answer lies in co-ordinated communication, controlled information flows, and clear roles.

Product models are the base

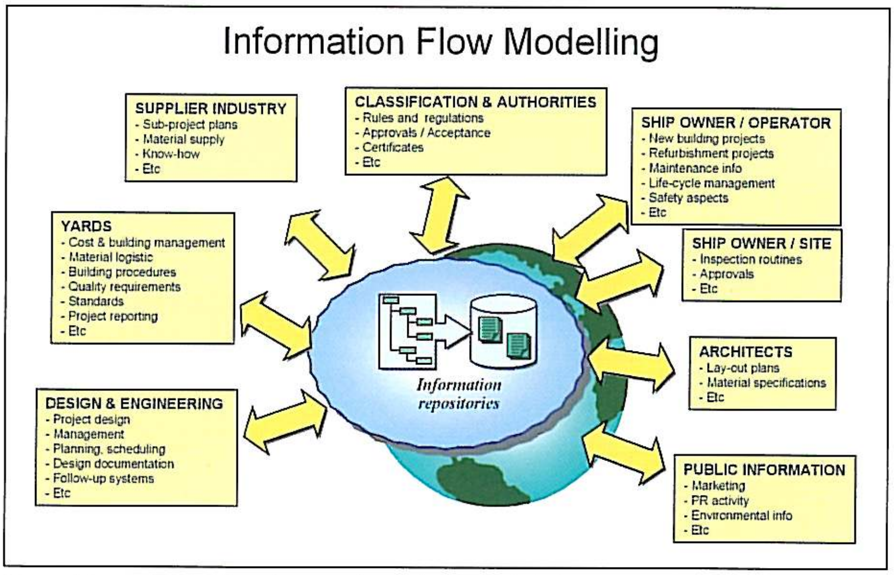
The heart of Deltamarin's new tool is the 3D product model (development of product models is a theme in which Deltamarin has taken a leading role), and at the centre of this is an 'Information Structure'; this feature will contain the operational lifetime information that is so necessary both for the owner, and for Deltamarin to assist the owner both in maintaining the ship - and for obtaining vital information that can be passed back for future new tonnage. Today, it is very easy for the accumulated details of a new ship to be lost or disseminated beyond recovery, following completion.

The company feels strongly that it is essential for a model to be developed very early on in a ship project, ie, at the project and basic design stages - at the detail design stage it is too late and too complicated, it believes. Information will be built up, using data banks, from the ship specification, to provide a Generic Service Breakdown and to provide work procedure descriptions - the latter can be used right up to the time that a ship is scrapped.

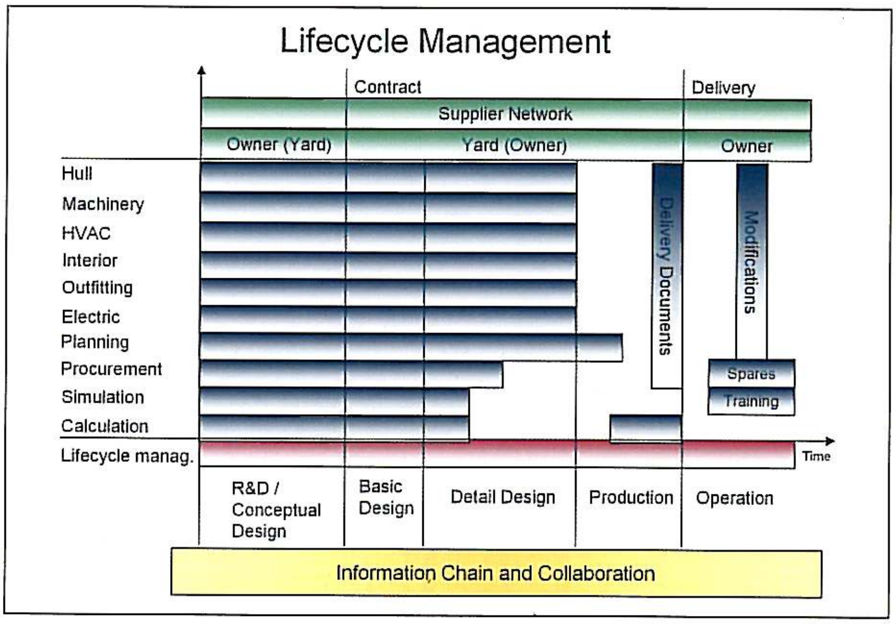
User interfaces can be developed, and the software will enable information to be sent to various participants automatically; special 'flags' will be included so that information (particularly for alterations) is only modified by authorised persons. It is anticipated that when a ship is in service, information from maintenance software such as SpecTec's AMOS system, can be incorporated, while, of course, drawings from different CAD systems, such as Tribon and Autocad, can always be easily called up. The complicated interlocking of various aspects of this block can be seen in the accompanying diagram Collaboration Solution for Extended Enterprises.

