WATERBORNE TRANSPORT
HUMAN RESOURCES

REWORD

"Research for Enhancement of Working Conditions Onboard Ships"

FINAL PUBLIC REPORT

REWORD

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1. EXECUTIVE SUMMARY OF THE PROJECT

Background

For the first time ever, the people working on the ship and the passengers were taken as a key parameter in the design of the vessel. Innovative work had to be carried out to produce tools that could replicate both the human behaviour and the impact of ship design on human performance. But not only safety at sea will benefit from this; passengers will benefit from the improvement of the comfort level offered by modern ships, hence contributing to the further development of the shipping and cruise market.

Various aspects of the ship board environment e.g. noise, vibration, climate and severe motions can significantly interfere with work efficiency, well-being and comfort. A better control of these adverse sea/ship environmental factors should therefore markedly improve task performance at sea, hence enhance efficiency and safety of shipping operations. In this context, REWORD was set up in order to

- Produce an inventory of adverse environmental factors and their effects on the physical and psychological characteristics of the crew.
- Produce an overview of the present tools adopted in reducing adverse influences.
- Assess alternative remedies by testing their effectiveness using simulation or full-scale experimental techniques.
- Provide a cost-benefit analysis on the most effective remedial solutions.
- Suggest tools and models to be adopted for the design of new ships and for the improvement of existing ones.

Main findings and practical results

The overall main results of the project are:

- Development and validation of mathematical models for the quantitative estimation of human performance on board.
- Demonstration of the effectiveness of incorporating the developed human performance models in standard procedures for the analysis of measured or calculated wave-induced ship motions.
- Assessment of the feasibility to develop an integrated software package able to evaluate the impact of the main design parameters and the possible remedial actions on human performance.

- Different end-user groups and stakeholders such as ship-owners, shipbuilders, the crew as well as passengers can benefit from the results.

- Ship-owners will appreciate the availability of ships easier to manage and safer to operate due the to reduction of discomfort onboard. Furthermore, passengers will benefit from the improvement of the comfort level offered by modern ships, hence contributing to the further development of the shipping and cruise market.

Specific results

The specific results of each individual task of the project are listed below according to their logical sequence:

- Identification of the main human stressors related both to the external (i.e. ship motions) and internal (i.e. vibration/noise, light, heath, atmosphere, layout) environment of the ship.

- Definition of performance criteria for each identified human stressor relating the action of the environment to the physiological/mechanical reaction of the people on board.

- Specification of the remedial actions which can be taken before, during and after the construction of the ship either to decrease the adverse action of the environment (e.g. installation of a motion damping system) or to increase the human threshold of acceptability.

- Feed-back on the identified human stressors and the corresponding remedial actions from ‘real service life’ through crew response to a specific questionnaire on living/working conditions onboard.

- Evaluation of the efficiency of the proposed remedial actions from the economic point of view through a cost/benefit analysis accounting for the complex interrelationships between problem areas, remedies and operating tasks.

- Simulation of typical human tasks on the ship bridge through application of the Integrated Performance Modelling Environment software able to model the real-time interaction between human performance models and mechanical environment models.

- Improvement of the models currently used to evaluate the human stressors related to ship motions both from the point of view of the accuracy of the human performance model and the integrability of the model in existing sea-keeping computer codes.

- Application of the developed human performance models to the experimental results of available full-scale sea-keeping trials on fast ferries and the numerical results of existing sea-keeping computer codes.

Social key impact and inputs to the shipping world

The REWORD project aimed at contributing to safer maritime transport in Europe through the reduction of the adverse impacts of sea and ship environmental factors, hence higher comfortability during both working and living onboard.

Different end-user groups and stakeholders such as shipowners, shipbuilders, the crew as well as passengers can benefit from the results.

One of the main results of the REWORD project is the assignment of new comfort levels and organisational models to enhance the attractiveness of maritime transport. The shipbuilding industry will benefit of the new tools set-up by REWORD for the design of more comfortable ships.

Shipowners will appreciate the availability of ships easier to manage and safer to operate due the to reduction of discomfort onboard.

The results of the project – enhanced living and working conditions onboard ships which are properly designed for people and which entail a safer and more comfortable environment - can also contribute to the improvement of the image of the seafaring profession

Furthermore, passengers will benefit from the improvement of the comfort level offered by modern ships, hence contributing to the further development of the shipping and cruise market.

The inputs to the shipping world can be summarised as follows:

- Criteria for the definition of the most important disturbing factors.

- Development of a formal procedure to rationally assess the efficiency of remedial actions from the economic point of view based on the evaluation of potential cost of related operational tasks failure.

- Guidelines for conduction and analysis of comfort oriented sea trials.

- Assessment and adoption of mathematical models for simulation of human behaviour.

- Guidelines for a comfort-oriented ship design and management able to take into account human factors.

Partnership

The REWORD project assembled a team of experts which enabled a holistic view – ship design and ship operation - on the issue of the human element onboard ships and the impact of environmental factors on human performance, hence the efficiency and safety of maritime operations. The project involved 6 partners from 4 European countries:

- CETENA, Italian Ship Research Centre, Genoa, Italy. (Co-ordinator)
- DERA, Centre for Human Science, Fareham, U.K.
- CETEMAR, Centro de Estudios Tecnico Maritimos, Barcelona, Spain
- FINCANTIERI, Naval Shipbuilding Division, Genoa, Italy
- UNIVERSITY of STRATHCLYDE, Dept. Ship and Marine Technology, Glasgow, U.K.
- HELINTEC, Hellenic Information Technologies & Engineering, Athens, Greece.

2. OBJECTIVES AND ACHIEVED RESULTS

2.1 Task 1 - Review of literature and indication of current knowledge

Objectives

The overall aim of this task was to collect and review the existing material in order to identify adverse environmental factors representing specific problem areas at sea, and to provide an assessment which of these should receive further consideration in subsequent REWORD tasks. Models with the potential to enhance knowledge and prediction of the adverse effects of stressors for future ship design should be listed. Finally, remedial measures which could be applied to improve conditions at sea in the future should be identified. Several topics were identified for particular investigation, these are:

- Identification of relevant tasks and activities, especially those in primary ship areas
- Identification of important environmental factors e.g. noise and vibration, motion, thermal factors, lighting, work-rest schedules
- Review of the effects of the environmental factors on performance and well-being
- Identification of human performance models developed to describe relationships between environmental factors and performance and well-being
- Identification of models of the mechanical environment to provide the necessary background for linking with human performance models
- Identification of design tools which include environmental and organisational influencing factors, and which incorporate human factors parameters
- Identification of remedial actions which may be taken to reduce the adverse effects of environmental influences on performance

Methodology

A number of different methods have been employed to obtain relevant information. Subject Matter Experts (SMEs) and experienced seagoing personnel were approached to provide initial lists of potentially significant tasks at sea. Both informal and more structured interviews were used. The information gathered was supplemented by examination of task analyses carried out for training design, and by scrutiny of general documents and manuals on seamanship and other tasks at sea.

Literature reviews were conducted to gather information on stressors and their effects on human performance in both laboratory and field situations. The literature reviews also revealed further data on tasks conducted at sea, upon analyses of marine accidents and injury, and a range of standards applicable to ships.

Data was also extracted from surveys administered to shipping companies and seagoing personnel. This provided evaluations of the relative importance of shipping activities and tasks, and stressor effects, based upon the knowledge and experience of individuals at sea.

Surveys, literature reviews and searches through organisational records also provided data on levels of stressors measured at sea, for comparisons with recommendations contained in the literature and in standards.

Overview of achieved results/main findings

Significant ship activities and tasks at sea

- A number of different types of shipping activity were identified. Transit in confined waters and coastal passage were thought to be particularly important as they frequently take place in busy waters, and impose high demands on personnel, particularly for precise navigation and collision avoidance. Both can include frequent incidence of harbour exit and entrance, mooring, canal or river transit, and loading and discharge of cargo and passengers. All impose added load on the operator.

- A range of different tasks is carried out on ships within these primary shipping activities. Bridge, engineering and deck tasks feature especially, and important ship tasks include operations such as collision avoidance and maintenance of key machinery such as main engines and steering gear.

- It was argued that focus on human activities, rather than ship tasks was likely to be a fruitful line of approach, since it allows the identification of common factors among ship activities. However, a human abilities classification was found to be too precise in practice for use by Subject Matter Experts (SMEs), and research literature did not reflect this taxonomy. Generic human tasks descriptions e.g. problem solving, communications, and vigilance were therefore used to categorise the human activities identified as important at sea.

- Additional information from ship operating profiles was used to supplement the assessments of significant shipboard tasks. Critical activities for short-haul Ro-Ro ferries in UK waters, UK navy ships and North Atlantic and North European container and general cargo ships were listed and evaluated.

- Task performance was not the only human response judged to be significant at sea. The health and safety, and the general well-being and comfort, were considered equally important. There are a variety of health and injury hazards in ships. Injuries from trips and falls, and the possibility of hearing damage from high noise levels were identified from a number of different sources. For well-being, sleep requirements and the social environment, which underpin maintenance of reasonable mood states were especially important.

- A wide range of tasks and human activities was identified. In practice, it proved extremely difficult to reduce these down to a small number on a prima facie basis. Typically, contributions from a larger number of respondents or sources simply increased the number of tasks considered important. It is believed that this can be explained by the significant interdependence of tasks at sea. A considerable number of individual tasks are all essential to successfully conduct an overall ship task. To avoid the difficulty of having to specify a large number of tasks for future REWORD activities, tasks and stressors were therefore considered together to identify a smaller number of problem areas.

Significant stressors at sea

- The external operating conditions considered to create most difficulty for successful task completion were traffic, especially where no traffic separation schemes operate, and weather.

- Onboard, problem areas indicated by Subject Matters Experts (SMEs) and interviewees concerned training, mixed language crews and social and organisational issues. These were as frequent as physical stressors, particularly for bridge tasks. However, for deck and machinery tasks, physical factors like the thermal environment, atmosphere (fumes), noise and motion remain important.

- The frequency and levels of stressor effects is commonly unknown. This is of particular significance where situations are relatively infrequent or rare, but the level of the stressor is high and the severity of the effect is likely to be substantial. Therefore it was important to know what the typical magnitude of particular stressors was, e.g. noise levels on the bridge or in machinery spaces, or temperature levels in different working areas like the deck, where seasonal variations are important. Although not an originally specified part of the REWORD Task 1 activities, attempts were made to collect together at least exemplary data in a number of key areas. Data were obtained for noise, vibration, temperature, work/rest schedules and working hours. For others e.g. motion, information was not readily to hand, but some should be available in ship designers or shipbuilders records.

Combinations of human activity and stressor

- To properly address the interaction between important tasks and stressor effects, a matrix of tasks and abilities and environmental influences was constructed in order to identify specific topics to investigate. The objective was to identify those task and stressor combinations which are of key importance at sea, and which should be the focus of future data collection, research and modelling activities, and application of remedial measures.

- A series of reviews in key stressor areas was conducted, and the information from these summarised in data sheet format. Topics considered in detail were**:**
    - Atmosphere

  - Heat and cold
  - Noise
  - Vibration
  - Ship motion
  - Lighting
  - Work/rest schedules and work period length
  - Social influences

- Key human activities were identified in relation to the judged likelihood of problems existing as a consequence of the stressors listed. Three criterion areas of health and safety, well-being and comfort, and task performance were used to categorise the human activities and responses of concern.

- Using health and safety criteria, effects of heat on thermal strain, noise on hearing damage and motion on bodily injury were judged to need further consideration.

- For well-being, ship motion is judged to have a number of appreciable effects, and means for controlling it require evaluation. As far as the adverse effects on human activities are concerned, sleep is an important activity that is influenced by a range of factors, so should take priority in consideration of remedial measures. This suggests emphasis on stressor control in sleeping spaces. Comfort and mood effects also require consideration, but these are likely to be more difficult to quantify.

- The risks of atmosphere effects, vibration, and lighting influences on performance at sea are judged to be limited. This does not mean that they could not have adverse effects, but that the control of these factors at sea is normally adequate to minimise problems. However, the evidence for these conclusions is limited and further data collection is advised. The possibility of adverse effects on visual and lookout (vigilance) tasks on the bridge at night and in poor visibility is an exception to these general conclusions.

- The thermal environment (mainly heat), and motion can adversely affect physical tasks, in one case because of the development of thermal strain, implying need for rests and body cooling, and in the other, because unpredictable ship motions disrupt postural stability. Primary difficulties from excess heat are confined mainly to working in non air-conditioned spaces.

- The other primary clusters of effect are those resulting from noise on communications activities, and work/rest schedules and workload on the general efficacy of mental activity. The latter is judged to be especially high because the incidence of night work, long working hours and irregular patterns of work and rest is very common at sea.

- By using the co-incidence of stressor effects and task and other human activities at sea, it proved possible to identify a reasonably small and manageable number of problem areas for further consideration in the REWORD project. These are listed in the first column of the table below. It is emphasised that this shortlist reflects the assessed incidence of high levels of specific stressors at sea, in addition to the known adverse effects of stressors per se. For example, vibration problems do not feature as they are judged to be relatively limited in practice in comparison with those, which are listed.

