BriteEuram project 97-4229 «MEPdesign» WP4b

Det Norske Veritas AS (DNV) and Institut Français de Navigation (IFN)

**MEP design:**
Evaluation of Pragmatic Value

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1. Abstract

The present report is an evaluation of the pragmatic value of the project MEPdesign: Mustering & Evacuation of Passengers. In addition to evaluation of each work-package, and how well the project delivered as planned, an evaluation of the project irrespectively of the plans is also made. This is what is understood by pragmatic value.

Efforts have been made to distinguish between these two types of evaluation. The project is only formally responsible for carrying out what is planned. However, everyone that are not involved in the project will only be interested in how useful the results are, and are less interested in how well this corresponded to the plan. In research it is well known that some of the most successful projects are successful because more interesting results than initially proposed in the project plans are identified.

The report starts by describing the background for the project, and goes on with a description of the general trend in developing rules for life saving appliances and evacuation, including a description of modernisation of the regulations by use of risk analysis (formal safety assessment).

Thereafter the report reviews the various work packages of the project one by one, including a description of projects with aims similar to MEPdesign. The report ends with listing the main achievements, a final evaluation and a gap list.

2. Background of the project

In emergencies, passengers should assemble at their assembly (mustering) stations. From the assembly stations, the passengers can reach the embarkation stations, and leave the ship in the event that this is necessary. Musterering, embarkation, abandon ship, and survival at sea are critical for successful evacuation.

In order to limit the consequences of the emergency, mustering and evacuation should proceed in a fast and orderly fashion. National and international regulations are increasingly stricter in this respect and, secondly, prescribe norms on total evacuation performance rather than on the performance of isolated parts of the system. In order to document compliance with such performance standards some form of formulas or software is necessary; otherwise real exercises would be required, as is the case with High Speed Crafts. Also in the case of documentation of compliance by real exercises, some other predictive tool is necessary, as no owner would build a ship and run the risk of failing a compliance test.

With the use of software simulation, the behavioural aspects must be included to be realistic. The industry needs new design features as well as new methods to comply with regulations and standards in a cost-effective way. Many computer models that predict mustering and evacuation as a function of time are promising tools, but they fall short of reality because they neglect passenger behaviour, and ignore ship motion completely. Moreover, they can not easily address the effects of new design features, as the effect of new features on human behaviour is not modelled.

The aim of the MEPdesign basic research project was to study the effect of new design features such as “intuitive” systems for guiding the passengers; corridors and stairs that offer improved walkability in a moving or a listed/heeled ship. These effects were assessed under realistic ship-motion and behavioural conditions such as “group binding”. The data is made available in reports but also in the form of improved tools (computer programs) for the prediction of mustering and evacuation. The approach is based on a combination of behavioural and technical expertise. The outcomes of the project have been tested and this
The report is assessing the pragmatic value of the project results. This is carried out by a representative of a classification society and a national maritime institute. The initial promise of the project was: improved safety, improved safety standards, and cost reduction.

Safety is a highly sensitive issue for the maritime world, especially for ships carrying large numbers of passengers. In particular as the potential consequences of ship disasters are increasing as the size of the larger ships are increasing. Giant ships with more than 10,000 person onboard are now on the drawing table. A prognosis that point to this fact may be found in MSC 73/Inf.3 (USA). At MSC 73 (December 2000), a new workgroup dedicated to safety challenges relating to the large passenger ships was established. Whilst the workgroup regard the ship “it’s own best lifeboat”, it is fairly clear that some of the work will relate to life saving appliances and evacuation.

The public and the authorities alike, require safe design and safe operation. Regulations (such as the ones for assembling/mustering and evacuating the passengers) become continuously amended. Therefore, the maritime industry needs to know how to improve safety in a cost-effective way. In particular this will become more relevant as the international regulations are based on Formal Safety Assessment (FSA, MSC/Circ.829&MEPC/Circ.335), which make cost effectiveness important decision criteria.

The new trend in regulations is to specify overall safety performance rather than the safety requirements to isolated components. In consequence, the industry needs tools for the assessment of overall safety performance. These tools should be realistic and, for example, take into account behavioural aspects and moving ships. With decisions made by using these tools, a reduction in the number of casualties in emergencies at sea may be expected.

The MEPdesign project intended to contribute to all these issues by addressing the safety of mustering and evacuating the passengers. The objective is: the scientific test of new design concepts and demonstration of their effects on mustering and evacuation. A secondary objective is: produce prediction tools that are sufficiently realistic. Areas of study include concepts for route-guidance systems, and features of corridors and stairs. Data on the effects of these new design features was collected with due attention to behavioural aspects, e.g. regressive behaviour under stress/panic, under non-stable or moving environmental conditions. The outcomes of the data-collection studies were made available by means of a demonstration tool — a computer program that predicts how passengers muster over time, given a particular design. This way design features can thus be compared.

The new design concepts were expected to find their way to ship designs between 5 to 10 years. For the demonstration tool, the time to the market was expected to be 3 to 5 years. Parts of the outcome of the project were expected to be applicable to areas outside the maritime sector, for example evacuation from aircraft, (underground) railway stations, and (underground) parking garages.

At the start of the project many prediction tools were available for simulation of evacuations. They had names like ASERI, BFires, EMBER, EGRESS, EVACNET, EVACSIM, and EXODUD. At first sight, they suggest a wealth of possible applications. Closer inspection, however, reveals surprising omissions (see also Wood, 1996). Only a few models were developed for ships; the majority was for areas such as the chemical process industry, nuclear power plants, and offshore industry. In consequence, most models ignore the special features of the ship environment and fall thus short of reality. Even more surprising is an omission in “ship” models, namely, that none of the ship-evacuation models takes into account the effects of static heel/list and dynamic ship motion due to sea and swell. Nevertheless, it is very obvious (and has been convincingly demonstrated in experimental study, see Wertheim et al. (1994) that these factors have strong effects on walking speed. Moreover, the more vehement types of ship motion have also indirect effects, on evacuation, because they disorient, cause seasickness, stress, or even panic the passengers. The
consequence of stress can be described as “narrowing of attention” or “regression towards more primitive levels of functioning” which, in turn, means that guidance should be provided in a way that is self-explanatory or intuitively clear. In short, the tools that existed at the time MEPdesign was initiated were simply inadequate and failed to represent the maritime environment. The likely reason for the omissions is research costs. The research costs to provide the necessary databases exceed the potential benefits, at least in the short term.

The previous defined the agenda for MEPdesign and legitimated a multinational project. A first accomplishment of the project was the recommendations for new concepts, based on realistic conditions and human behaviour; that is, ship motion conditions and somewhat regressed passengers. One way to deal with regressed people is to guide them by intuitive information rather than by cognitive information. These new design concepts may make mustering and evacuation faster and more efficient. A second major accomplishment of the project was the development of prediction tools, including effects of ship motion. Designers, builders, and shipowners may to some extent use all accomplishments to assess the safety of existing and new ships, and to explore the safety gains (less casualties) of a new guidance system, of refurbished escape routes, more muster stations, etc. Because effects of ship motion are included, the idea was that designers could also explore the safety gains of better stabilisers and use of a different ballast system. Initially the plan was also to develop tools that could demonstrate that a design satisfactory for a large ship could be unsatisfactory on a smaller ship because of less stability.