Ready for marketing next year

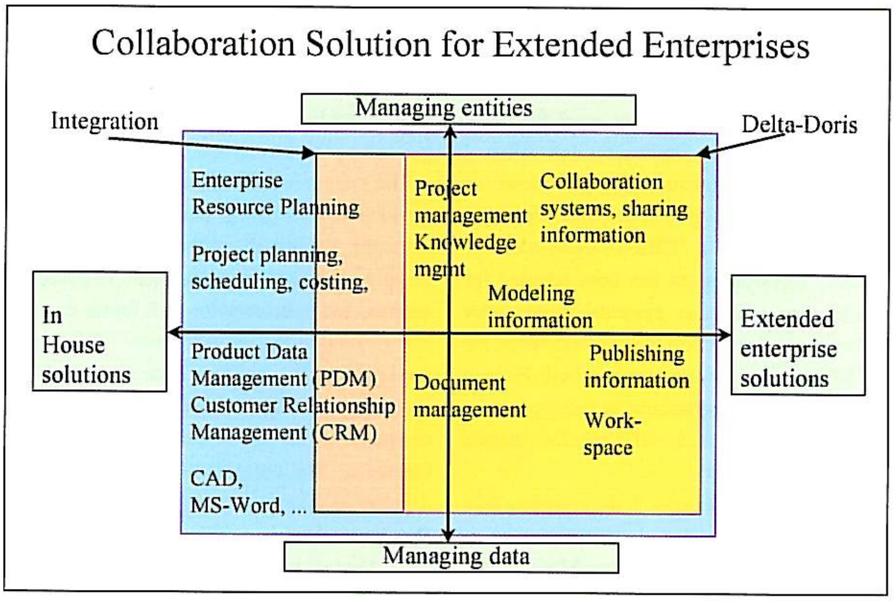
The first Knowledge Management system is currently undergoing preliminary tests in association with Aker Finnyards on that builder's new 40,000gt cruise-ferry project for Tallink, and a presentation has recently been made to a leading owner. It is hoped that all tests will be fully complete in August this year and that the complete package and 3D product model will be ready for the industry early in 2002. This remarkable new product could bring tremendous benefits to many in the shipbuilding and ship operating industry, smoothing the hectic three years of a typical large-ship construction programme and providing a seamless link into the following 30 years of life at sea.



The problems of controlling a large marine project in a disciplined way are extremely challenging, as illustrated by this diagram.



The complexities of managing a project's life cycle – which includes the period after the ship is delivered – are further shown here.



The complicated interlocking of a project model can be seen in this collaboration block.

Production planning: new services for shipbuilding

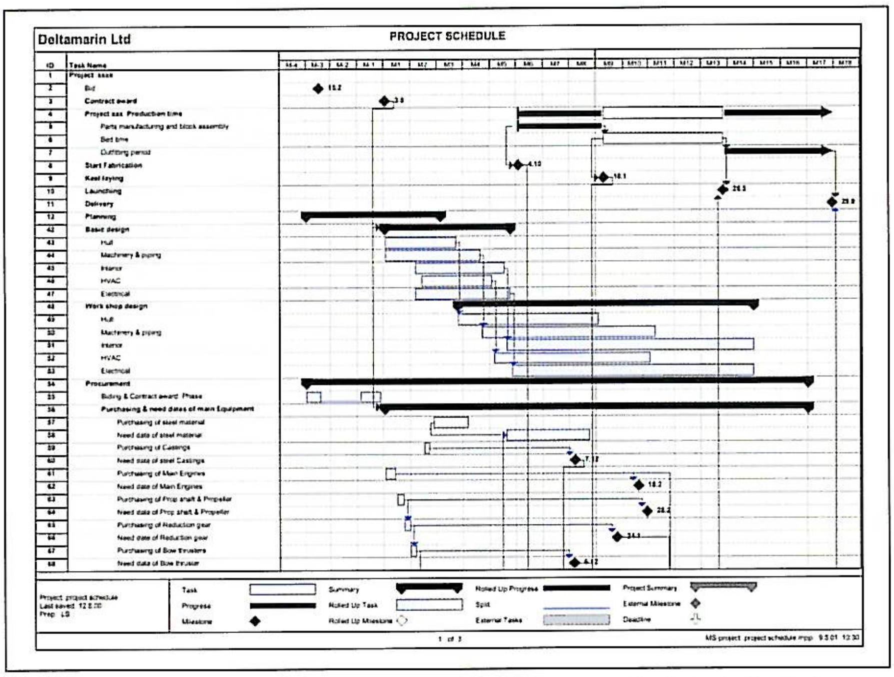
Matti Lietepohja, from Deltamarin, discusses the many benefits possible by employing careful planning in association with computer models before starting a new shipbuilding project.