Models of human response to stressors

- A range of models of human performance and comfort was identified. Those having greatest interest for subsequent REWORD tasks reflect the combinations of stressor and tasks at sea identified previously. The list is shown in the second column of the table below.
- The models vary widely in maturity, the extent of validation, which has been undertaken, and scope. An important activity in future REWORD Tasks will involve comparative assessment to identify those with most current value and potential.

Table 1: Models of human functions with possible application to identified problem areas

Problem area	Possible Models
Physical task performance in high temperatures	CHS Thermal model Texas Thermal model
Hearing damage in spaces with high noise levels	Cochlea models may be suitable; further investigation is needed.
Communications in conditions of multiple auditory channels	ISO 9921-1: 1996: Ergonomic assessment of speech communication: Part 1
Injury and disruption to whole body tasks in ship motion	Graham 1990 postural stability model Maki 1987 postural control model
Motion sickness in ship motion	ISO 2631: 1997: Part 1 Colwell 1994 habituation model
Sleep in motion, noise and altered thermal environments	None identified
Mood changes at sea in relation to the social environment	None identified
Monitoring of navigational hazards in conditions of poor visibility	BAe-ORACLE DERA CHS Mesopic Vision Model
Conflict between lighting requirements of different bridge tasks	A number possible
Efficiency of all mental activities in prolonged periods of work, irregular rest and work, and at night	DERA CHS Alertness model DERA CHS IPME modelling tool
Efficiency when working alone	Sanders (1981) Attention Process model DERA CHS Alertness model
Situation appreciation and procedural errors in emergency situations	None identified at present. Requires Further consideration of human error models DERA CHS ARIADNE database

Models of mechanical processes at sea and design tools

- REWORD Task 1 included the requirement to consider models of the physical and mechanical environment at sea, and design tools potentially suitable for use in REWORD modelling and remedial measures evaluation.

- A range of different models of the physical environment is available, together with design procedures for the physical and mechanical characteristics of ships and ship systems.

- Models of the ship's physical environment have a substantial history, and are frequently complex. Nevertheless, they may not always include all the parameters of relevance to human performance and response.

- It will be essential to specify appropriate criteria for evaluation of models to ensure that those chosen have reasonable potential for use in future REWORD activities. Interfacing physical and human response models can only succeed if the viability of each is comparable.

Remedial measures

- A simple category system of types of remedial measure has been developed. Particular issues discussed comprise identification of the feature changed, e.g. a specific piece of machinery, how the change is achieved i.e. what item along the route from source of the stressful effect to its point of application is altered, who - individual or authority - is responsible for the modification undertaken, and when this takes place.

- This categorisation was intended to provide a basis for the specification of criteria in REWORD Task 2, and the evaluation of remedial measures to be undertaken in REWORD task 4.

- The categories covered include:

    - Design philosophies and procedures
    - Standards
    - Modification of stressor sources (control of risk at source)
    - Modification of transmission pathways (modification of risk remotely)
    - Changes to the task or activity undertaken
    - Changes to the conditions under which exposure occurs
    - Change to the recipient's responses

- The timing of action: pre-design, during design, or during operation; and the originator e.g. legislators, ship designers, ship operators or the individuals themselves, are also considered.

Activities for future consideration

- The principal problem areas likely to be experienced at sea are shown in the table above. These imply a requirement for a number of data collection and modelling exercises. Areas of ignorance in data availability, and in prediction of effects of stressors on particular tasks include:

  Data at sea

  - comprehensive knowledge of vibration levels and chemical levels at sea
  - reports of sick building syndrome and chemical exposure
  - levels of vibration in localised areas
  - detailed knowledge of spectral characteristics of noise, especially in machinery spaces and on the bridge
  - detailed characteristics of sleep, in both quantity and quality
  - independent measures of personnel mood changes

  Model development and application

  - Predictions of performance changes in physical tasks. Prediction of work/rest routines to allow sustained maintenance task performance.
  - Predictions of speech interference on the bridge in characteristic (intensity and frequency) noise conditions. Prediction of audio channel levels required to avoid speech interference.
  - Predictions of ship motion characteristics required to reduce postural disturbance below a range of specified levels.
  - Development of models which relate fatigue changes to ship motion (possibly mediated by motion sickness)
  - Prediction of alertness and task performance as a function of work time, sleep time and length, and duty period lengths. Prediction of work/rest schedules needed to preserve alertness and performance.
  - Prediction of detection rates for shipping contacts in degraded visual environments. Prediction of the benefits of vision enhancement techniques in reducing missed shipping contacts.
  - Development of models of the effects of social environment on mood, and of mood upon performance.
  - Most attention has been given to factors that can be influenced and controlled, directly or indirectly, by the design of a ship and its equipment. Others are likely to be more difficult to investigate, because the database of research information is much more limited, or the mechanisms of effect much more complex.

Conclusions/Summary

- There are many tasks of importance at sea. Many of these are interdependent, and all required for safe operation at sea. A simple approach of ranking these to identify those of most importance was not judged likely to be successful.

- Evaluation of the research literature on stressors considered to be potentially harmful to successful task performance, health and safety or well-being, shows that effects are frequently equivocal. At the levels of stressors observed at sea, some factors like vibration, the chemical atmosphere and internal lighting are judged to be of little consequence, or generally easily controllable, whilst ship motion is judged to have a number of appreciable effects. Others are likely to have effects, but only in particular tasks, and in particular locations on board. Other effects are considered to be more general in nature. Thus, a number of factors may disturb sleep, while work/rest schedules and duty period length are reckoned likely to degrade a range of tasks and activities.

- Data were not always available to provide a full assessment of actual stressor levels at sea, and it was concluded that a review of existing data bases, and possible further measurement at sea, might be extremely useful. This would enable a more definitive evaluation of the extent of the existence of harmful levels at sea.

- By combining assessment of stressor effects with shipboard tasks, it was found possible to identify a reasonably small set of tasks and activities for further study. These were based upon the partitioning of problem types relating to three separate sets of criteria. The effects of stressors at sea fall into the three topics of health and safety, well-being and comfort, and task performance.

- Information about a variety of human performance and well-being models has been collected. Models vary widely in their maturity, the degree of evaluation to which they have been subjected, their validity, and predictive value. An important task will be to apply appropriate criteria to identify those models with suitable characteristics for further investigation. Only a small sub-set may be suitable.

- An important factor in model development and use is the complexity of the stressor concerned. Past studies have frequently failed to record all relevant parameters to ensure that models can represent the full array of pertinent parameters with realistic values. Any data collection exercise must ensure that these are recorded, and any modelling exercise that they are properly represented.

- A large number of remedial measures has been identified. These range widely in likely cost, timing and time-scale of application, and the degree to which they will eliminate or ameliorate adverse effects. A key activity in future REWORD activities will be to apply appropriate criteria to choose among the many possible solutions for further consideration.

Table 2: Summary Task 1 - Specific topics for further consideration in REWORD

Problem area	**Data collection**	**Research**	**Modelling**	**Remedial measure development and evaluation**
Physical task performance in high temperatures				Methods for effectively cooling machinery spaces
Hearing damage in spaces with high noise levels		Investigation of training and monitoring techniques to develop and improve compliance with safety cultures		Methods for noise control in machinery spaces, or reductions in noise exposure
Communications in conditions of multiple auditory channels	Measurement of detailed spectral characteristics of noise in communications areas	Development of techniques for separating multiple channels of information, and improving discrimination		Investigate use of bridge head-sets, and pseudo-spatial separation techniques
Injury and disruption to whole body tasks in ship motion	Examine records of ship motion at human task locations. Measure at sea where necessary	Investigation of unconventional hull designs to control lateral forces	Modelling of human postural stability responses to complex ship motion	Improved ergonomics of ladders, hatches and other spaces aboard
Motion sickness and motion induced fatigue in ship motion		Investigation of unconventional hull designs to control heave and pitch	Development of models which relate experienced fatigue to motion exposure	
Sleep in motion, noise and altered thermal conditions	Measurement of sleep parameters at sea, including EEG measurements	Investigation of motion and noise characteristics which influence sleep	Extension of noise interference models to sleep disturbance	
Mood changes at sea in relation to the social environment		Development of reliable and valid measures of mood and the social environment		

Area of concern	**Data collection**	**Research**	**Modelling**	**Remedial measure development and evaluation**
Monitoring of navigational hazards in conditions of poor visibility		Research into techniques for combining radar, IR and visual EM spectrum signals	Prediction of detection rates using degraded vision models	Investigate use of vision enhancement devices on the bridge
Conflict between lighting requirements of different bridge tasks	Measurement of bridge lighting levels and task conflicts	Development of techniques for combining bridge task information		
Efficiency of all mental activities in prolonged periods of work, irregular rest and work, and at night	Logging of actual periods of work in a representative sample of ship profiles	Development of models to predict crew numbers needed to achieve specified levels of task performance	Prediction of performance and alertness changes in work periods typical of those at sea	
Efficiency when working alone		Development of models to predict multi-person versus individual performance	Modelling of social facilitation on performance	
Situation appreciation and procedural errors in emergency situations	Accident and incident surveys Development of structured databases	Investigation of training techniques to promote effective performance	Development of models which relate measures of training achievement to subsequent task performance	Consider use of specialist language training in mixed language crews to avoid communications problems

2.2 Task 2 - Development of criteria

Objectives

The objective of this task was to identify human response criteria for remedial measures in ship design and operation which, if applied, enhance human performance, health and safety, and well-being and comfort at sea as well criteria for model assessment. The task was composed of the following elements:

- to identify typical operational profiles for selected ship types
- to assess the relative importance of different tasks for different ship operations
- to measure the impact of each identified environmental factor/human stressor on human performance and comfort,
- to identify criteria
  - for assessing the accuracy of human performance models,
  - for assessing alternative methods to ameliorate adverse effects of environmental factors as well as
  - for the evaluation of remedial actions.

Human response criteria for remedial measures in ship design

Methodology

- Selected remedial measures application areas were taken from Task 1, based upon the specific design issues identified there. The topics covered are the thermal environment, noise, ship motion, lighting, work/rest schedules, and the social environment including performing in teams.

- The methodology employed literature search, evaluation of standards documentation, and consultation with subject-matter experts and ship designers and operators. Relevant criteria were extracted or inferred from working papers supplied or prepared in-house, and then collated and tabulated.

- It did not prove possible to use shipping activity and operating conditions information to prioritise key tasks in as much detail as had originally been intended, due to a lack of operating profiles. Criterion variables, but not values, are therefore all that are identified in some cases.

Overview of achieved results/main findings

- Primary criteria evaluated are divided into three types:

    - human response criteria including task performance measures, comfort indices and measures of health and safety;
    - stressor criteria, including measures of working and living conditions such as noise levels, illumination, and work/rest schedules;
    - remedial measures criteria.

- For the latter, a small set of criterion measures has been identified. Primary categories proposed comprise technical, non-technical and implementation criteria. These are further sub-divided as shown. The comparability with criteria developed for model assessment is noticeable. This is not surprising as modelling is effectively a sub-category of design techniques.

Table 3: Remedial measures criteria

Technical:	Applicability to problem domain
	Validity
	Effectiveness
Non-technical :	Cost
	Availability
	Track record
	Time factors
	Conformance with legislation
	Efficiency
Implementation :	Feasibility (ease of use)
	Time savings
	Acceptability
	Robustness

- It is normally possible to determine individual values on criterion variables as optima for human response. However, in practice, it is the derived values of stressor variables that are specified in standards and design guidance documentation. These can be stated in general, but require detailed examination of the individual design problem for full specification.

- An exception to the general availability of criterion values occurs in the area of the social environment. Although some tentative guidelines and principles for team performance and training exist, these have not been well-validated, nor their scope established, and there are no clear recommendations for the social support needed to underpin maintenance of individual mood and subjective well-being. There is, however, guidance regarding the physical conditions and facilities, which should be provided in accommodation spaces and for off-duty activities at sea.

- It is evident that, in practice, constraints on the design situation mean that non-technical and implementation criteria may be as significant as the technical ones in choosing a design option or remedial measure.

- An important difficulty with the use of multiple criteria is that methods for the weighting of relative importance among criteria, and the manner in which they should be combined or traded off against one another, have not been well-developed. However, simple comparative trade-offs are possible within criterion dimensions, and minima or maxima for individual parameters may be set.

- It was recommended that the chosen criteria should be used to select among the alternative measures considered in Task 4. Time, cost, availability and implementation constraints, like acceptability, are likely to be at least as important as technical issues of applicability and validity.

- For Task 5, the remedial measures criteria identified are all factors, which need to be considered in the development of cost-benefit analyses. However, they may be difficult to apply and test unless applied to specific exemplary design problems.

Criteria for model assessment

Methodology

- Task 2 required the listing of criteria appropriate to ship design procedures which include human performance and well-being requirements. One specific aspect of this task was the identification of criteria to evaluate alternative models and their accuracy, which may be used in the specification and design of ships and ship facilities.

- Selected model application areas have been taken from Task 1. Those covered are the thermal environment, noise, ship motion, lighting, work/rest schedules, and mood and social facilitation.