Because of the ongoing activities at the IMO relating to agreeing on functional requirements for evacuation simulation and procedures for carrying out simulations at an early stage of design of ships, MEPdesign is not the only ongoing project with the aim of developing HF related information and preparing software. Similar activities are identified in Japan, Australia, Canada, as well as other projects in Europe. Some available information is given at the end of this report. The message is clear: There is likely to be competition amongst various software products. Furthermore, many delegates at IMO question the usefulness of any software.

3. The Current and emerging Regulations for Life Saving Appliances and Evacuation

The activities are ongoing both in the Marine Safety Committee and the Fire Protection subcommittee.

3.1 DOCUMENTS OF REFERENCE :

SOLAS regulation II-2/28-1.3 ; SOLAS 95, resolution 4 ; MSC/Circ.909 4 June 1999 ; MSC 72/12/1 February 2000 ; FP 44/WP2 February 2000, FP 44/WP7 march 2000, MSC 73/21,FP 45/WP.8 .

Besides the SOLAS regulation and resolution (evacuation time 60 minutes on a ro-ro passenger ship), the basis for the present undertaken works is :

1.1 the « Interim Guidelines for a simplified evacuation analysis of ro-ro passenger ships » MSC Circ.909
1.2 the Evacuation analysis for ro-ro passenger ships submitted by Australia to the IMO in February 2000
1.3 the report of the Working Group of the Sub-Committee on Fire Protection «Recommendation on Analysis from the point of view of the evacuation for passenger ships and High Speed Passenger Craft (HSC) »,
1.4 the report of the Sub-Committee on Fire Protection to the Maritime Safety Committee (MSC)
1.5 the Work Programme on large passenger ship safety matters.

### 3.2 MARITIME SAFETY COMMITTEE POLICY

In the end of 1998 the Secretary-General of IMO expressed admiration to the industry for delivering mammoth cruise ships and hope for that the safety aspects in emergencies had been properly studied and satisfactorily resolved. Some time later he suggested that the Sub-Committee on Fire Protection should consider « whether Guidelines on an evacuation analysis for passengers ships, in general with special emphasis on new large cruise ships, needed to be developed ». A Working Group was established at MSC73 to work on Large Passenger Ship Safety. At MSC 73 a Correspondence Group was established under the co-ordination of the United States and instructed to:

1. consider future large passenger ship issues, using a systematic risk-based approach with a view to finalising the preliminary list of concerns identified;
2. further develop the philosophical approach, goals and objectives for dealing with matters relating to future large passenger ships;
3. consider how areas of concern should be analysed taking into consideration tools such as formal safety assessment, human element analysing process, cost/benefit analysis, risk assessment, etc., with a view towards linking these tools to each area of concern. «

Last December 2000, MSC 73 by resolution MSC 97/73 adopted the updated version of the mandatory High-Speed Craft (2000 HSC Code), which entry into force will be 1st July 2002. It will apply to HSC built on or after this date. The changes incorporated in the new Code intend to bring it into line with amendments to SOLAS and recommendations which have been adopted in the past 4 years.

### 3-3 SUB-COMMITTEE ON FIRE PROTECTION ACTIVITIES, FP 45 (January 01)

Since already several years (1999) a Working Group and a Working Group by Correspondence were established by the Sub-Committee on Fire Protection and instructed:

1. To work on the evacuation analysis guidelines for new passengers ships using as a basis MSC/Circ909 and the report of the Correspondence Group chaired by Italy.
2. To finalise work on the draft Guidelines for the evacuation analysis of HSC, and ro-ro passengers ships, taking into account relevant issues which may be raised during the intersessional period, with regards to survival craft on HSC and to prepare a covering draft MSC circular for their dissemination;
3. To further progress the development of the basic guidance on the use of microscopic model, taking into account the contributions of:
   United States with a « Recommended guidance for computer-aided evacuation analysis tools » paper dated 03/11/00 (see United States Project),
   Germany with a « Draft Guidelines for a microscopic evacuation analysis for ro-ro passengers ships and high-speed passenger craft » papers dated 10/10/00 and 15/11/00 (see Germany Project);
4. To further consider the matter of evacuation analysis on existing passenger ships with reference to the full scale data obtained from passenger ships emergencies: 5 cases of passenger musters in real emergencies, submitted by International Council of Cruise Lines (ICCL).
Point 1 Based on previous works (FP 44) and the Australian Project, the new input came from the industry (ICCL) which is considering the Interim Guidelines (Circ 909) as a basis for an evacuation analysis of non ro-ro passenger ships; their belief is « that a holistic or total system approach to passenger ship safety and the vessel evacuation is necessary » and ICCL makes the following comments:
- the group may wish to consider whether a risk-based methodology versus a deterministic approach may have merit. »;
- consider that protection guidelines based on building evacuation for shipboard application should be carefully considered;
- there was considerable confusion and difficulty in attempting to apply the Interim Guidelines to existing ship and it is « obvious that computer application of the guidelines is necessary to achieve meaningful results. »
- several questions are arising regarding the source of some of the factors utilised in the calculations and whether or not these are realistic for shipboard application.

Point 2 The WG brings to the attention a new version of the Draft MSC Circular and the attached « Interim Guidelines for a simplified evacuation analysis of High Speed Passenger Craft » for a new consideration.

Point 3 Basic guidance on the use of microscopic model. Two projects were presented, by the U.S. and Germany, respectively. The work is focusing on formulating the Philosophy, Methodology, Parameters to be used and developed for the validation of the microscopic models. The model should be capable of representing individual persons and relevant human behaviour characteristics, space, and interaction between space, people, and human behaviour.

Point 4: Application of evacuation analysis to existing passenger ships. It has been agreed that Guidelines related to existing passenger ships would be to provide suggestions for improving procedures on board. Nevertheless a plan of action was adopted:
- To ensure that methods for carrying out evacuation analysis of passenger ships are developed and finalised,
- To analyse the 5 actual emergencies reported, to gain additional information for validation and with a view to the possible establishment of a database,
- To take into consideration any measures aimed at avoiding the need for evacuation, based on the principle « the ship is the safest lifeboat »,
- To collect information from the industry with regard to evacuation procedures.

4. Modern Regulatory Framework - General

This chapter describes general trends in the ongoing modernization of safety and environmental protection regulations. The aim is to view the MEPdesign activities in a broader perspective. The status of the use of risk assessment (formal safety assessment) is described next, followed by a chapter on the development of regulations relating to life saving appliances and evacuation.