OUTSOURCING has been a principal tendency in shipbuilding in general, but particularly in the cruise ship sector. Dividing workloads between specialised companies and a yard obviously leads to shorter delivery times and more efficient construction methods. Nevertheless, the increase in efficiency and quality is not necessarily always the obvious result of outsourcing, and co-ordination has become a key issue.

This has also had an impact on the role of engineering offices, and today's standard practice is that a major part of any design documentation is prepared outside the shipyard by independent design offices. Design and engineering work requires a lot of information from suppliers, architects, and others, and it is critical that co-ordination of large volumes of information within the design and engineering process is handled carefully and precisely.

This means greater responsibility for a design office and deeper involvement in a shipyard's activities. Today, it is quite common to see consultancy staff communicating directly with suppliers, architects, and the production department of a yard, as well as handling all the necessary procedures for production co-ordination, materials, and project planning. As a result, having already accumulated much experience in working with different yards and suppliers, and following requests from customers, Deltamarin has established a production co-ordination and planning team.

Production planning covers, in a broad sense, every step of the shipbuilding process from project design through different design steps, procurement, supplier co-ordination, fabrication, and production, right up to sea trials and delivery. Services are provided not only for a shipyard, but also to owners, suppliers, and turnkey contractors, who can benefit from this expertise and experience.



Master planning for large ship projects is essential. This is an example of a typical project progress chart.

Build strategies and master planning for newbuilding projects

Build strategies and master planning are typical products for shipyards. Characteristically, problems arise when a new type of a ship is introduced. Examples of questions to be answered are: What could be the delivery time? How much outside capacity is required? How will the company deal with turnkey subcontractors? How will the project be co-ordinated? Which are the correct outfitting procedures for different areas?

The first step is to define the shipyard loading and to prepare build descriptions for modules, sub-assemblies, areas, and other sections. A major part of ship construction today is outfitting work, and this is an area where many savings in man-hours and materials are possible with good planning procedures and co-ordination. A perfect example is ro-ro deck outfitting, where much piping, ducting, and cabling is installed on the deck above, often in equal quantities. If all this installation work could be carried out on the block panel line, man-hour consumption could fall by between 40% and 60%. This procedure was carried for the ferries *Superfast III* and *Superfast IV* at Kvaerner Masa-Yards, and it was then only necessary to erect scaffolding to join the major assemblies. A 3D design model was utilised, together with a planning tool, to define the task to follow and to make corrections when actions were needed. The outfitting work was carried out by a subcontractor, Turun Prosessiasennus, and the design, planning, and follow-up by Deltamarin.

Shipyard evaluations

Shipyard evaluations are an integral part of yard development. Today, improvements in production technology and new ship types are setting new requirements for shipyard organisation, but identifying the problems and the need for improvements can be difficult within the yard organisation.

This is where an independent outside organisation can have an unprejudiced and objective approach to solving problems and presenting proposals to improve functionality. Deltamarin has carried out this type of task in Italy, Germany, the USA and the UK, as well as in Greece.

These evaluations can also be very helpful to owners when they are intending to order a new ship. Candidate builders can be evaluated and the possible risks in quality, delivery time, and infrastructure can be assessed; a valuable report for decision-making is the final result. Problem situations during an on-going project can be assessed with the same methodology.