- The methodology employed literature search, evaluation of standards documentation, and consultation with subject-matter experts and model developers and users. Relevant criteria were extracted or inferred from working papers supplied, and then collated and tabulated.

Overview of achieved results/main findings

- Although the relative immaturity of the field means that many terms are used without precise definition (and therefore similar concepts may be used but labelled differently), a small set of criterion topics has been identified. Primary categories proposed comprise technical, non-technical and ease of use criteria. These are further sub-divided as shown in Table 4.

Table 4: Criteria for model assessment

Technical
Applicability to problem domain
Validity
Responsiveness
Reliability
Non-technical
Cost
Availability
Track record
Time savings
Efficiency
Ease of use
Model input procedures
Model operation
Model output
Learning
Reconfiguration possibilities
Portability across different platforms

- It was not possible to specify individual values on criterion variables. These can be determined only following detailed examination of the individual design problem.
- Applicability to the user’s problem domain is a key criterion to apply. A key aspect of this is the representation of the primary variables of the phenomena being modelled. However, the compilation of the criterion list focuses on generic criteria applicable to models from any domain, and upon model use for both exploration and understanding of phenomena, and as design tools.
- It is evident that, in practice, constraints on the design situation mean that non-technical and ease of use criteria may be as significant as the remaining technical ones in choosing a model. This applies equally to the choice of models as alternatives to other design approaches (like experimentation), and to choices among models.
- An important difficulty with the use of multiple criteria is that methods for the weighting of relative importance among criteria, and the manner in which they should be combined or traded off against one another, have not yet been well-developed. However, simple comparative trade-offs are possible within criterion dimensions.
- It was recommended that the chosen criteria should be used to select among potential alternatives for tasks 6 and 9. Time, cost, availability and ease of use constraints are likely to be at least as important as technical issues of applicability and validity.

2.3 Task 3 - Assessment of living and working conditions onboard

Objectives

The overall objective of this task was to gain a better understanding of the living and working environment onboard vessels with a view to improving habitability and safety and in order to validate and substantiate previously achieved results. The method chosen was the one of a questionnaire accompanied by interviews. The actions under this task concentrated on

- the definition of the questionnaire and of the distribution method,
- the comparison with existing data banks and the refinement of the questionnaire,
- the definition and choice of the sample – decision on types of ship, crews, working areas and operations,
- the distribution of the questionnaire and the collection of answers
- the preparation of selected interviews,
- the analysis of the results, identification of weak points, if any, and quantification of results and, finally,
- the input to remedial actions.

Methodology

In order to become better aware of the living and working conditions of seafarers and to be able to suggest improvements to enhance the design and safety of ships, it was decided to choose the method of questionnaires and direct interviews. The assessment of the results was meant to help establishing a ranking of environmental factors, to identify high-risk areas onboard, the crew needs regarding comfort onboard, the level of satisfaction with living and working conditions, as well as requirements for workstation designs and work organisation.

The reader should keep in mind that a ship is both, a working as well as a living place for long periods of time, hence it is felt that the physical and social environment, and to a certain extent the factor of social isolation, has a significant influence on the seafarers comfort and well-being, hence their performance and reliability.

The questions posed in the questionnaire focused on eight key areas:

- Personal information
- Ship identification
- Living conditions onboard
- Leisure
- Safety at work
- Working conditions (in general)

- Bridge working conditions
- Engine room working conditions.

A pre-test was conducted in four phases for different types of merchant ships in the ports of La Coruna and Barcelona, in order to validate the working tool and to assess the time needed to answer the questionnaire, refine it, and to edit its final version.

Limitations on finances and time available, inherent to any research activity, determined the population of the sample in order to tailor the resources allocated to the objectives of the task. Therefore, the population was distributed among:

- Officers in active service onboard ship
- On merchant ships over 1600 tons
- Under any flag
- Stopping at six Spanish (Barcelona, Tarragona, Gijon, La Coruña, Bilbao and Cadiz) and two Italian ports (Genoa and Triest).

Overview of achieved results/main findings

More than 120 answers to the questionnaire were collected and analysed. The choice of both the ships to visit and the members of the crew - mainly engine and bridge officers - to be interviewed was made based on the list of personnel onboard and a random choice.

Some of the main findings among many others are:

- Personal information: The average age of the staff member interviewed was 48 years. On average the members of the crew interviewed had 21 years of service.

- Ship identification: The sample of ships was composed of general cargo vessels, bulk carrier, container ships, roar, reefer and crude oil tanker, all built after 1983, from all flags. The average number of brew members was 18. Up to 59% of the trips were ocean-going with an average duration of at least 15 days. On average, crew members were 5 months at sea and two months off.

- Living conditions onboard: Were considered not to be always sufficient, in particular with a view to space and privacy.

- Leisure: About 40% of the people onboard do not use any of the available leisure facilities due to lack of atmosphere. 53% revealed that they are not able to carry out the activities they would like to do, because they do not have access to the right resources.

- Safety at work: In spite of not being asked directly, an important majority of the interviewees revealed that they had been involved in at least one accident onboard during the last two years. 70% of the interviewees stated that accidents onboard are more likely to happen during mooring manoeuvres and loading/unloading. Regarding space and accessibility, deck access, the deck itself and the engine room were considered to be those with the greatest risk of accidents. It is therefore very important to approach structural and design parameters with ergonomic criteria.

- Working conditions (in general): Regarding human stressors, 60% of the respondent stated that noise is a serious problem during their working time and that vibration affects the work of about 63% of the interviewees, whilst only 5% did not feel affected at all by it. There seems to be a problem of abuse of coffee and tobacco, as well as alcohol. Reasons provided for the abuse of drugs were isolation, boredom, lack of sleep, fatigue, stress, excessive working hours.

- Bridge working conditions: In general, it can be concluded that the working conditions received a better rating on ships with renewed bridges. With a view to completeness of installation and vision, the best rated vessels were the one with integrated ship control bridges. However, just in 16% of the vessels, the bridge was an integrated bridge.

- Engine room working conditions: The best working conditions appear when the actual engine room is unmanned and being controlled from engine control rooms that are completely isolated, both thermically and acoustically, and with an ample view of the engines themselves. In 39% of the vessels the engines were completely automated, and in 60% the engine control was isolated from the rest of the engine.

2.4 Task 4 – Remedial actions

Objectives

This task aimed at the identification of remedial measures which may be applied to ship design and operation in order to maintain or enhance the performance and well-being of crew members in stressful conditions. This implied the

- definition of remedial actions during the ship design stage,
- the definition of remedial actions as ship devices, and the
- the definition of remedial actions during ship operation.

Methodology

The method chosen to address this topic involved initial identification of the problem areas, the selection of possible remedial measures which might influence these problems, both taken from the results identified in REWORD Task 1, and the evaluation of these remedial measures against a set of criteria developed previously in REWORD Task 2. A set of general problems areas were identified in Task 1. The general problem areas as identified previously and taken into consideration for the remedial actions definition can be summarised as:

- Thermal Environment
- Acoustic Environment
- Ship Motions
- Visual Processes and Lighting
- Work/Rest Schedules
- Social and Team-Work Environment

The specific topics selected are the following:

- Physical task performance in high temperatures
- Hearing damage in spaces with high noise levels
- Communications in conditions of multiple auditory channels
- Injury and disruption to whole body tasks in ship motion
- Motion sickness and motion induced fatigue in ship motion
- Sleep in motion, noise and altered thermal conditions
- Mood changes at sea in relation to the social environment
- Monitoring of navigational hazards in conditions of poor visibility
- Conflict between lighting requirements of different bridge tasks
- Efficiency of all mental activities in prolonged periods of work, irregular rest and work, and at night

- Efficiency when working alone
- Situation appreciation and procedural errors in emergency situations.

Overview of achieved results/main findings

The remedial measures, as identified in Task 1, were subdivided into three different areas of concern and addressed respectively in the following:

- Sub-task 4a: Remedial Actions during Ship Design

- Sub-task 4b: Remedial Actions as Ship Devices

- Sub-task 4c: Remedial Actions during Ship Operation.

The **first group** of actions - remedial actions during ship design – are subdivided into:

- Combined approaches
  - use modified design philosophies and procedures
  - apply standards/develop new standards

- Physical changes to the conditions under which exposure to stressors occurs
  - redesign space in which stressor and individual interact
  - redesign equipment in workplace
  - modify equipment layout

The **second group** of actions – remedial actions as ship devices – are subdivided into:

- Modification of the source (control of risk at source)
  - automate activity to remove human involvement
  - introduce equipment with lower stressor characteristics
  - modify running characteristics of equipment
  - improve maintenance access for control

- Modification of transmission pathway at source (modification of risk at source)
  - enclose noisy or hot machinery
  - relocate sources or recipient or both away from one another
  - erect deflection barriers e.g. sunshades on deck
  - use absorption techniques
  - use interference effects (noise cancelling systems, etc.)

- Changes to the task or activity undertaken (change task)
  - redesign activities to reduce or remove need for human functions sensitive to stressors
  - reduce task objectives or performance standards
  - reorder task elements and procedures
  - simplify or standardise procedures
  - change interfaces

The **third group** of actions – remedial actions during ship operation – is subdivided into:

- Modification of transmission pathways at recipient (modification of risk at recipient)
  - use barrier creams
  - use ear protection devices
  - use body cooling clothes
  - use protective clothing
  - provide more user control over levels of stressor experienced

- Organisational changes to the conditions under which exposure to stressors occurs
  - shorten exposure periods
  - lengthen time available to complete task
  - perform task at times of least risk and exposure
- Changes to the task or activity undertaken (change task organisation)
  - rotate personnel away from vulnerable tasks more frequently
  - transfer susceptible individuals away from adversely affected tasks
  - incorporate rest pauses
  - modify work/rest schedules
  - change individual's duties

Only the potential remedial measures that could be adopted to cope with the chosen problems due to the range of identified stressors, as explained in the previous chapter, have been evaluated on the basis of a range of the criteria - technical, non technical and implementation - that were devised in Task 2.

Remedial measures criteria

Technical:	Applicability to problem domain Validity Effectiveness
Non-technical :	Cost Availability

Implementation :	Track record Time factors Conformance with legislation Efficiency Feasibility (ease of use) Time savings Acceptability Robustness

Among them, the following criteria were selected as more relevant to the work in Task 4, in order to limit the dispersion of available data and to concentrate the analysis on the more characteristic criteria that have been restricted to:

Applicability:	This refers to the remedial action applicability to the potential user problem domain.
Effectiveness:	This refers to the degree the respective stressor is controlled by means of adopting this remedial measure.
Cost:	This refers to the cost requirements implied by the application of the measure.
Feasibility:	This characterises practical applicability issues.
Acceptability:	This refers to the acceptability of the proposed measures by the ship owners/ operators/crew.

In the following, matrixes of problem areas, relevant remedial measures, and evaluation criteria for assessing those measures were prepared in form of tables. For each problem type, each remedial measure has been evaluated with the above five criteria by mean of a numerical voting method that used simple scoring rates ranging from 0 to 3, with the following meaning: 0 = poor or unsuitable, 1 = medium, 2 = good and 3 = very good.

Based on these tables, it has been possible to construct synthesis graphs, which compare the best remedial actions drawn from the sub-task 4a and 4b against the best of sub-task 4c; so in general between remedial actions which act on the ship design or ship’s systems against other remedial actions which act directly or indirectly on the personnel on board. From these comparisons one can easily indicate the most valuable remedial measure for the different analysed problem types.

Only the three problem areas, where remedial actions of the two kinds were available, have been analysed. In fact, these areas are: thermal environment, acoustic environment and ship motions.

For the generic purpose of this particular study, the identified problem areas have been kept on a general level without linking them to a particular ship type or a particular ship mission profile or human task. However, this makes it more difficult to assess the goodness of a certain remedial action against another. For the above reasons the comparison of the various remedial actions remain to a certain extent general, in some cases appearing quite obvious, while it in other cases can give precious indication for ship designer, ship owners and ship operators.

As examples of the results obtained in this task it is possible to observe from Fig. 1 and 2, the rank of remedial actions suggested for enhancing:

a) Physical task performance in high temperature.
b) Sea sickness for ship motions.

According to these results the most effective remedial actions seems to be air conditioning in living and working spaces for the item a) and ship design for sea-keeping characteristics for the item b). The last result has been linked with the development of Task 9 and 10, as will be discussed in the following.