In general a modern regulatory framework for safety and environmental protection contains the following elements:
- the objectives and the underlying philosophy of the regulations are clearly stated
- high-level principles and policies are formulated
- functional requirements are described
the associated guidelines contain standard solutions to meet these functional requirements, but other alternative means for achieving the same objectives are permitted. These guidelines are not mandatory.

This is illustrated by the triangle in Figure 1.

![Diagram of Modern Regulatory framework]

Figure 1: Modern Regulatory framework

The current regulatory regime for shipping is defined by a set of IMO regulations, classification rules, regional agreements, national requirements and other technical standards. As compared to a modern regime, this regime is to a considerable extent lacking safety objectives and statements of functional requirements. Most of the regulations are prescriptive and to some extent very detailed. The development is based on a very broad experience, a gradual development, re-use of proven solutions and technologies, and only occasional introduction of new equipment and solutions. For conventional ships this type of regulations is cost-effective, easy to use and predictable. In the situations of the introduction of innovative equipment, approval may be obtained by using Regulation 5 of SOLAS, which is stated below.


CHAPTER I GENERAL PROVISIONS
PART A APPLICATION, DEFINITIONS, ETC.
Regulation 5 Equivalents

(a) Where the present Regulations require that a particular fitting, material, appliance or apparatus, or type thereof, shall be fitted or carried in a ship, or that any
particular provision shall be made, the Administration may allow any other fitting, material, appliance or apparatus, or type thereof, to be fitted or carried, or any other provision to be made in that ship, if it is satisfied by trial thereof or otherwise that such fitting, material, appliance or apparatus, or type thereof, or provision, is at least as effective as that required by the present Regulations.

(b) Any Administration which so allows, in substitution, a fitting, material, appliance or apparatus, or type thereof, or provision, shall communicate to the Organization particulars thereof together with a report on any trials made and the Organization shall circulate such particulars to other Contracting Governments for the information of their officers.

Guide:
For certain types of ships IMO has issued own safety codes which are intended to give safety levels equivalent to this Convention for those certain ships. Attention is drawn to:
- Code for dynamically supported craft: Resolution A.373(X).
- Code for offshore supply vessels: Resolution A.469(XII) (OSV Code)
- Code for special purpose ships: Resolution A.534(13) (SPS Code)

Regulation 5 contains a “technical equivalence” concept and does not relate to the objective of the regulations. In periods of rapid technology developments the pace of regulatory developments is too slow to cope with industrial needs. For innovative design, e.g. high-speed craft and next generation cruise ships, it is hardly possible to use this technical equivalence. In such cases, specific safety objectives or functional requirements are needed. Therefore, there is an urgent need for formulating these safety objectives and functional requirements. This would allow for the introduction of a “safety equivalence principle” that may be found in most modern regulations.

This is illustrated in Figure 2.

![Figure 2: Illustration of the difference between “technical equivalency” and “safety equivalency”](image)
In order to develop extensive use of risk assessment in design it is necessary to develop more modern regulations, and an associated safety equivalency principle. This is currently ongoing in relation to the revision of SOLAS Chapter II-2, see FP 43/3/2 and FP 43/3/5.

Regulation 17 of FP/43/3/2, presented in two versions, in paragraph 1.2 introduces a safety equivalence principle. In the current status of the review it appears that the main text of the proposed SOLAS chapter will include a part of the design guidance (Currently drafted in FP 43/3/5). This can be regarded as a step forward in moving from the technical equivalence to the safety equivalence principle. Safety equivalence is referenced in regulation 17, paragraph 1.2.

The design guidance is a fire risk analysis guideline specifying:
- Preliminary hazard identification
- Qualification of the fire risk analysis team
- Specification of involvement of the flag administration
- Description of the system
- Principles for identifying elements for equivalency
- Principle of identifying decision parameters in SOLAS
- Identification of fire scenarios
- Quantitative analysis
- Specification of design fires
- Estimation of consequences of fire scenarios
- Design evaluation and documentation

In the EU FSEA Concerted Action, Metselaar et al. (1999) made the following observation:
- This current version of SOLAS chapter II-2 is still missing the safety objectives and functional requirements (but there is a clear intention of filling these gaps in the final version)
- It is left to the fire risk analysis team to identify the implicit decision parameters
- It is up to the flag state to agree on the decision parameters and corresponding acceptance criteria as proposed by the fire risk analysis team
- The design guidance in the quantitative analysis (section 4) stresses the deterministic part at the expense of the probabilistic part, which is not avoidable in risk assessment. For example: advanced CFD calculation based on the assumption of the reliable operation of an advanced ventilation system that may in fact fail in an emergency
- For a certain regulation seen in isolation, proving equivalence may seem trivial especially when it is related to performance of passive fire protection means. The complication is to understand the intricacy of the inter-relationship between the various regulatory requirements

This procedure opens up for an agreed procedure for accepting innovative design solutions. This is a high demand e.g. in the cruise industry.

5. The Current and emerging Regulations in General – Use of Risk assessment (FSA)

The application of risk assessment techniques is generally well established in most industries, both as a means for the owner/operator to manage own risks and for the regulator to prioritise work on the development of rules and regulations.

Most risk analysis techniques have their origin in the nuclear industry, for which risk analysis became an important tool in the 1960s, and has now developed into a Living Probabilistic Safety Assessment (PSA). The word “Living” refers to the regular updated of the PSA after upgrades, modifications, inspections and maintenance of the plant. The focus is on the probability of releases from nuclear containment.
In the hazardous chemical industry, risk analysis techniques were adopted in the '70s. Within the EU and the European extended economic area, risk analysis was required by the EU Seveso I directive in 1982, which has later been replaced by the Seveso II directive.

In the offshore industry the use of risk analysis has been required since 1986 in Norway, and in the UK since 1992 as a consequence of the Piper Alpha disaster. The risk analysis is carried out on behalf of the owner of the plant, and is to be carefully documented. The document is called a Safety Case in the UK. The Safety Case Report will be approved by the UK Health and Safety Executive. This regulatory regime is usually referred to as a “Safety Case Regime”. In Norway the authorities do not approve such documentation or any safety targets, but they are allowed insight in the safety related decision making process of the individual enterprise, and act on situation which are not acceptable. The regime is usually referred to as “Industrial Self-Regulation”.

On a generic policy level, most OECD countries require risk analysis as basis for regulation, e.g.: According to the US President Executive Order # 12866 on ‘Regulatory Planning and Review’ e.g. the US Coast Guard has to base its rules and regulations on risk analysis and cost benefit evaluation.

It should also be noted that both ISO and CEN have their structural standards based on risk assessment (Structural Reliability Analysis), see Skjong et al.(1996).

In the shipping industry, most of the statutory regulations in the past have been developed as a reaction to major accidents and disasters. In 1992, the UK House of Lords Select Committee on Science and Technology recommended a Safety Case Regime for shipping, similar to that already adopted in the oil and gas industries. It also recommended a move towards performance standards in place of prescriptive rules, and a concentration on the management of safety.