During the evaluation, the primary target is to form an accurate total picture of the shipyard's performance and operating principles, including strengths and weak operational areas. The actual scope of the survey depends on its goals, but the following topics should always be included:

- production processes
- production technology
- design processes
- scheduling
- procurement
- turnkey and subcontracting
- project management
- quality assurance.

Each of the above topics contains standard headlines to be analysed as a routine part of the evaluation.

Turnkey project co-ordination

Since shipyards are today using more and more subcontractors, and specifically turnkey deliveries, suppliers must be prepared to take total responsibility. This means taking care of design, scheduling, production planning, procurement, and resourcing, in addition to actual production and installation work. In addition, planning and scheduling project management, co-ordination, and follow-up become essential throughout the whole contract.

When the shipyard is following the assembly concept, it is totally depending on turnkey deliveries and subcontracting. Reliable partners, well-defined contracts and mutually agreed schedules create suitable conditions for good performance.

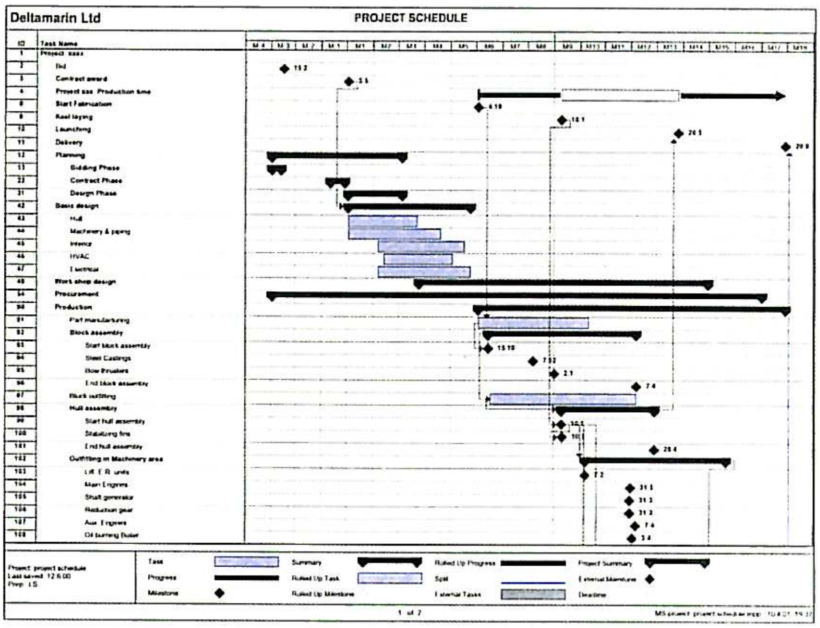
Items to be included into the evaluation are:

- forms of turnkey and subcontracting
- subcontractor database and assessment
- scheduling and follow-up systems
- project management
- material management.

Turnkey of public areas such as restaurants and stairways is very long lasting, easily 15-20 weeks of calendar time. Outfitting of public areas often starts very late and therefore these areas are almost always in a critical path of the production schedule. This necessitates close follow-up of the subcontractor activities and progress.

Subcontractors are not always experienced in preparing scheduling and progress reports. The shipyard's advantage is to require and when necessary to guide the supplier to prepare the production schedules and follow-up documents.

Definition of turnkey scope, including clear borders between other suppliers and the shipyard, is the starting point for good contracts. Failure to make these definitions leads, in the worst cases, to complete chaos and large financial losses.



Another example of a project chart; this one is for an engineroom module.

Virtual shipyards

The virtual shipyard is an interesting new possibility. Using advanced computer models, it is possible to simulate the shipbuilding process to check the physical limitations, production capacities, bottlenecks, resourcing, and schedules through the complicated articulation of a project.

This kind of simulation will make production planning much easier, by giving a tool for analysing efficiently and quickly a yard's production capability for any kind of prototype. Calculating the panel line load, finding the number of block building places, testing the effect of new production facilities, or analysing required outfitting spaces or material flows are typical aspects which can be easily solved by a virtual shipyard model.

Simulations can easily be run with several different prototype combinations and delivery schedules. By combining this tool with available statistics of throughput times, capacities, and supplier data, the most efficient production arrangement can be found within a reasonable time. Virtual shipyards are here!