Figure 1:

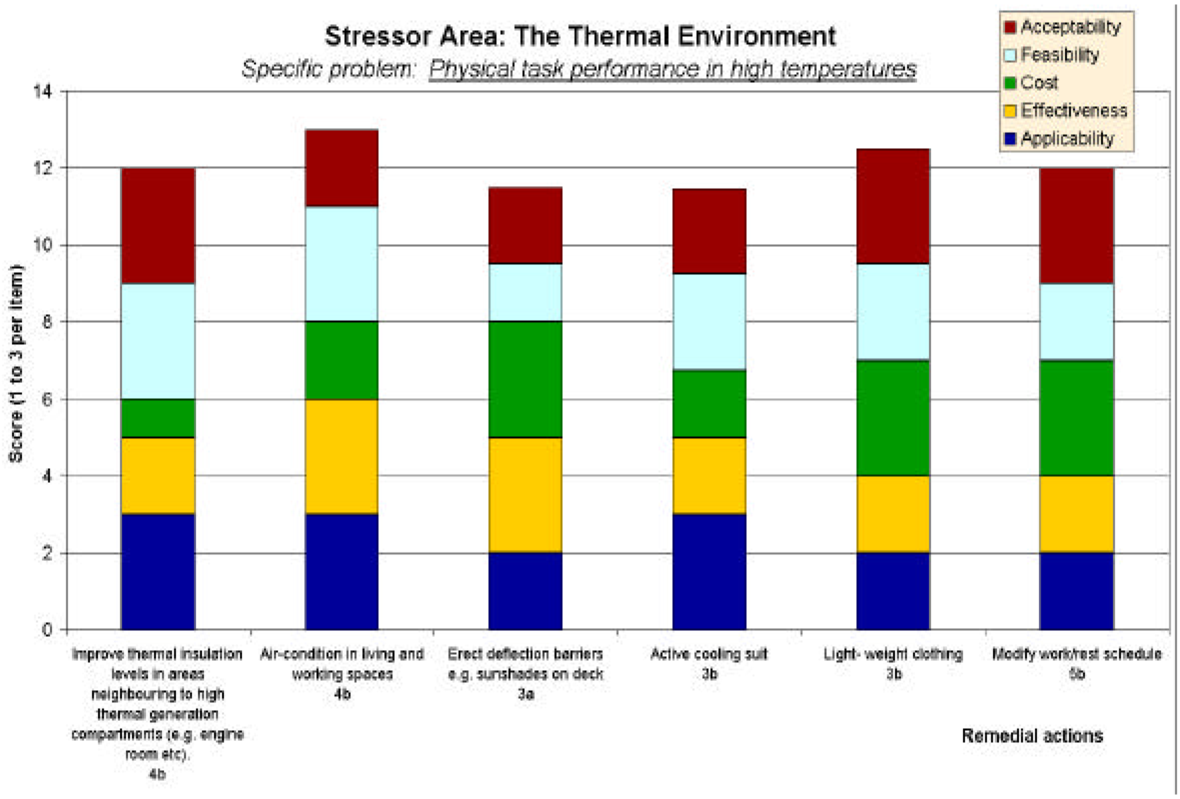
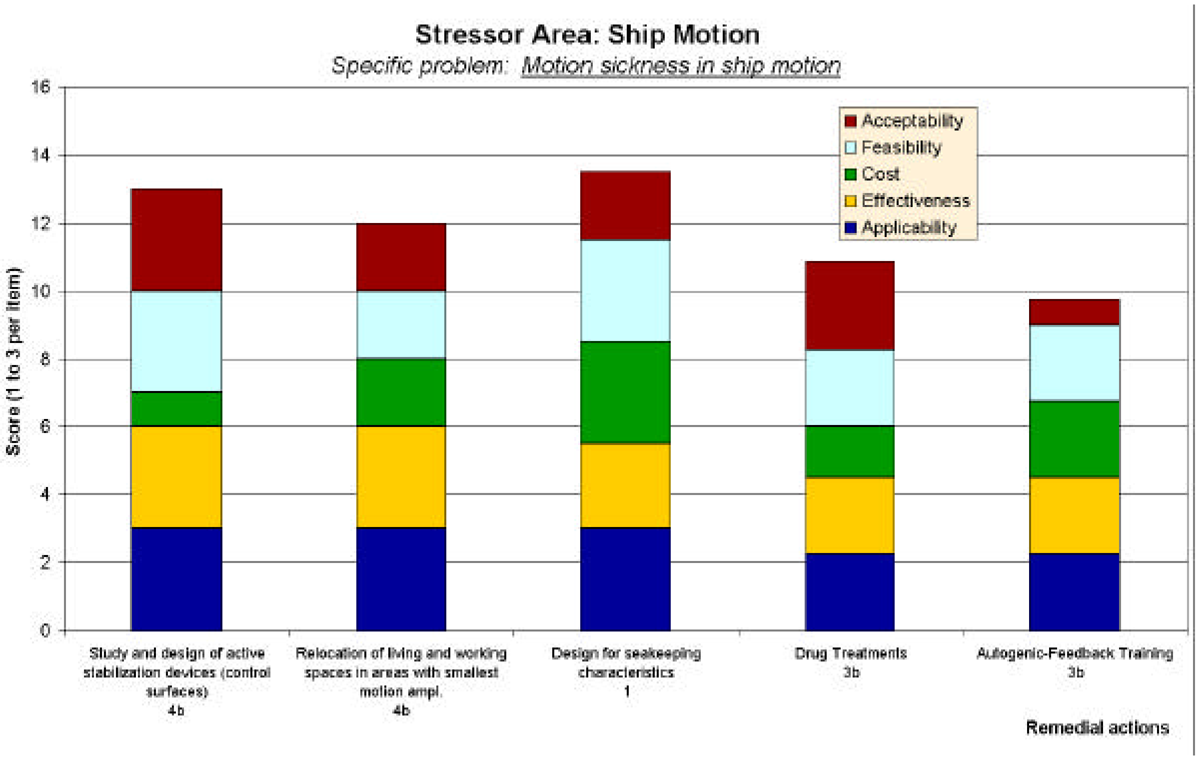


Figure 2:



2.5 Task 5 - Cost-Benefit Analysis

Objectives

The purpose of this task was to examine the remedial actions as identified in the previous tasks, and to assess the resulting level of improvement regarding ship operation and safety (and the resulting level of benefits thereof) in comparison to the cost level associated to their implementation.

Methodology

The work carried out focused on the following main areas:

- Review of cost-benefit assessment methodologies.

- Identification and classification of key cost areas and elements involved or influencing the ship operation and its social and environmental impacts.

- Assessment of approaches on splitting costs and overview of both normal and extraordinary cost components, including review of documentation on impact of human factors (e.g. P&I clubs or legal reports, as practicable, and useful for impacts assessment purposes).

- Review and classification of operational profiles and the respective remedial measures, which may affect costs.

- Assessment of the significance of impacts to provide yardsticks related to potential operational tasks failure.

- Remedial actions analysis, grouping, rating and correlation to potential impacts, in order to provide an indication regarding the value and criticality of the remedial actions.

- Assessment of the degree of improvement due to the remedial actions, and analysis of the potential impact (avoidance of failures) on various operational tasks.

- Examination of the proposed remedial actions from different viewpoints, taking into account operational profiles requirements and the identified impacts, in order to enable assessment of their importance to shipping. This was formulated, so that to provide information and assist the task of cost benefit analysis on specific future problems.

It has to be underlined that the benefits are not examined in the narrow sense (traditionally used to refer to revenues). Instead, they also refer to expenditure which is avoided, or even to more general improvements such as in the social and environmental fields.

Cost-benefit assessment was also, as in many practical cases, addressed as a balance of ‘marginal’ advantages (or benefits) and ‘marginal’ disadvantages (potential costs) which was weighted in a sufficiently clear manner (in many cases using domain expert – empirical - knowledge) to enable sensible and justified conclusions. The term ‘marginal’ is used here to depict the advantages and disadvantages stemming from the introduction of a variation or change to the current practice.

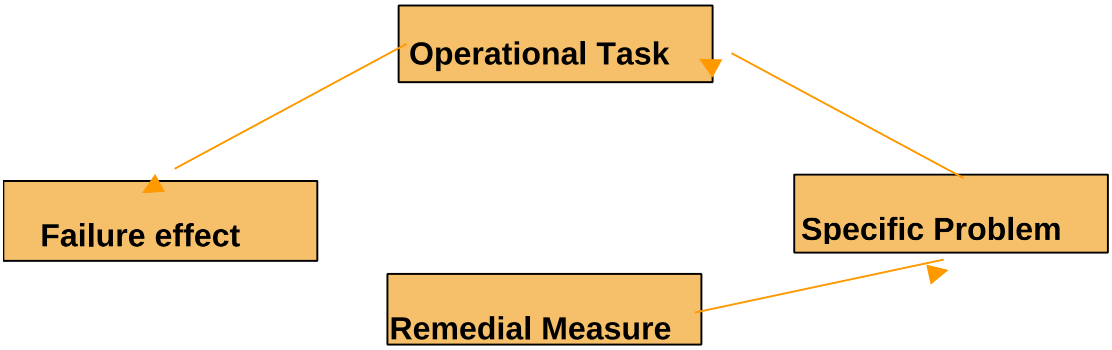
Overview of achieved results/main findings

A number of remedial measures to address specific problems during ship operation have been identified and summarised. A list of the most sensitive ship operation tasks (mainly examined from the safety, human and social importance points of view), has been established. As a result of this task, the cost level of the implementation of each measure has been rated, based on empirical domain criteria knowledge.

The cost level related to the adoption and implementation of a remedial action has been assessed. A key issue is to be in the position to provide an indication regarding the potential direct or indirect (e.g. through cost avoidance) benefits that can be expected from the application of a remedial measure. However, such an analysis can not be straight forward. Ship operation is a multi-functional and multi-parametric environment, where impacts from individual changes cannot be assessed in isolation with an acceptable level of accuracy and confidence.

In addition, impacts may heavily vary depending on the particular problem and circumstances, the nature of the trade (e.g. dry, liquid or standardised cargoes, passenger vessels), the geographical area of trading, the operating mode of the vessel (liner or tramp market, time or voyage charter), average stay in ports due to the trade/market nature and many other circumstances.

It is well understood that the value of a remedial action, if examined independent from particularities that may apply in a specific case, should at the end of the day have a positive effect on the ship operation. Hence, the assessment of the benefits from the adoption of a remedial action should focus on the identification of the level of improvement, the safety-criticality of this improvement and the potential of cost avoidance or savings for the operator. Hence, the assessment of remedial actions should take into account all links in the impact chain, which is graphically shown in the figure below.



Tasks 2 and 4 have already addressed, to a certain level of detail, the first link - remedial measure/specific problem. The identified specific problems for further consideration are shown on the following Table 5 taken which are based on the work in Task 1:

Table 5: Specific Problem Areas (Predominant)
1. Physical task performance in high temperature
2. Hearing damage in spaces with high noise levels
3. Communications in conditions of multiple auditory channels
4. Injury and disruption to whole body tasks in ship motion
5. Motion sickness and motion induced fatigue in ship motion
6. Sleep in motion, noise and altered thermal conditions
7. Mood changes at sea in relation to the social environment
8. Monitoring of navigational hazards in conditions of poor visibility
9. Conflict between lighting requirements of different bridge tasks
10. Efficiency of all mental activities in prolonged periods of work, irregular rest and work and at night
11. Efficiency when working alone. Situation appreciation and procedural errors in emergency situations
12. Hearing loss and/or disruption of verbal communications

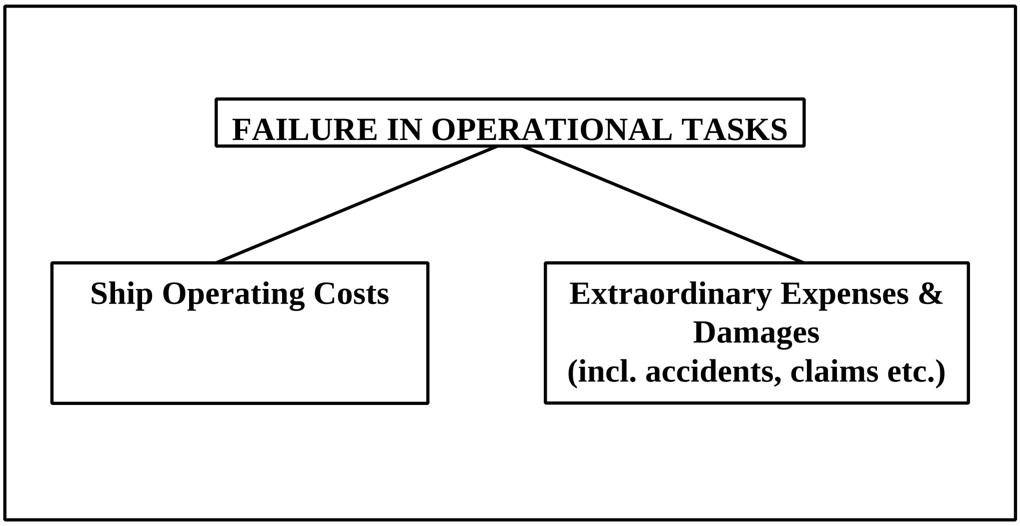
The operational tasks of interest in this project were also identified in Task 1. Each operational task needs then to be related to the identified specific problems. This analysis clarified for which problem, if totally or partially addressed, an improvement in the task performance can be achieved. The analysis was carried out for each operational task and has been based on operational task functional requirements and profiles. In addition, the level of criticality for each task has been assessed, especially from the safety point of view and the aspect of the ship exposure to potential costs and extraordinary expenses, in case of operational task failure.