In 1993, during the 62nd session of the IMO MSC, the UK Marine Safety Authority (MSA), now Marine and Coastguard Agency (MCA), proposed a five step risk based approach, in agreement with a standard description of Quantitative Risk Assessment (QRA) which was called Formal Safety Assessment (FSA). In 1996 the IMO established a working group on FSA, and by 1997 a Circular on Interim Guidelines on the Application of FSA to the IMO Rule-making Process (MSC Circ. 829/MEPC Circ. 335) had been developed, which was adopted by the MSC and MEPC that year. Since then, a number of FSA trial applications have been carried out and presented to the IMO. In the process of developing FSA at IMO, the initial ideas of developing a Safety Case has been abandoned.

The main difference between the use of QRA in a safety case regime and QRA as suggested in the IMO FSA Guideline is as follows:

Safety Case:
1. QRA of specific plant in specific environment
2. Reduce risk as far as practical in design
3. Define risk management for operation

Formal Safety Assessment:
1. QRA of generic ship in representative environment
2. Develop rules and regulations for generic ship to reduce risk as far as practical
3. Design according to rules
4. Operate according to regulations, including identifying operational risks (ISM)

It may be noted, that for structures an advanced, explicit and mature theory and procedures for these two ways of regulating safety has been developed in the past and implemented in e.g. ISO standards, CEN/Eurocode standards, see Skjong et al.(1996) for a comprehensive guideline.

A standard presentation of the 5 steps of Formal Safety Assessment as compared to the current process may be found in Table(1).
UK initially proposed that “Formal Safety Assessment” (FSA) should be used to provide a more systematic and proactive basis for the IMO rule-making process. FSA included techniques of safety assessment, such as hazard identification, risk analysis and cost-benefit analysis. In 1997, IMO adopted the Interim FSA Guidelines and has since been evaluating trial applications of the technique.

FSA is described as a 5-step process in Table(1). Formal Safety Assessment (FSA) is a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk and cost/benefit assessments.

FSA can be used as a tool to help in the evaluation of new safety regulations or making a comparison between existing and possibly improved regulations, with a view to achieving a balance between the various technical and operational issues, including the human element, and between safety and costs.

FSA is consistent with the current IMO decision-making process and provides a basis for making decisions in accordance with resolutions A.500(XII) "Objectives of the Organisation in the 1980's", and A.777(18) "Work Methods and Organisation of Work in Committees and their Subsidiary Bodies".

The decision makers at IMO, through FSA, will be able to appreciate the effect of proposed regulatory changes in terms of benefits (e.g. expected reduction of fatalities or of pollution) and related costs incurred for the industry as a whole and for individual parties affected by the decision. FSA should facilitate development of regulatory changes equitable to the various parties thus aiding the achievement of consensus.

These Guidelines are intended to outline the FSA methodology as a tool, which may be applied in the IMO rule-making process. In order that FSA can be consistently applied by different parties, it is important that the process is clearly documented and formally recorded in a uniform and systematic manner. This will ensure that the FSA process is transparent and can be understood by all parties irrespective of their experience in the application of risk assessment and related techniques.

In the interim period, these Guidelines provide the basis for interested parties to perform trial applications aimed at demonstrating the potential of FSA within the IMO rule-making process.

The FSA methodology can be applied:
- by an individual Administration or an organisation having a consultative status with IMO when proposing amendments to safety and pollution prevention and response-related IMO instruments in order to analyse the implications of such proposals, or

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**Table(1) Formal Safety Assessment and Tradition**

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<thead>
<tr>
<th>Steps</th>
<th>Layman terminology</th>
<th>Professional terminology</th>
<th>Traditional</th>
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<tbody>
<tr>
<td>Step 1</td>
<td>What can go wrong?</td>
<td>Hazard identification</td>
<td>What went wrong?</td>
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<tr>
<td>Step 2a</td>
<td>How often or how likely?</td>
<td>Probability estimation</td>
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<tr>
<td>Step 2b</td>
<td>How bad?</td>
<td>Consequence estimation</td>
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<tr>
<td>Step 2c</td>
<td>Risk = Probability x Consequence</td>
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<tr>
<td>Step 3</td>
<td>Can matters be improved?</td>
<td>Identify Risk Control Options</td>
<td>How can we fix this?</td>
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<td>Step 4</td>
<td>What would it cost and how much better would it be?</td>
<td>Cost Benefit Assessment</td>
<td></td>
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<tr>
<td>Step 5</td>
<td>What action should be taken?</td>
<td>Decision</td>
<td>Decision</td>
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by the Committee, or an instructed subsidiary body, to review the overall framework of safety and environmental regulations, for instance for a particular ship type or hazard, aiming at identifying priorities or areas of concern of the current regulations.

It is not intended that FSA should be applied in all circumstances, but its application would be particularly relevant to proposals which may have far-reaching implications in terms of either costs (to society or the maritime industry), or the legislative and administrative burdens which may result. In these circumstances, FSA will enable the benefits of proposed changes to be properly established, so as to give Member Governments a clearer perception of the scope of the proposals and an improved basis on which to take decisions.

Further details about the status and development of FSA is described in Annex.

6. Evaluation of Project Results

This chapter contains the evaluation. This is first done for each work-package (Chapter 6.1), followed by a chapter on projects with aims similar to MEPdesign (Chapter 6.2). This is followed by an overall evaluation (Chapter 6.3) and finally a gap list (Chapter 6.4).

In evaluating the pragmatic value of MEPdesign, it is noted that there are many potential users of the results of the project. Relating to the software the main ones are:

**Designer:** The user could be a designer involved in the dimensioning escapeways, public spaces, and selection/dimensioning of life saving appliances. For the designer it is important that all information is integrated in a tool that integrates well with other tools he is using, and that the results of analysis and reanalysis are produced fast and timely.

**Researcher:** The researcher may be interested in testing new hypothesis, including new knowledge into the models developed etc. This would particularly relate to HF research. For the researcher it is not very important that the results are delivered fast.

**Regulator:** The regulator may be interested in running the software on a number of generic cases with the purpose of deriving design rules that may be generally used as requirements. The analysis may typically be carried out as a Formal Safety Assessment. In this type of applications the integration with other tools is not important, computation time may be somewhat important, but not as important as for the designer. The risk assessment (for fire, collision, contact, grounding, foundering etc.) will define the likelihood for each scenario, and the evacuation software will be used to establish the number of fatalities and injuries in each scenario. The analysis is carried out with and without Risk Control Options implemented in order to quantify the risk reduction achieved. A decision on implementing the Risk Control Option may be made based on the risk reduction achieved and the cost of the Risk Control Option.

**Trainer:** The information may be used to provide insight to the evacuation process for crews that have duties during the evacuation. Illustrations are generally important in explaining critical factors for successful evacuation. Crowd management is a topic where more training may be required.

**Accident investigations:** Project results could be used after accidents to understand, explain, or simulate what happened, or could have happened, in the accident.
6.1 Assessment of Results from Each Work Package

This chapter reviews the work-packages one by one. The evaluation is based on the status of the project as reported by March 1st 2001. The objectives, background and activity description closely follows the project plan. This is followed by a formal comparison between the project plan and the progress made. The pragmatic value is described under the section “potential users”. The same format is used for all work-packages.

WORK PACKAGE 1a, GUIDANCE

OBJECTIVE: To provide a specification for new maritime guidance systems
BACKGROUND: Current guidance systems are static. For example, they may point to the nearest exit or muster station even if the exit or muster station is on fire. An evaluation is required whether it is feasible to have guidance systems that allow for a guidance direction that depends on the actual emergency.
ACTIVITIES: The first step was the evaluation of guidance systems used outside the maritime domain (buildings, other transport modes). A second step was recommendations for remotely controlled guidance systems enabling different route direction. The last step was recommendation of at least two new guidance systems for further testing.
DELIVERABLE: A report on Guidance systems - Preliminary recommendations. The report compares at least two new systems with the existing situation. This deliverable is listed as R1.
EVALUATION: The WP 1a deliverables are according to the specification. The review of existing systems in other industries is interesting and comprehensive. The review onboard a ferry is interesting and the documentation is very good as illustration of a typical situation, and the problems that may arise with the current systems. The document demonstrates that simple improvement may be easily done, at almost no cost. To have a thorough review of the wayfinding systems for ships seems to be a good investment for most owners, and this should not be limited to verification that the system satisfies the regulations.
PROGRESS MADE WITH MEPdesign: The progress made in MEPdesign is reported in R1. The WP is mainly a review of wayfinding systems onboard a specific ship and a review of literature. Two systems are suggested for testing see WP2a. The evaluation is discussed under WP2a.
COMPLIANCE WITH OBJECTIVES: All objectives are met.
POTENTIAL USE: An extract of the report should be published in relevant forums, as the results serve as a demonstration of how easy it is to improve current systems with due consideration of HF competence. The users are primarily designers and ship owners.

WORK PACKAGE 1b, DESIGN FEATURES

OBJECTIVE: To propose innovative concepts for stairs and corridors, which will improve mustering on a listed and moving ship.
BACKGROUND: The idea was to provide the passengers with improved walking surface.
ACTIVITIES: A number of innovative concepts were proposed and assessed including introduction of a bevelled edge between decks and bulkheads. The work was broken down into two activities: (1) recommendations for the design of corridors and (2) recommendations for the design of stairs.
DELIVERABLE: The deliverable with the preliminary recommendations is R2
EVALUATION:
PROGRESS MADE WITH MEPdesign: The progress made in MEPdesign is reported in R2. The report reviews current regulations and quotes relevant portions of SOLAS. The report goes on with quoting from the Estonia Investigation (1997) and some relevant aspects for the design of the ship interior. A survivor is also interviewed. This interview add little information to what is known from the reports, but serves as detailing some of the experience. The report also sums up experiences from the Scandinavian Star inquiry and have carried out brainstorming sessions with experience seafarers on how ship design could improve evacuation success. There is generally good correspondence between the various proposals for improvements between the different sources. The description is, however, rather anecdotal, and although a large number of improvements for general ship layout, stair, corridors, cabins, halls and public spaces are made, no clear conclusion may be drawn from the study. However, as planned two concrete proposals are made and suggested for testing in WP 2a. The two proposals are
- A moving light. The movement is generated by arrays of light emitting diodes that are turned on/of in sequences that generates an apparent motion
- Photoluminescent strips with arrowheads

The project planned to disregard costs relating to the proposed improvements. With the benefits of hindsight, it may be realised that this is not a particularly useful approach, as this approach will not allow for the possibility of judging which improvements should be recommended, except when there is no or almost no cost involved. All designers know possible improvements and have a large number of proposals for such improvements in all newbuilding projects. The problem is usually that the benefits does not defend the increased costs (or the benefit and cost are too uncertain). In making regulatory implementation of proposed improvements, this will also have to be made based on the cost effectiveness of the improvements if the IMO FSA Guidelines are adhered to.

To arrive at recommendation it is not sufficient to point to improvements in specific accident scenarios. It is necessary to define all scenarios and their probabilities of occurrences. Than the effect of the improvements needs to be quantified, as well as the costs. Any recommendation needs to strike a balance between these two aspects.

COMPLIANCE WITH OBJECTIVES: There is full compliance between the project goals and the deliverables. However, there is no quantification of effects of proposed improvements that may be used to quantify the contribution to the project objectives of 20% improvement in evacuation effectiveness.

POTENTIAL USE: As no well-documented improvement is suggested there is no obvious potential users. However, the results may be used as input in a later more focused research project, or as input to step 3 of an FSA project: “Identification of risk control options”.

WORK PACKAGE 1c, SHIP MOTION

OBJECTIVE: To produce the ship-motion scenario of a typical passenger ferry in listed (damaged) conditions in different types of weather.

BACKGROUND: To give the project MEPdesign a proper idea of the types of ship motion during an evacuation.

ACTIVITIES: A time series was produced for surge, sway, heave, roll, pitch, and yaw. The time series was extracted from model tests and recordings of motions of damaged ferries in different sea states and from numerical calculations of motion patterns (based on strip theory).

DELIVERABLE: Report Ship motion time series

EVALUATION:
PROGRESS MADE WITH MEPdesign: The progress made in MEPdesign is reported in R3. The analysis is standard, and was not meant to be innovative.

COMPLIANCE WITH OBJECTIVES: All objectives are met.

POTENTIAL USE: This was an analysis prepared as a common basis for other work packages. There are no potential users, except maybe for other research project needing a case to study where relevant ship motion is input.

WORK PACKAGE 2a, GUIDANCE

OBJECTIVE: To determine the Effectiveness of Guidance Systems from the accommodation area and public spaces to the assembly station of passenger ships for an improved evacuation process of passengers and crew and to provide recommendations for ship design and computer modelling of the "prediction" phase of the project.

BACKGROUND: The strategy was to see how real people are guided in a mock-up of a ship’s interior. Guidance starts at the individual who interprets the guidance system correctly or erroneously. Error correction was assumed to be likely if the majority of the surrounding passengers interpret the guidance correctly.

Therefore,

- the efficacy of guidance systems was determined
- the persuasive power of these guidance systems was determined. Moreover,
- the efficacy of guidance systems was determined for groups with 4-6 people.

Under conditions of a listed ship, passengers associate the high side of the ship with safety. Hence,

- the efficacy of guidance systems was determined under listed/heeled conditions.

ACTIVITIES. A ship’s interior of 10 x 10 m (actual 10.65 x 7 m) was built in the form of a symmetric maze. The mock-up was equipped with a number of wayfinding systems: two new guidance systems as proposed in WP 1b and, for purposes of comparison, a traditional guidance system. The systems were a low location lighting (LLL) photoluminescent strips and light-emitting diodes (LED). Systems were used one at the time. The mock-up was equipped as realistic as possible; for example, there were advertisements on the walls and engine sound. A listed mock-up was also built with at an angle of 15 degrees. Two routes X,Y respectively 16.2 and 19.2m long.