Another issue which is of importance in order to enable the remedial actions assessment, is the rating of such actions, i.e. the evaluation of their criticality for the ship safety and operating (mission) success. Significant parameters that were considered were both the importance of the remedial action for the specific problem as well as the level of importance of the specific problem for the ship operating tasks performance. By combining the above aspects, using domain expert knowledge, a combined level of criticality results could be obtained, providing a unique criticality measure for the remedial action. The results of the above analysis are summarised in Table 6:

Table 6:

	Tasks	Specific Problem Areas involved	Criticality
T1	**Pilotage**	3/8/10/9	3
T2	**Berthing/unberthing**	1/3/4/8/9/11	2
T3	**Coastal navigation**	5/7/10/11	3
T4	**Ship handling**	3/5/7/10/11	3
T5	**Entering and leaving harbour**	1/3/4/11	3
T6	**Anchoring and mooring at buoys**	1/3/4/11	2
T7	**Launch and recover boats**	3/4/ 11	1
T8	**Lifeboat drills**	3/4/11	1
T9	**Cargo checking**	1/10	2
T10	**Safety checks**	11	3
T11	**Deck maintenance**	1/4/10/11	1
T12	**Equipment maintenance**	1/2/4/10/11	1
T13	**Equipment inspection**	2/5/7/10/11	2
T14	**Equipment operation**	1/2/3/11	3

In order to establish a framework regarding potential effects (i.e. costs) which are generated through operational failures, it has proved necessary to analyse the different cost categories applicable to ship operation tasks, as well as the extraordinary costs (such as the failure costs) both private or social, which may occur as a result of failure(s) in ship operation tasks.



Although experience, statistics and maritime knowledge can in many cases provide a good and reasonably acceptable picture of the advantages/disadvantages or costs/benefits related to a potential remedial measure, documented support of quantification assessments is not always straight forward, due to the multi-parametric and extremely complex nature of the ship operation environment. Some reasons which play a significant role in this respect are, for example, that costs related to social factors or the environment are many times difficult to quantify or intangible (hence the use of empirical merit statements/factors), or the dependency of costs on the ship type/trading area, or the lack of objective measure for costs related to design improvement etc.

It is noted that for remedial actions addressing one single specific area, a unique ‘criticality’ level characterises the action. Actions affecting more than one specific area, are assigned, using the above approach, different criticalities, depending on the specific area they refer to. In case a unique criticality level is to be selected to characterise such a remedial action, the highest level of criticality among the already assigned different criticalities should be used for the action. Such remedial actions addressing multiple areas were clearly identified.

It has shown that this analysis enables the establishment of relationships between remedial actions and operational tasks. The adoption of remedial actions can help to avoid operational tasks failure, which, whenever occurs, may result in significant operating overheads and extraordinary expenses. The latter, if quantified, can be used as a basis for the determination of the financial, social and environmental benefits that can be potentially related to the implementation of a remedial action.

When assessing the benefits of the application of a remedial measure, one should take into account the number of specific areas and operational tasks a remedial action is affecting, so that a combined benefit measure is established for an activity under evaluation. The potential benefits need to be compared to the cost level associated to the implementation of the measure.

Finally, apart from the cost level related to the adoption of a remedial action, additional considerations (such as the efficiency and criticality of the task affected) have to be investigated.

In order to summarise the work, one can state the following

- Remedial measures affect operational task performance.
- The task performance has implications on the ship operating costs and potential extraordinary expenses.
- Failure in critical tasks may cause casualties and huge economic disasters.
- The ultimate criterion for the assessment of the benefits of remedial measures from an economic point of view, is the potential cost implication of operational tasks failure.
- In order to assess the benefits of remedial measures, a methodology was applied focusing on linking remedial actions, problem areas and operating tasks.
- The remedial actions have been systematically analysed from different viewpoints (cost level of implementation, efficiency, and applicability, number and nature of affected operational tasks, criticality etc). The results were presented in an easy to use, formalised format.

The above analysis provided a valuable tool to decide which measures to adopt, depending on the priorities set forth, whilst optimising resource allocation. The assessment of the potential benefits from the application of remedial measures is determined as a function of task performance improvement or task failure avoidance.

Hence, questions such as which remedial action to adopt or which remedial measures are the most important to improve safety (address the most critical tasks), or even which measures are cost-efficient to adopt (as they may influence the performance in many operational tasks) can now be addressed in a straight forward manner.

The results were presented in a easy to use format (see as example the following Table 7). In this way more than 80 type of remedial actions have been assessed.

Table 7:

REMEDIAL ACTIVITY	AREAS AFFECTED	SHIP OPERATIONAL TASKS AFFECTED
Acustimulation	Motion sickness in ship motion	T3,T4,T13
Adjust availability and type (e.g. introduce modern training equipment/multimedia) of information to simplify onboard training and equipment maintenance preparation task.	Efficiency of mental activities in prolonged periods of work, irregular rest and work, and at night	T1,T3,T4,T9,T11,T12,T13
Air-condition in living and working spaces	Physical task performance in high temperatures	T1,T5,T6,T9,T11,T12,T14
Air-condition in living and working spaces	Sleep in motion, noise and altered thermal environments	
Audible alarms of different type for different sources	Communications in conditions of multiple auditory channels	T1,T2,T4,T5,T6,T7,T8,T14
Autogenic-Feedback Training	Motion sickness in ship motion	T3,T4,T13
Aux lighting	Conflict between lighting requirements of different bridge tasks	T1,T2
Avoid stimulants (e.g. caffeine) and heavy meals before sleep time	Sleep in motion, noise and altered thermal environments.	
Binoculars	Monitoring of navigational hazards in conditions of poor visibility.	T1,T2

2.6 Task 6 - Demonstration in a simulated environment

Objectives

This task aimed at the simulation and analysis of the alertness of crew members in a given situation and under varying conditions. The operational task chosen was the highly-demanding and safety-critical task of watchkeeping during nights. The task required an experiment or demonstration in a simulated environment with the aim to examining the influences on alertness in bridge lookouts at sea at night, and to compare the human behaviour in different bridge lookout conditions (one or two person on the bridge etc.).

Methodology

In the light of earlier reports, it was agreed that the trial would involve the use of a well-established computer-based tool, Integrated Performance Modelling Environment (IPME), to simulate human tasks on a ship's bridge.

In the light of preliminary information gathering, it was determined that the most appropriate objectives of the trial would be to investigate the effects of the following factors on human performance

- Operation with a full versus a reduced bridge team;
- Operation in day watch versus early morning watch conditions.

The approach to the simulation was conducted in the following stages:

- Acquire basic information;
- Acquire detailed information for task analysis;
- Convert detailed information for IPME, enter data and run program;
- Analyse data;
- State results;
- Draw conclusions.

The first stage was to obtain an overview of the roles and tasks of ship's bridge personnel and the scenarios in which they were required to operate. This information was obtained from both documents and interviews with senior merchant ship personnel at a training establishment.

In the second stage, a detailed knowledge of the tasks of the bridge personnel was obtained together with details of a specific geographical scenario from a Royal Navy (RN) officer responsible for navigation training.

In the third stage, details of the operator task analysis together with parameters defining the scenario, full and reduced bridge crews and day/night watches, were inserted into the IPME tool.

In the fourth stage, a series of simulations was run covering the above factors under investigation and the results were analysed in terms of a number of operator performance parameters.

Overview of achieved results/main findings

The results obtained may be summarised as follows:

- The reduction in crewing levels resulted in the OOW (Officer of the Watch) being able to devote less time to performing visual lookout and monitoring potential hazards.
- In a reduced crew, the OOW took more time to detect potential hazards in both day and early morning conditions than in a full crew.
- In a reduced crew, the OOW took more time to take avoiding action with respect to other vessels than in a full crew, for the early morning watch only.
- For both full and reduced crews, the OOW’s overall early morning performance, when it can be assumed that he was fatigued, was degraded relative to that during the day.
- In one respect alertness state had a larger impact on the OOW’s performance than the crew size. It took substantially longer to decide to take avoiding action in a full crew in the early morning watch than in a reduced crew in the day watch.
- Both the maximum number and the proportion of tasks carried out concurrently by the OOW in the reduced crew appeared to be greater than in the full crew.
- The study provided evidence that IPME is an appropriate and cost-effective tool for examining the influences of environmental and organisational stressors on shipboard operators.

The brief recommendations are as follows:

- Although it is beyond the scope of this study to estimate the magnitude of the enhanced risk of collision, it is clear that alertness is an issue which should be addressed before recommendations about reductions in bridge manning levels can be made.

- Meanwhile it should be mentioned that the present simulation was a relatively small one of necessity, it was confined to Royal Navy shipping procedures only, so that the results might not be directly applicable to merchant shipping per se. Therefore, it would be desirable to validate the results obtained in a comparable simulation in a merchant shipping scenario.

- In addition, and again of necessity, only one shipping operation, approach to harbour, could be investigated. Other simulations could focus on other operations.

- It would be highly desirable to carry out a man-in-the-loop experiment to compare with the results of this computer-based simulation.

2.7 Task 7 - Sea trial demonstration

Objectives

The objective of this task was the acquisition and review of full-scale data for the assessment of human factors criteria in real-life ship environment, if possible through a limited number of specific sea trials, as well as the definition of improved guidelines for the conduct of sea trials.

Methodology

According to the project workplan a set of sea trials were intended to be carried-out for one of the fast ferries recently delivered by Fincantieri. During the period of ship availability for these sea trials and the corresponding time window within the project schedule the prevailing weather and sea conditions did not allow for the sea trials intended, the sea conditions did not fulfil the requested sea conditions. However, the objectives of the project were not infringed since a large amount of full-scale data, collected during 30 years of sea trials, was available with the co-ordinator. The complexity and consistency of these data ensured a high quality of the results.

The focus was laid on seakeeping behaviour and its effects on the well-being of the people onboard. Based on in-house experience, available information from Task 1 and results from Task 3, the co-ordinator carried out a preliminary selection. A set of available seakeeping trials was selected as suitable for a re-analysis of the evaluation of human factor against existing performance criteria to be carried out in Task 8.

Overview of achieved results/main findings

In order to assess in a quantitative way the influence of the ship environment on human performance, well-being and comfort, the following measurements should be in principle considered:

- **air-borne noise** measurements, according to IMO Code A.468 designed to provide standards to prevent the occurrence of potentially hazardous noise levels on board of ships and to define an acceptable environment for seafarers;
- **vibration** measurements, according to ISO 2631-1978 and ISO 6954-1984 designed to provide standards for the evaluation of the effects of vibration exposure on human safety, performance capability and comfort of the crew;
- **seakeeping** measurements, devoted to monitoring ship motions / sea conditions aiming to assess the performance of the vessel in relation to its task / mission;

- **climate** measurements, addressed to monitor the parameters that characterises the working/living environment on board (i.e. temperature, humidity, air velocity);

- **lighting** measurements, devoted to assess the level of artificial illumination on the ship in compliance with the requirements of ISO or UNAV 1012 standards;

The attention was focussed on ship seakeeping measurements in relation to the assessment of human factors and especially comfort. The co-ordinator's database of seakeeping trials carried out during the last decade was examined in order to identify the most suitable trials from the point of view of the task objectives, the screening led to the following six data sets:

- Ship 1 *small-size fast catamaran ferry*
- Ship 2 *small-size fast hydrofoil ferry*
- Ship 3 *small-size fast hydrofoil ferry*
- Ship 4 *small-size fast SES ferry*
- Ship 5 *medium-size fast mono-hull ferry*
- Ship 6 *medium-size fast mono-hull ferry*

The main dimensions of the above listed ships are reported in the following table a) along with an outline of the available measurements.

Table 8.a: Dimensions of Tested Ships

	Ship 1	**Ship 2/3**	**Ship 4**	**Ship 5**	**Ship 6**
Length overall (m.)	40.0	31.2	39.0	82.0	88.0
Beam (m.)	10.1	6.7	11.8	16.0	17.1
Mean Draft (m.)	1.5	3.7	2.2	2.6	2.6
Displacement (tons)	150.0	100.0	167.0	1200.0	1200.0

Table 8.b: Tested Conditions

	Ship 1	**Ship 2/3**	**Ship 4**	**Ship 5**	**Ship 6**
Ship Speed (knots)	32 20 15	35	~30 25 20	27	36 30
Angle of encounter	180° 90° 0°	180° 90° 0°	135°	180° 135°	180° 135° 90 45 0

During the full scale tests the following data had been measured:

- ship speed and heading
- shaft RPM and torque
- roll and pitch angle
- vertical acceleration at points of interest
- wave elevation at a fixed location
- sea power spectra.

In a next step, the project defined "Guidelines for human factors-oriented *seakeeping* trials" on the basis of the co-ordinator’s practical experience in the execution and analysis of sea-trials and based on the recommendations of the foremost international institutions, namely the Specialist NATO Group on Seakeeping and the ITTC Specialist Committee on "Trials and Monitoring", in which the co-ordinator has been an active member.

For each selected test, guidelines have been defined for full-scale experimental techniques suitable to achieve the project objectives. For example, as to human factors related Seakeeping Performance Criteria (SPC), the co-ordinator identified the ship-motions related statistical quantities required.

These guidelines address the following issues:

- preliminary control
- selection of the area
- selection of the sea state
- estimation of the sea state
- duration of the runs
- conduct of the runs
- data collection and instrumentation
- data acquisition
- data analysis

Finally, a number of specifications for seakeeping trials, having in mind the evaluation of passenger comfort on ferries, have been formulated, in particular addressing the measurements, the monitoring system, the acquisition system as well as the analysis of measured data.