Behavioural experiments were used to determine the effectiveness of a guidance system (poorly, reasonably, or perfect). The procedure was as follows. Participants were told that the aim was to study ship evacuation. The task was described as: find the muster station if the alarm is sounded. The task was described as: find the muster station if the alarm is sounded. Participants were told to act as if it was real; the situation was urgent and they should walk quickly. After these instructions, participants were brought over blindfolded to the starting point: a chair in a resting area. The blindfold was taken off, and the alarm was sounded shortly thereafter. Time needed was recorded and hesitations were recorded by video cameras. Afterwards, the participants were asked how sure they were that the direction they took was right.

The population in the first study was 220 participants recruited to be representative of "ferry passengers". The second study used 72 new participants.

DELIVERABLES: (a) report describing method and results of the different guidance systems, (b) database with three dimensions: guidance system (3) and ship list (2). This is all included in report R4.

EVALUATION:
PROGRESS MADE WITH MEPdesign: The progress made in MEPdesign is reported in R4. This WP intended to observe at a reduced scale the first phase of an evacuation process starting from a cabin area to a ‘sub-assembly’ station distant of less than 20 m. Nevertheless the research remains of significant interest, providing answer to a number of unsolved problems.

In particular the research highlights:
- the necessity to inform the passenger from the inside of the cabin on the way to assembly station
- the enhanced performances of groups of people in comparison with those of individuals, except for time performance
- the difficulties to design a convenient guidance system by means of panels and lighting devices
- bottlenecks which may occur when leaving cabins, passing through doors and in the vicinity of corners
- same walking speed when ship in horizontal or listed position
- the strong need for strict and clear evacuation procedures

The progress made corresponds well to the initial plan. To carry out this type of experiments, with real people in a realistic environment is quite new to shipping, where all sorts of human factor related information is scarce. The only area where shipping has previous experience with simulations with real people relates to navigation, bridge layout and bridge resource management.

The concrete proposal of a moving light did not turn out as a solution that should be recommended. This is a useful result, as this proposal has been made a large number of times over a large number of years. We now know, that this is not such a good idea because of the limited effect. In addition there are unfavourable cost and maintenance aspects. However, the results should not be stated too conclusive, as later improvement of such systems (e.g. more densely packed arrays of LEDs) may prove effective.

The other concrete proposal of photoluminescent strips with arrowheads turned out to reduce way finding errors and increase speed significantly. With the good results and the minimum costs of these systems, they turn out to be highly recommendable. However, the new strontium-zinc materials are probably necessary, and the lifetime of these systems needs to be documented before implementation. It should also be noted that the tests showed that wayfinding errors still would exist after such a system was implemented.

Concrete improvements that could easily be implemented were also proposed. These improvements relates to:
- A sign on the inside of cabins
- Portholes in doors
- Floor markings
- Marking of doorknobs
- Turning down the lights to improve visibility of signs in darkness

The tests also gave a large number of other useful results relating to
- walking speed in groups and by individuals in level and listed environment in dark and daylight (more of this in WP 2b)
- Way finding errors in groups and by individuals (doors, T/L corridors)

COMPLIANCE WITH OBJECTIVES: The project results fully comply with the specifications. A strict comparison between the specification and the project results indicate that the results are better and contain more useful information than expected.

The research was conducted on a sound scientific basis with due consideration of human behaviour aspects.
POTENTIAL USE: The results are clearly useful for designers. It is also relevant to consider some of the proposals implemented in regulations (SOLAS). The best place to do this is probably in the ongoing work with large passenger ships, where a work group was established at IMO/MSC 73 (December 2000), but reports could also be prepared for the Fire Protection Committee, a MSC Subcommittee.

Further, there are a number of useful results that could be used in software for simulation of the assembling process.

The WP demonstrated that the described tests are adequate tools for comparison of systems performances. However, one might expect that in a near future, additional observations on board real ships would allow to confirm the validity of data coming from the research.

WORK PACKAGE 2b DESIGN FEATURES

OBJECTIVE: To determine the walking speed of individuals and groups of people on the way to the ‘assembly station’ in the unstable environment of a moving vessel (listed static ship; rolling and pitching dynamic ship), such as a roro passengers ferry ship and to provide input data for a computer-based assembly model.

BACKGROUND: The strategy was to find out how a group of people performs in a moving ship. Also, the relationship between group performance and capability of the individual group member was studied. The prospect was to find general relationships and, hence, to predict group performance on the basis of individual capability and ship motion. Ship motion effects are categorised as stable, somewhat moving, and moderately moving (within the range of TNO’s ship motion simulator). To these categories, the ship list to one side (5, 10, 15 degrees) was imitated and a normal environment is added (in imitation of a level ship). This created 12 categories.

ACTIVITIES: A first step was to rig a "ship's interior" to TNO's ship motion simulator (SMS) and to install recording equipment. Then, participants were invited. Their task was to go around a number of times in a rectangle with and without a limited staircase. Participants did this while the ship motion simulator moved and listed to one side. Time was recorded. Separate ship motion simulator runs were used for the different conditions. Normal walking speed for the individual participants was established on the ground.

In total 20 subjects from 4 age categories (10-20, 20-40, 40-60, and 60-80) participated as individuals or groups (4 people). The tests were performed in the ship motion simulator (SMS), 4,8x2,2m., pitching : 40°, rolling : 30°, frequency : 0-0,83r/s for the simulation of corridors and corners, open spaces, stairs and doors.

Due to the characteristic of the reference ship and that one of the SMS and mock-ups, simplifications were adopted as a first order approach. Interaction between pitch and roll motions, vertical motion and horizontal linear acceleration were neglected.

DELIVERABLES: (a) report describing method and results of the different motion categories, (b) a database containing the net propagation speed in a crowd under various degrees of motion; and (c) a method for estimating crowd walking speed given ship motion and normal walking speed of the group members. This is included in R5.

EVALUATION

PROGRESS MADE WITH MEPdesign: The progress made in MEPdesign is reported in R5. The progress relates to the details of behaviour data relating to:

- Walking speed in corridors, open spaces, rounding corners, climbing and descending stair, for level ship, listed ship, pitching and rolling ship, as a function of age, in groups or individually.

The data were recorded mainly to be input to software simulations of individual behaviour. This is the main reason for the detailed studies. This is quite new. This type of data has, to our
knowledge not been recorded earlier. Again, in shipping, it is quite unusual to produce such
data although software simulation has already been suggested in regulations, currently
according to a simplified procedure described in MSC Circ.909.
The following general remarks are relating to the conditions under which the experiences
have been performed.

1. Ship motion profiles based on sinusoidal representations of roll and pitch at various
frequencies were preferred to those provided by DMI. The latter would not have allowed
covering rolling periods other than those of the experimental ship "Kronprins Frederik".
2. Pitching measures with wide angle have no practical application.
3. The duration of the experiences in particular those adopted when using the SMS had to be
somewhat limited to take account of physiological constraints such as motion sickness or
fatigue and also for safety reasons
4. The fact that both the mock-ups and the SMS are closed spaces has imposed to subjects
different constraints from the reality. On board a vessel the perspective is in general far
less limited than in the experimental conditions. This might also have led to negative
effects on the subject’s performances.

As a consequence, it was observed that subjects had not yet reached maximum walking
velocity when passing the first sensor and that they started to decelerate before passing the
last sensor.

Therefore the walking speeds as measured may be seen as conservative.

There are two sets of results:
The first one concerns the ship listing study with 4 tables presenting data on the walking
speed in corridors, corners, stairs and doors as a function of the following variables:
- age of the subjects,
- list of the ship
- and specifics factors.
The second one result of the study is a set of 6 diagrams and one table representing the
walking speeds as a function of the following variables:
- age of the subjects
- frequencies and amplitudes of pitch and roll angles.

COMPLIANCE WITH OBJECTIVES: The design features suggested in WP 1b, has not been
tested as planned, for reasons given in R5, page 3 and explained above. The data collection,
with the main purpose of providing input to the software simulation meet the requirements.
POTENTIAL USE: The data will be in high demand if software simulation based on
individual behaviour will be the general approach. It is currently not obvious that this will
happen, as simplified methods may be better suited. Much of the data are also directly useful
to assess effects of ship movement, and if the knowledge was put into suitable formats it may
be expected that the data could be used directly by designers. The usefulness of the data is
therefore large, irrespectively of the actual implementation.

WORK PACKAGE 2c, INDIVIDUAL INTERESTS/GROUP BINDING

OBJECTIVE: To determine realistic composition of passengers in terms of groups.
BACKGROUND: The strategy was to determine empirically the proportion of passengers
travelling in groups and composition and the size of the groups. This is important for
estimating mustering times because a group will tend to unite prior to going to the muster
stations and, once united, will travel at the pace of the slowest member.
ACTIVITIES: The work-package started with scanning through potential sources of group
data such as ticket sales/group bookings. This was followed by an empirical investigation
aboard ships. The method was to question passengers during a number of real ferry trips. It was assumed that groups would spread during some segments of the voyage; for example, during the transit and when no meals were served. In consequence, time of the day, time since departure, voyage time remaining, and month of the year (seasonal effects) were recorded along with the results of a structured interview. A list of preliminary interview questions was "do you travel alone"; if no, "where are/is the other member(s) of your group", where would you go if you now had to find them, etc. The questionnaire was be used again in a later work package, WP4a, when the exercise was carried out. The input of this work-package should be implemented in the prediction tools. One risk of this work package was assumed to be unrealistic data because what people say in an interview does not necessarily agree with what they do in an actual emergency. It was assumed that the exercise offers an opportunity to validate the interview data. Interviews were therefore also carried out during that trip.

DELIVERABLES: Report on passenger composition for a Baltic day-ferry project.

EVALUATION

PROGRESS MADE WITH MEPdesign: The progress made in MEPdesign is reported in R6. The results for the population of passengers are very detailed.

COMPLIANCE WITH OBJECTIVES: To the knowledge of the reviewers, in the present state of the research, the data collected from the experiments are the best that are currently available. The report on WP 2b - Design features – fully comply with the project objectives.

POTENTIAL USE: The results for the population of passengers are very detailed. Later use of the data is probably unrealistic, as it may be expected that this information is quite route-specific. However, the study demonstrates that some such information is generally available through ticked sales. To collect such information without easy access to such data is unrealistic for future studies, as this would be too costly.

WORK PACKAGE 2d, EVACUATION

OBJECTIVE: To develop a database on effectiveness of evacuation systems.

BACKGROUND: Evacuation systems are designed and tested for calm weather and on ships in level (upright/intact) condition. There is insufficient knowledge about the effectiveness and the risks of these systems in rough weather and under damaged ship conditions. The objective was to create a database with information on the effectiveness of three different evacuation systems in waves and with a damaged (listed) ship.
ACTIVITIES: The first step of the work package was to specify the different evacuation systems. This specification was made on the basis of state-of-the-art knowledge and discussion with manufacturers and maritime administrations. The second step was to manufacture small-scale models of three evacuation systems: 1) conventional lifeboat, 2) liferaft/slide and 3) free-fall system (the proposed scale was 1:30, but the actual scale was 1:40). The lifeboat model included a davit system the height and reach of which could be varied. The lifeboat and free-fall models were instrumented with accelerometers and inclinometers. The liferaft/slide model had elastic rafts and slides of different length. During the tests it was possible to modify the details of the evacuation systems to improve their efficacy.

Included was the construction a mid-ship section of the mother-ship (planned scale 1:30, actual 1:40) from which the life-saving equipment was launched. The mother-ship was manufactured such that both intact and damaged conditions (listed with increased damping) could be implemented. These models were tested in the wave basin at KTH (60 x 3 x 1.3 m). The mother-ship was moored (soft moorings) in beam seas at zero speed in the basin; the evacuation system was launched from this platform. The same set of wave and list conditions was created for all three evacuation systems. For the lifeboat system, the amount of slamming against the mother-ship and the waves was recorded and ratings for damage and passenger discomfort were derived from the data of the accelerometers and inclinometers. According to the plan for the liferaft system, the motions of the raft were recorded with a video camera with special attention for the critical events of buckling of the slide and steep slide angle. During the project this was done for all systems. For the free-fall system, estimates for damage and passenger discomfort were derived as described above.

Data from the model tests were recorded in a database. Launching discomfort ratings were categorised as high, moderate or low. The last step, according to the plan, was to use mathematical modelling to extrapolate the data base. Extrapolated data should be earmarked as extrapolated.

DELIVERABLES:
(a) Report describing evacuation systems, models, suggestions for further improvement, testing procedures, and extrapolation of results,
(b) A database for three different systems under various environmental and damaged conditions.

Both deliverables were in agreement with the plans, as R7 and R8.

EVALUATION:
PROGRESS MADE WITH MEPdesign: The progress made in MEPdesign is reported in reports R7&R8. The project also resulted in a Licentiate Thesis, T1, and a paper P2.

The R8 report relates to the conventional davit launched lifeboat system. The report has demonstrated interesting results from small-scale tests. Previous research in this area has relied more on full scale test and mathematical modelling. By using smaller test specimens the costs are reduced and the number of tests (parameter variations) is increased. The research into life saving appliances usually also rely on performance in emergencies, as may be reported in accident investigation reports and to some degree on results from evacuation drills. For passenger ships drills involving passengers and lifeboats are generally considered too risky, and are not carried out. Also in the future the progress in this type of research is likely to rely on all four elements. Full scale, small scale, accident investigations and mathematical modelling. The report R8
contains a large number of conclusions (Page 49 and 50), which may deserve to be brought to the attention of the relevant decision maker (e.g. IMO/MSC):

- The tested davit launched lifeboats fulfil their purpose only in gentle weather conditions. (Note that in most emergencies the ship is damaged and the weather poor, except in fire scenarios when the weather tend to be normal/calm.)
- Lowering speed is critical. (This recommendation probably belongs in a training package for the persons with the duty to lower lifeboats.)
- Short release time. (May be implemented by a manufacturer by improving release mechanisms, but also relates to training.)
- Increase davit arm. (Could be a requirement in SOLAS)
- Proper seating and seat belts (Could be a requirement in SOLAS)
- Avoid obstructions (Could be a requirement in SOLAS.)