2.8 Task 8 - Sea trial analysis

Objectives

The objective of this task was the (re-)analysis of full-scale data obtained during sea trials - in this case focusing on the seakeeping factors which are originally gathered in order to assess the vessel performance in relation to her task/mission - regarding the impact on the human factor in terms of performance, well-being and comfort.

Methodology

As explained in the previous chapter, it was not possible to conduct any sea trial due to weather conditions and sea states during the time window available within the project life time and schedule. The consequences did not to infringe the objectives of the project due to the fact that a huge amount of full-scale data was available with the co-ordinator. The complexity and consistency of these data ensured a high quality of the results. Hence, the alternative was chosen to reanalyse the sea trials carried out on a medium-size fast mono-hull ferry, which is the ship N°6 in Task 7.

The procedure adopted was an innovative one: together with the usual index MSI (Motion Sickness Incidence) adopted to assess the comfort onboard, based on ISO 2631 (1985) 1/3 octave band analysis, a new approach has been implemented, on the basis of Task 9 results, adopting the new ISO 2631 (1997) which incorporates the British Standard 6481 and which is based on the frequency filtering of the time signal.

In addition, the consortium introduced the index related to postural stability MII (Motion Induced Interruptions) criterion into the analysis, which consists of evaluating the motion induced interruptions due to the combination of vertical and lateral acceleration on the people.

Overview of achieved results/main findings

New approach - Data analysis

Processing of the measured time series to derive statistical parameters, allowing the evaluation of the performance of the ship and / or of the crew and passengers, was accomplished both in time-domain and in frequency-domain according to the guidelines defined in Task 7.

- **Time domain analysis**

For each measured quantity *wave analysis* of the time series was performed, that is to pre-process each time series in order to refer first the signal to its mean value and hence subdivide it into a set of wave cycles identified by two subsequent zero up-crossings or down-crossings; each cycle is characterised by its duration (period), its minimum (through) and maximum (crest) values and its height (crest-through). Averaging these values over the cycles allows to derive the short-term statistics of the signal, i.e. the zero-crossing period, the significant amplitude and the significant height of the signal.

- **Frequency domain analysis and comfort evaluation**

Frequency domain processing consists of performing a harmonic analysis of the time series to derive energy density spectra. The powerful framework of spectral analysis allows hence to easily correlate the frequency-domain results with the relevant statistical parameters of the signal, i.e. zero-crossing period, rms, significant amplitude / height.

Frequency domain analysis is especially suited to the interpretation of the measured ship motions in terms of human suffering.

Human suffering due to ship motions, and in particular the so-called *motion* or *sea sickness*, is of primary concern in the case of fast ferries.

The sea-sickness seems to be caused by a number of external factors among which :
- the level of vertical accelerations on the ship
- the frequency content of such accelerations
- the exposure time to such accelerations

Other concurring causes may be: passengers gender, age, health or physical conditions, anxiety, fatigue, particular smells, sitting stance, sense of claustrophobia in closed windowless spaces, etc.

Related quantitative criteria are essentially MSI (*Motion Sickness Incidence*) and SMM (*Subjective Motion Magnitude*). They are both based on laboratory experiments on young male volunteers not accustomed to ship motions and depend on the frequency content and level of the vertical accelerations.

MSI measures the percentage of people that, subjected to a certain regime of vertical acceleration, will be likely sea sick within a given exposure time.

For a given RMS value, the MSI curve versus wave encounter frequency has a bell shape peaked around 1.07 rad/as illustrated in the following diagram.

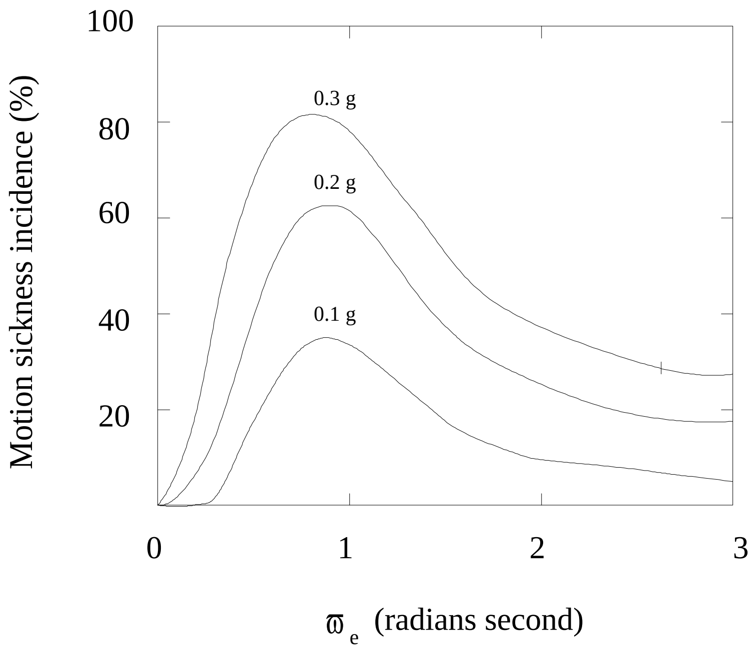


Figure 3: MSI versus encounter frequency for different RMS values

The first step is the sampling of the spectrum in one-third octave band, to the centre-frequency of each band; it will be therefore associated the RMS (in g) value corresponding to the square-root of the area of the spectrum in the related band. The resulting curve is then plotted in a bilogarithmic paper and compared with a severe discomfort limit which consists of a two-parameters family of curves depending on the exposure time *t* (in hr) and the MSI level (in %):

$$\begin{cases} MSI(az) = 10 \cdot (az / AZ)^{1.8} & MSI < 20\% \\ MSI(az) = 20 + 109 \cdot [\log(az / AZ) - \log(1.47)] & 20\% < MSI < 80\% \end{cases}$$

where *az* is the *rms* value (in g) of the acceleration and *AZ* is the *az* value which causes a 10% MSI at an exposure time of 2 hours. To calculate MSI for other than 2 hours exposure time, the following formula (derived from ISO 2631/3) applies :

$$az\,(t) = az\,(t_1) \cdot \sqrt{\frac{t_1}{t}}$$

where $az(t)$ causes the same MSI level over exposure time t as $az\,(t_1)$ over exposure time t_1.

By tentatively adjusting the MSI parameter of the limiting curve, for the desired exposure time, it is possible to determine the value for which the sampled acceleration spectrum is just below the limiting curve over the relevant frequency range; this value represents the actual MSI level experienced at the measurement position. A practical illustration of the procedure is given below :

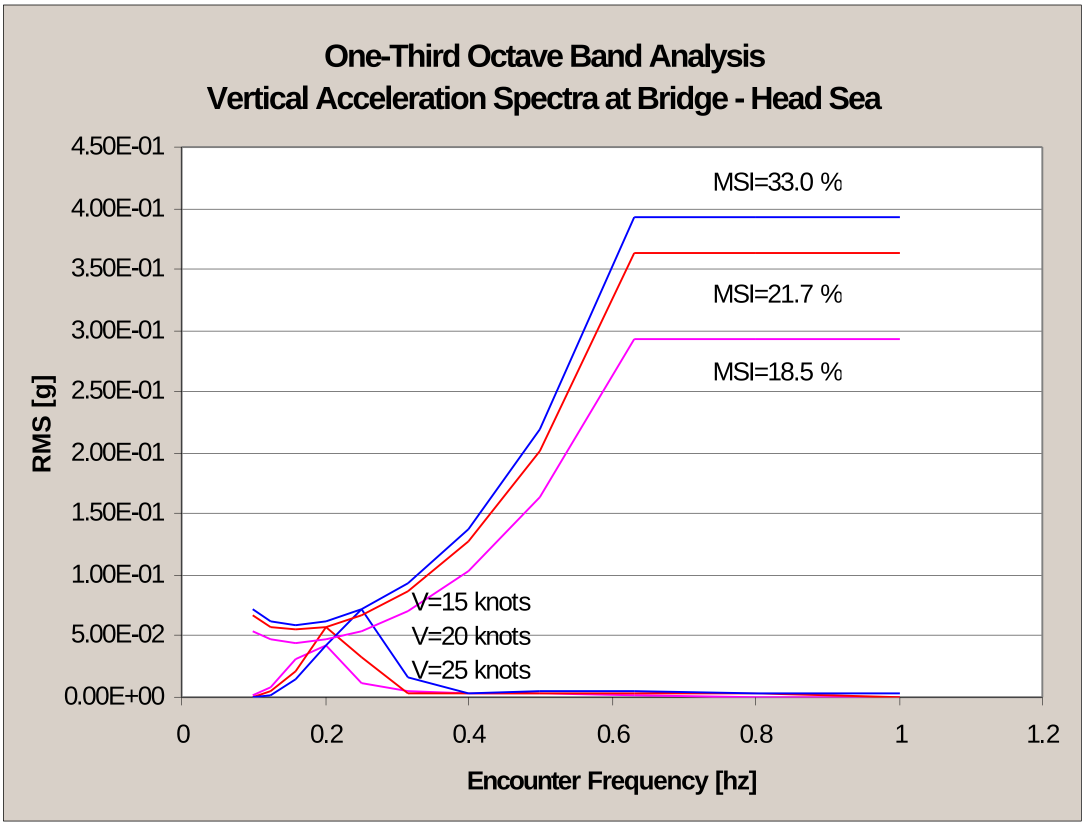


Figure 4: MSI evaluation via O'Hanlon & McCauley method

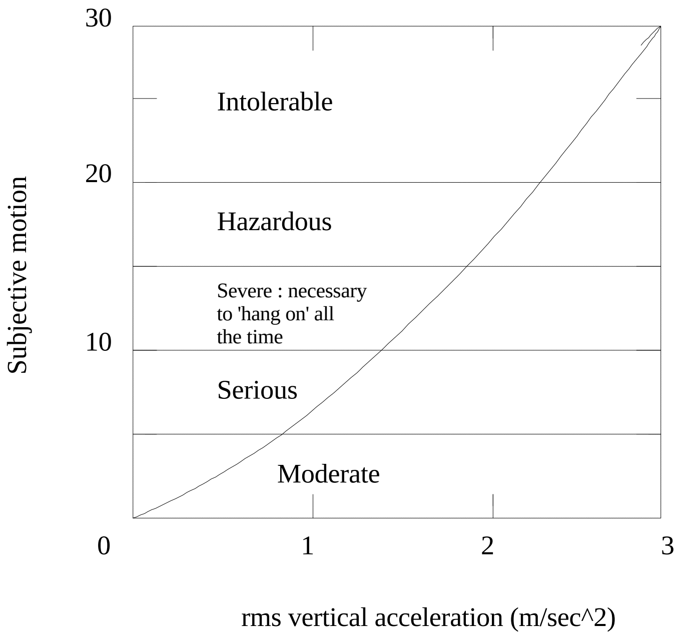
As the MSI is location dependent, an overall assessment of comfort on board would require to determine the MSI at several locations properly distributed over the relevant areas of the ship; the weighted average of these values will then provide a global evaluation of the seakeeping qualities of the ship with respect to comfort.

The SMM criterion indicates the subjective perception of the severity of the ship motions by people on board. SMM depends on both vertical acceleration amplitude and frequency according to the formula:

$$SMM = \left(1 - e^{-1.65 \cdot w_z^2}\right) \cdot \left(75.6 - 49.6 \ln w_z + 13.5 \ln^2 w_z\right) \cdot \left(2 \cdot az\right)^{0.43}$$

where $w_z = 2p/T_z$, T_z is the zero-crossing period of the vertical acceleration.

The dependence of SMM on acceleration amplitude, for the critical wave frequency of 1.07 rad/s, is illustrated below:



Subjective magnitude and vertical acceleration at 1.07 rad/sec

Figure 5: SMM versus RMS for the critical frequency

Re-analysis of full-scale data of ship N° 6 - medium size fast monohull ferry

A re-analysis of the seakeeping trials of ship 6, a medium-size fast ferry, was performed. The objective of this re-analysis was to evaluate both the applicability of the newly developed MSI and MII criteria to the standard seakeeping trials practice as well as the remedial effect of an innovative control system for the vertical and lateral motions reduction integrating the action of a pair of active fins (roll reduction) and trim-tabs (pitch reduction) – Motion Damping System.

The time histories of the measured vertical accelerations were re-analysed in order to determine the MSI according to the new criterion developed. The time histories of the measured vertical and lateral accelerations were re-analysed in order to determine the MII according to the new postural stability criterion developed.

The MSI and MII values were evaluated with (MDI On) and without (MDI Off) the Motion Damping System in operation in order to assess the effect of the remedial action on the comfort onboard.

The results of the re-analysis showed that the new criteria can be quite easily applied to the analysis of seakeeping trials. The comparison of MSI and MII values with and without the Motions Damping System operating showed that it has an effective remedial effect.

2.9 Task 9 - Improvement of existing models

Objectives

The objectives of this task can be stated as follows :

- To suggest methods in which current performance models identified in Task 1 may be improved.
- The demonstrate how design tools could be enhanced by way of integration of appropriate performance models.

Methodology

The results in relation to the first objective – to suggest methods in which current performance models may be improved – have been described already in the previous chapter, since the new methods had been used in the re-analysis of seakeeping data and their impact on the human performance, well-being and comfort.

In order to exploit best the knowledge obtained on the impact of adverse environmental factors on the human performance, well-being and comfort, the integration of selected performance models into design tools would lead to significant improvements in ship design (- ships designed for people -). The integration would enable the ship designer to measure, hence take into account the effects of design changes on the performance, well-being and comfort of crew members as well as passengers.

The first required step in the process of producing such a tool is assessing the design tools suitable, and identifying what physical modelling tools would be required in order to predict the inputs to the environmental human performance models. Having identified and assessed these design tools and physical models a demonstration of the integration offers the best opportunity to assess the practicality of such an integration, and compare the results with real cases.

In order to fulfil the objectives of this task the following working steps are required:

- Identify the human performance models considered potentially best suited to be integrated with a design tool.

- Identify and assess the suitability of design tools and the required physical modelling tools for producing an integrated design tool with human performance modelling.

- Each design tool identified will be assessed for the feasibility of integration with the appropriate performance model(s), the ease of the integration, and the general improvement that the integration is considered to have on the design tool, hence the design of the ship or element of the ship.

- Demonstrate the application of the ‘best’ integrated design tool and human performance model combination.

Overview of achieved results/main findings

The human performance models which were identified to be potentially best suited for the integration with a design tool are those shown in the following table.

Problem area	**Possible Models / Techniques**
Injury and disruption to whole body tasks in ship motion	Graham 1990 postural stability model
Motion sickness in ship motion	ISO 2631: 1997 Part I Colwell's 1994 habituation model

In order to assess the integration feasibility, a fast mono-hull ferry, designed and built by Fincantieri Navali Italiani S.p.A. and already referred to as ship N° 4 in Task 7 was chosen as test case.

The main design characteristics of the above listed ships are reported in the table below:

Dimension	**Units**	**Value** [m]
Length	[m]	82.0
Beam	[m]	16.0
Draft	[m]	2.6
Displacement	[t]	1200.0
Design speed	[knots]	40.0

Main design characteristics

The following calculation conditions were utilised for the demonstration:

- 15 headings between 0° (following sea) and 180° (head sea), equispaced of 15°
- 5 speeds, between 15 knots and 35 knots, equispaced of 5 knots
- 2 sea states, long-crested sea, JONSWAP wave spectrum - SS3: Hs = 1.0 m, To = 7.0 s ; SS4: Hs = 2.0 m, To = 8.3 s
- 1 calculation point (Bridge) - Midship, Centre-Line, Main Passenger Deck

For the present demonstration purposes the following quantities were evaluated by means of SOAP package:

- linear transfer functions (in/out-of-phase components) of roll angle / acceleration
- linear transfer functions (in/out-of-phase components) of vertical \ lateral rigid-body accelerations *MSI* for various exposure times, based on the combination of ISO 2631:1985 and O'Hanlon & McCauley (1974) methods
- encounter frequency (in Hz) vertical acceleration spectrum, sampled in one-third octave band.

ISO 263: 1997 Motion Sickness Model

As a reference, MSI has been first evaluated at the calculation point for *2 hours* of exposure using the motion sickness facilities already incorporated in SOAP, that is Lloyds (1988) simplified formula and one-third octave band analysis using both O'Hanlon & McCauley (1974) discomfort boundary and ISO 2631: 1985 discomfort boundary.

We may note that *MSI* is maximum around *120°* (bow-quartering sea), due to pitch resonance with the encounter waves, and that it steadily increases with ship speed. At the highest ship speed (that is *35 knots*), Lloyds (1988) formula predicts a maximum *MSI* value of about *10 %* , ISO 2631: 1985 a value of about *14 %* and O'Hanlon & McCauley (1974) a value of about *11 %* .

As a first step in the application of ISO 2631: 1997 guidelines, motion sickness dose value was evaluated according to the frequency weighting procedure previously illustrated. To check the calculations, *MSDV* was also directly evaluated in time-domain based on the time-series of the vertical acceleration provided by SOAP. The results are fairly similar as it is expected in the case of stationary processes, this is confirmed by the fact that the *rms* and *rmq* values (in units of *g*) of the vertical acceleration are pretty close (maximum values of about *0.06 g*). The maximum *MSDV* value is of about 40 $m \cdot s^{-1.5}$.

The corresponding values of the motion sickness incidence were, based on the frequency-domain approximation. The maximum *MSI* value is of about 14 % in good agreement with ISO 2631: 1985 predictions.

COLWELL'S (1994) Motion Sickness Habituation Model

As for the demonstration of Colwell's (1994) motion sickness habituation model, the most unfavourable conditions of *120°* and *35 knots* for *MSI* in *SS3* were considered.

The habituation model was applied based on the different motion sickness models reviewed in the previous paragraph, that is the ISO 2631: 1997 model and the one-third octave band models using O'Hanlon & McCauley (1974) and ISO 2631: 1985 discomfort boundary.

The results of the calculations are summarised in Fig. 6 below.

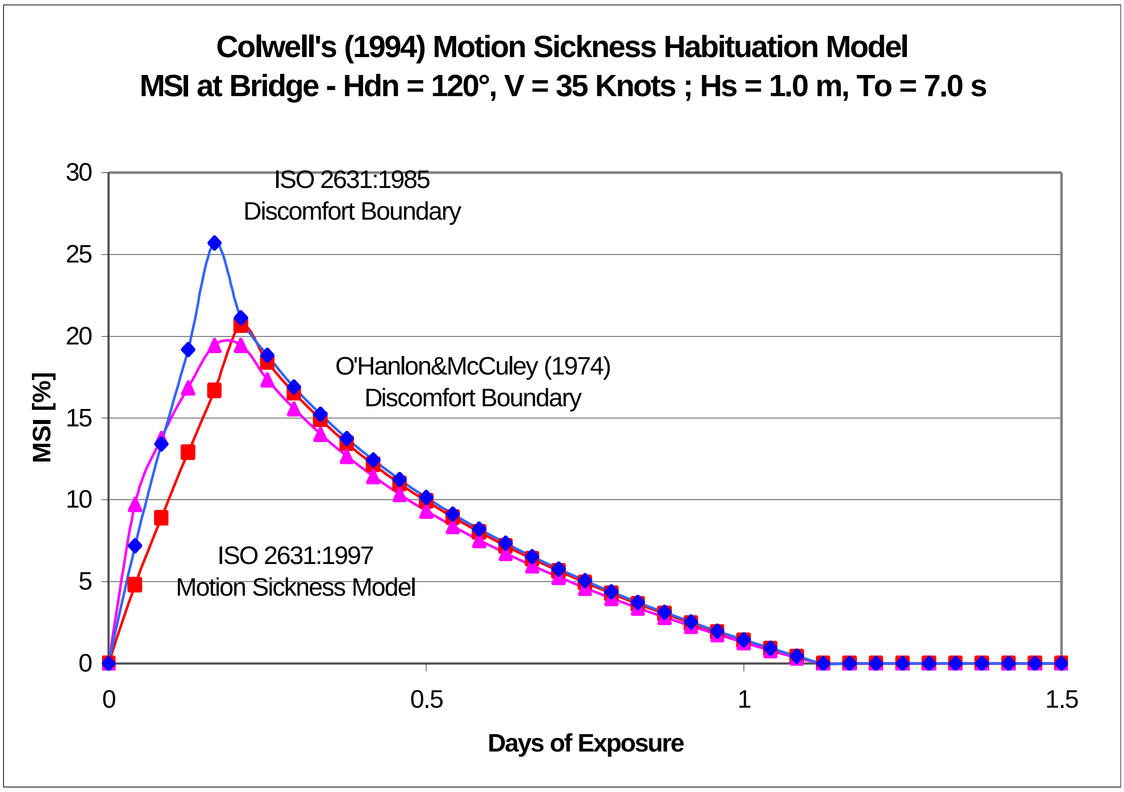


Figure 6: Effects of the use of different Motion Sickness Models on the Habituation Function

It can be seen that the maximum *MSI* value is reached around *4 ~ 5* hours of exposure. ISO 2631 models yield the sharpest rise and ISO 2631: 1985 provides the highest peak value (about *25 %*). The slow-down behaviour, after *5 hours* of exposure time, is pretty similar.

GRAHAM'S (1992) Postural Stability Model

To practically illustrate the feasibility of the integration of Graham's (1992) postural stability model the linear transfer functions of roll angle \ acceleration and of vertical \ lateral rigid-body accelerations (in/out-of-phase components) at the calculation points have been evaluated by manes of SOAP package for *SS4* and processed as previously described. Calculation results could be graphically illustrated, in terms of polar diagrams versus wave heading and the different calculation speeds.

Conclusions

Linear frequency-domain codes (mostly based but not limited to strip-theory assumption) have been identified as the sea-keeping design tools to be addressed for the present task scope of work. A minimal requirement for such tools is:

- ability to evaluate the linear transfer functions (amplitude and phase) of the 6 degrees of freedom, at centre of gravity ship motions, for a number of ship speeds, wave headings and wave frequencies;

- ability to evaluate the linear transfer functions (amplitude and phase) of the ship rigid-body motions / velocity / accelerations, for a number of ship speeds, wave headings and wave frequencies;

- ability to evaluate short-term statistics of the above referred quantities, based on linear spectral theory, for a number of sea states (couples of wave heights and periods).

The SOAP sea-keeping package, developed by the co-ordinator, provides the possibility to evaluate most of sea-keeping performance criteria, such as the occurrence of undesired effects (emergence, submergence, slamming), motion sickness incidence (one-third octave band analysis) and postural stability (effective gravity angle).

The following points highlight the potential for integration as drawn from the results of work with SOAP as a typical sea-keeping design package relating specifically to ISO 2631: 1997 motion sickness model, Colwell's (1994) motion sickness habituation model and Graham's (1992) postural stability model, as human performance models.

- ISO 2631: 1997 motion sickness model is the most critical integration item, as it in principle requires the one-third octave band sampling of the vertical acceleration encounter frequency spectrum. If such an operation is already incorporated into the sea-keeping tool (as it is the case of SOAP but it is not a standard features of sea-keeping codes) then the potential for integration can be considered as high. In this case implementation of ISO 2631: 1997 model only requires a frequency weighting of the sampled acceleration spectrum and it is actually much simpler than the previous ISO 2631: 1985 model, which required iterative adjustment of the discomfort boundaries.

- Integration of Colwell's (1994) motion sickness habituation model presumes to having already available a motion sickness model relating motion sickness incidence to exposure time. Upon this assumption, integration is quite straightforward as only implementation of an iterative scheme for the maximum *MSI* value is required.

- Graham (1992) postural stability model has a high potential for integration, as it was specifically developed for implementation into frequency-domain sea-keeping codes. It only requires a linear combination of the lateral / vertical accelerations and application of standard spectral theory.

2.10 Task 10 - Ship design & management procedures

Objectives

The objective of this task was to incorporate the lessons learned into a comfort-oriented design tool and to establish a list of guidelines for the design and management of ships on the basis of the theoretical investigations and demonstrations / experiments developed during the whole project.

Methodology

On the basis of the theoretical investigations and demonstrations developed during the whole project, links between the ship environment and human behaviour models have been established. The models, independently defined and improved within the activities of Task 9, on the experience of Task 6 to 8, have been combined together to form an organic design tool which can be used to directly obtain the comfort and operability criteria (defined in Task 2) satisfaction of a certain design solution or ship management operational procedure.

Ship design generally starts from a tentative set of main characteristics preliminarily defined by the designer on the basis of previous experience in order to satisfy the mission profile. According to a well-established design practice this is the inception of an iterative process (design loop) which eventually ends with the determination of all the features needed to define the ship.

Such a scheme cannot be easily modelled by a fixed sequential logic coded into a software procedure, this is especially true in case of non repetitive ships which features are in general very specific and thus require each time an "ad hoc" approach to the design. Furthermore most of the execution order and/or priority of the individual design activities critically depends upon subjective decisions and forcing these crucial actions along a pre-set decision-tree could jeopardise the end result.

Due to the practical impossibility to solve all problems related to human factors, Task 10 was mainly focused on the integration of human behaviour models, either crew or passengers, into the ship design procedure in order to obtain a design tool able to take into account adverse effects (such as rough sea state) on the human factor from the preliminary design stage onwards. Task 10 concentrated on the seakeeping module, because this was considered as one of the most important aspects associated with the comfort of crew and passengers onboard ships.

Overview of achieved results/main findings

With respect to the experience gained in previous studies on this subject this kind of integration was developed utilising the operability task of the seakeeping module and incorporating in this task the ship operability limitations due to human factors.

An example of this new approach was applied in a ‘seakeeping module’ developed by the co-ordinator of the project, CETENA in co-operation with Fincantieri Naval Ship Directorate, enabling the designer to consider the human performance in rough sea conditions as a limiting ship operability criteria. The operability module was developed in correspondence with this philosophy and was introduced in a comprehensive preliminary design tool, named PRONAVIN.

The design tool PRONAVIN was developed by the co-ordinator for the design department of FINCANTIERI Naval Ship Directorate. It has been specifically developed to provide ship designer with an open flexible architecture which integrates several calculation modules each devoted to a particular design aspect (e.g. hydrostatics, resistance & propulsion, sea-keeping, general arrangement, weight definition).

The open architecture of PRONAVIN means that each calculation module can be replaced or that a new module can be implemented into the system in a smooth way; on the other hand flexibility means that there is much freedom in the use of the various options / modules. The designer may therefore customise the system either to meet his own present procedures or to cope with innovative design problems which may occurs in the future.

The ‘seakeeping module’ is dealing with monohull ship of any type and dimensions. The module includes two main tasks:

- Ship response to regular waves - Ship Motions Task
- Ship response to irregular waves - Operability Task

The ‘operability task’ allows to manage:

- seakeeping criteria
- extreme values
- time domain calculation

in order to evaluate the operability indexes of the given ship.

The functions of the 'operability task' are the following :

- Initial Calculations
  which produces the XY diagrams of the centre of gravity response operators, as given from the ship motion task, and calculates short-term statistical values.
- Sea-keeping
  which evaluates the different 'Sea-keeping Performance Criteria' (SPC) as chosen by the user and providing the corresponding polar diagrams.
- Operability Envelops
  which creates 'Speed Polar Diagrams' for each criterion and the global 'Sea-keeping Operability Envelops'.
- SOE Operability
  which evaluates ship operability through the SOE method in terms of speed reduction for each sea state.
- PTO Operability
  which evaluates ship operability in terms of reduction of percentage of time operability for all the range of seed of interest and for the most probable sea conditions.
- Extreme Values
  which evaluates the extreme values of different criteria related to the probability of overcoming and generates the bi-longarithms diagram for statistic treatments of extreme values.
- Calculation in Time Domain
  which makes the time domain series of different criteria for each sea state chosen by the user and calculates the related XY diagrams. It is worthy to note that not all calculation options are independent, because some of them require to be operated in sequence as described in the user' manual.

Taking into account that the sea-keeping criteria enable the designer to have a quantitative index of the ship behaviour in rough sea, the operability task allows to manage the following seakeeping criteria :

- added resistance due to sea waves and wind;
- ship motions and accelerations amplitudes both linear (vertical, longitudinal and lateral) and angular (roll, pitch and yaw);
- human factors;
- unwanted effects (propeller emersion, green water, slamming, etc.);
- structural stresses (dynamic way loads, etc.).

The introduction of human factors into seakeeping criteria, oriented to the evaluation of passenger comfort and efficiency of the crew engaged in specific tasks, is in agreement with the results obtained in the previous tasks of this research project.

In detail the following human factors can be considered :

MSI	Motion Sickness Incidence	percentage of sea sick people;
SMM	Subjective Motion Magnitude	perceived motion amplitude
LFE	Lateral Force Estimator	lateral acceleration on the bridge
LON	Longitudinal Force Estimator	longitudinal acceleration on the bridge
EGA	Effective Gravity Angle	heebing angle of a person
MII	Motion Induced Interruptions (port,stbd,aft,fore)	number of lack of equilibrium of a standing person due to lateral or longitudinal motions
SO	Sliding Occurrence (port,stbd)	number of (sliding lateral) of an object on the bridge

In practice, taking into account the ship type and her mission profile, it will be possible to identify a set of seakeeping criteria and to assign to each of them a critical value.

The ship operability, indeed, gives a measure of her capability to be successful in fulfilling her mission in severe environmental conditions, through the comparison between the actual values and the critical values assigned to each criteria.

To this respect two different strategies have been developed which follow two alternative approaches :

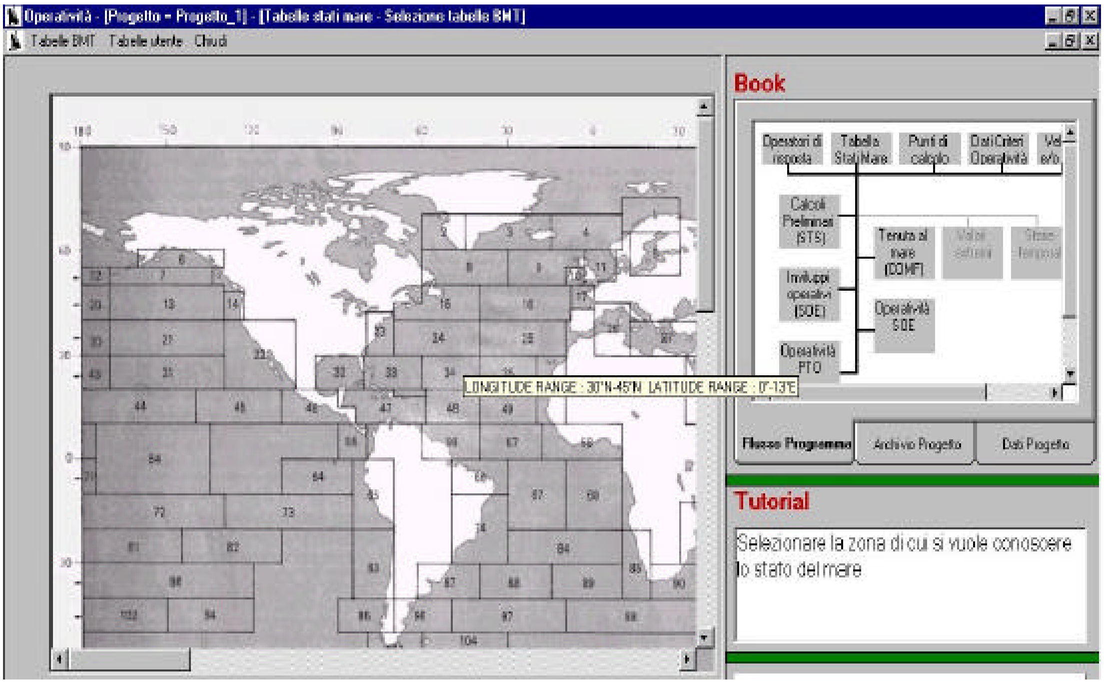
a) Method of operability envelopes (SOE)
For each sea state condition a draft with the envelope of speed/angle of encounter satisfying the chosen limits will be drawn. The ratio between the envelope area and the area given by mission required speed defines the ship operability for the given sea state called Performance Operability in Specific Environment (POSE).

In the wave scouter diagram the mean value of different POSE weighted with respect to the occurrence probability of each sea state, defines the comprehensive ship operability for the given mission, called Mission Effectiveness Index (MEI).

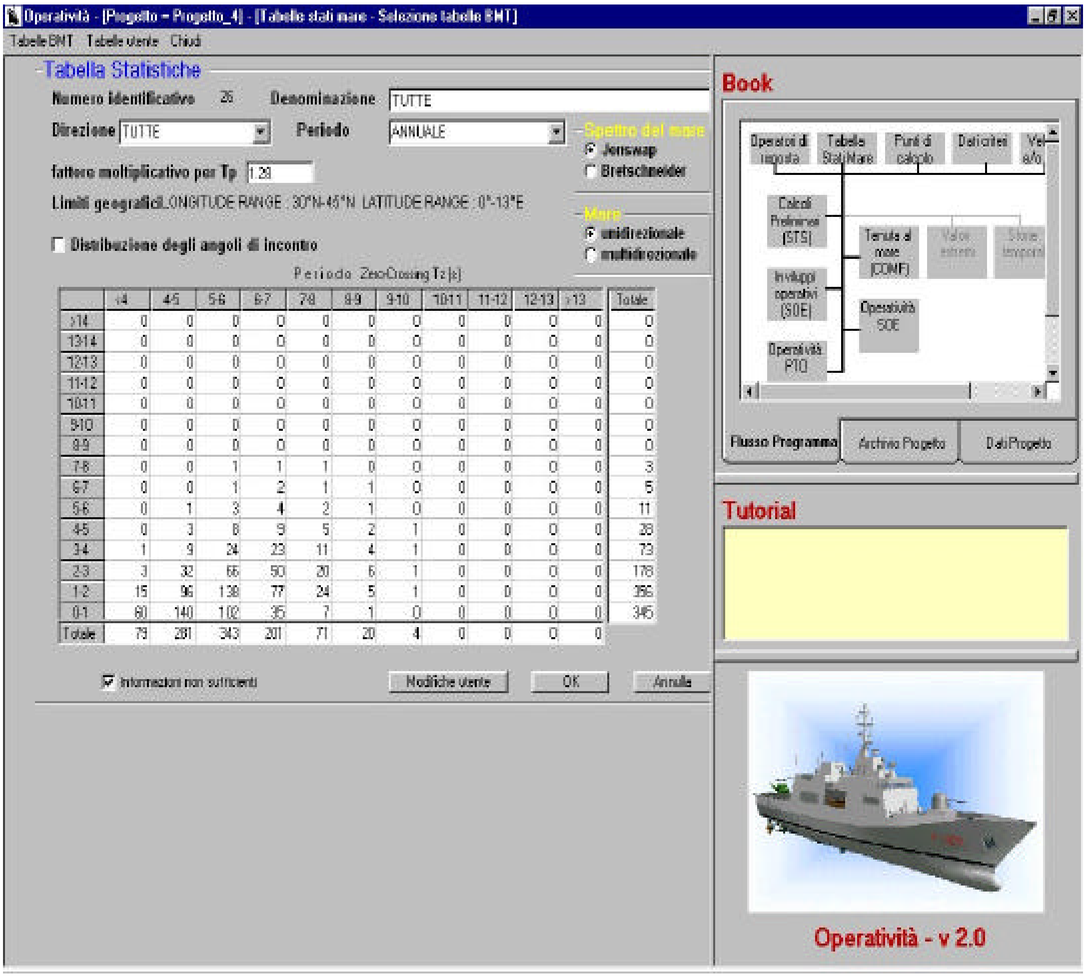
b) Method of Percentage of Operability Time (PTO)
For a given ship speed (f.i. mission speed) this method calculates the percentage of operability time with different encounter angles in terms of the probability of occurrence of each sea state.

> The mean value obtained, taking into account all the encounter angles, enables the designer to evaluate the PTO index for each speed.
>
> The additional weighting procedure over all the speed values considered for the ship mission leads to define the comprehensive PTO index of the ship.

The first method gives an evaluation of the ship operability in a given sea state, in terms of speed reduction related to the mission speed. The other method gives the ship operability for a given speed, in terms of the number of sea states allowed by the assigned criteria.



Selezionare la zona di cui si vuole conoscere lo stato del mare



Numero identificativo 26 **Denominazione** TUTTE

Direzione TUTTE **Periodo** ANNUALE

fattore moltiplicativo per Tp 1.28

Limiti geografici LONGITUDE RANGE : 30°N-45°N LATITUDE RANGE : 0°-13°E

☐ **Distribuzione degli angoli di incontro**

● Jonswap
○ Bretschneider

● unidirezionale
○ multidirezionale

Periodo ZeroCrossing Tz [s]

	<4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	>13	Totale
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13-14	0	0	0	0	0	0	0	0	0	0	0	0
12-13	0	0	0	0	0	0	0	0	0	0	0	0
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9-10	0	0	0	0	0	0	0	0	0	0	0	0
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7-8	0	0	1	1	1	0	0	0	0	0	0	3
6-7	0	0	1	2	1	1	0	0	0	0	0	5
5-6	0	1	3	4	2	1	0	0	0	0	0	11
4-5	0	3	8	9	5	2	1	0	0	0	0	28
3-4	1	9	24	23	11	4	1	0	0	0	0	73
2-3	3	32	66	50	20	6	1	0	0	0	0	178
1-2	15	96	138	77	24	5	1	0	0	0	0	356
0-1	60	140	102	35	7	1	0	0	0	0	0	345
Totale	79	281	343	201	71	20	4	0	0	0	0	

☑ Informazioni non sufficienti

This number is immediately related to time fraction in which the ship is operative with respect to a given period (season, year, etc.). These operability indexes, as said before, enable ship designers to characterize in a synthetic way the ship capability to operate in actual sea state.

Having had the possibility to introduce the human element aspects in this design procedure can be recognised as an important achievement of the REWORD Research Project.

3. FINAL CONCLUSIONS

For the first time it was possible to define a new approach to ship design which takes human factors and the man-ship interface from the first design stage onwards into account.

The project developed and validated mathematical models for the quantitative estimation of human performance on board. It demonstrated the effectiveness of incorporating the developed human performance models in standard procedures for the analysis of measured or calculated wave-induced ship motions. Finally, the project assessed the feasibility to develop an integrated software package able to evaluate the impact of the main design parameters and the possible remedial actions on human performance.

An example of this new approach was applied in a ‘seakeeping module’ developed by the co-ordinator of the project, CETENA in co-operation with Fincantieri Naval Shipbuilding Division, enabling the designer to consider the human performance in rough sea conditions as a limiting ship operability criteria. The operability module was developed in correspondence with this philosophy and was introduced in a comprehensive preliminary design code, named PRONAVIN.

These results showed that the introduction of human factor aspects in the ship design process is viable and technically feasible.