However, as compared to modern risk based approaches to safety regulations (MSC Circ. 829), none of these conclusions are properly documented. Their status is as proposed risk control options.

The first part of R7 relates to the small-scale tests of slide evacuation systems (marine evacuation systems). Tests on the small scale (1:40) have not, to our knowledge, been carried out earlier. The video recordings of the tests are extremely good in illustrating the phenomenological aspects of marine evacuation systems, and the difficulties in designing an effective and safe evacuation system. The dynamic effects of the excitation forces (the waves and the rolling ship), the “mass” represented by the number of people in the raft and platform (and the water), and the “stiffness” represented by the internal pressure in the slide, is very well illustrated. In particular the recordings make it clear that a marine evacuation system that are optimised for one set of parameters may behave poorly for other set of parameters (wave height, wave period, ship response, internal pressure in slide, length of slide). Due to this observations one generic improvement in the slide system was suggested: There should be a hinge in the slide. This would improve performance and e.g. avoid that the platform is pushed under water in some condition or passenger is launched into the air. The most important conclusions relates to:

- The marine evacuation systems are not very safe or effective except in good weather
- Current marine evacuation systems optimised for effectiveness and safety in one condition are unsafe an ineffective under other conditions
- The slide should have a hinge
- Slide length is an important parameter
- The number of liferafts should be increased, with fewer people in each

R7 also report on tests from an improvement of the lifeboat design based on the observations from the test of the conventional davit launched lifeboats (Partially Enclosed Lifeboats (PELs)). By improving the shape (increasing the deadrise angle) and allowing for increased lowering speed or falling the last few meters it is demonstrated that the risk in lifeboat evacuations may be reduced. It is concluded in the report that this new concept would need further tests before final recommendations may be made.

COMPLIANCE WITH OBJECTIVES: Generally all objectives of the project have been met. The tasks have been carried out according to plans, and largely on time. There is one clear deviation between the specification and the actual tests, as the scale has been set to 1:40 instead of the specified 1:30. Although, scepticism to too small scale tests are widespread, in particular related to measured accelerations (due to the
damping uncertainty), the reports seem to document that the tests are sufficiently accurate. Another deviation is the lack of mathematical modelling to extrapolate the database to more generic cases as compared to the specific parameters used in the database. Simplified presentations of the main results are only done for the marine evacuation systems (e.g. figure 20 of R7).

POTENTIAL USE: The main idea with this task as described in the project plan has been to provide input to the software development. This has not proven particularly useful, as the benefits of the software are only marginal. Rather, this work has been very useful in its own, and may be justified by its own merits.

The tests have provided very useful illustrations of the risks and efficiency of evacuation systems. The video recordings are the best available illustrations of many effects that cause risks in evacuation. The presentations at conferences and technical forums where evacuation methods have been debated have been very useful. The development of some training material based on this material should be considered. Many of the effects illustrated relates to decisions made by the crew in an emergency, e.g. lowering speed, phase angle of wave when lowering is initiated, launching side, etc. The videos could therefore be used in crew training.

The project results are useful in a risk assessment or Formal Safety Assessment. However, such an FSA would have to be very detailed to enable integration of the project results into the FSA. The reason is that the project produces risk figures for a specific ship, with a specific layout and davit system, a specific lowering time (phased with the waves). A specific lowering speed, a specific wave environment (H_s, T_z). Further, intact and damaged conditions are considered. Than the risk figures are produced varying the specific parameters. This generates a lot of data that in an FSA must be integrated over the probability of having to evacuate the ship (and other ships) under these specific conditions, including a variety of damaged conditions where evacuation is necessary. This would eventually produce a risk estimate that could be compared with real success rates in evacuation. This would be a big task, but clearly achievable, in particular as some effects are not as important as others are, and simplifications are possible. However, in such an endeavour there would still be data missing. The risk of loss of life and injuries to personnel is associated with all phases of the abandon ship process: releasing the lifeboat, turning the lifeboat from stowed position to embarkation position, boarding, lowering, water entry, disconnection and sail away phase. Risk in all phases depends on environmental parameters, details of design, operational procedures and crew training. Except environmental conditions these parameters are not covered in the study, and only risk estimation for the lowering and water entry phase is covered.

**WORK PACKAGE 3a, ASSEMBLY MODEL**

OBJECTIVE: To develop a computer-based assembly model

BACKGROUND: The assembly model (or mustering model) predicts mustering time by integrating all factors into a computer model. General factors were the number and location of passengers, the width of the escape routes, and the number and location of muster stations. Specific factors investigated during Phase 2 were group binding, the guidance system, the ship motion and/or ship list, and new design features. Some factors are fixed for a particular ferry: width of escape route, location of muster stations, guidance system, design features. Other factors are fixed for a
particular voyage: number of passengers, group binding, ship motion and ship list. The importance of most factors depends on other factors. For example, a good walking speed is a great help if the escape route is not congested at all; but a good walking speed does not help if the escape route is blocked. This way, the computer model may bring to light what factors are important given the circumstances of the ship or the particular voyage (e.g. environmental conditions).

ACTIVITIES: The work started with development of a software quality assurance plan, R9, and the functional requirements document, R13. Thereafter, the plan was to develop four different modules: a graphical module, a definition module, an assembly module, and an assembly-report module. The graphical module handles all user input (mouse/keyboard actions), the imported drawings of decks laid in the background and the visual presentation of results from simulations. The definition module saves and loads simulation set-ups, sets the grid-dimensions, defines stairs and corridors, and places passengers on the ship. The user can input passenger properties. The definition module communicates with the graphical module about how to show input given by the user. The assembly module calculates the mustering process itself. During a mustering run, the user has the possibility to inspect any given deck for details using the graphical module. The user can freeze the mustering process any time for closer inspection; then resume the process. The assembly module stores the mustering data temporary in memory, in a database, or to a file. The assembly-report module processes the mustering data to make a paper copy report of the mustering simulation or to show that information on a screen. To show the simulation data on the screen, the assembly-report module gives input to the graphical module. The report module can also process data to the graphical module to show simulation result on the screen as the simulation runs.

After integration of all modules into a working tool, the last activity of WP3a was to apply the tool to a large ferry.

DELIVERABLES: (a) various user requirements documents, R13, which are later integrated into a (b) software quality assurance plan, R9 (c) a report and a working demonstration model (that is software code) for the prediction of the assembly process over time, and (d) an application of the tool to one ferry R14.

EVALUATION:

PROGRESS MADE WITH MEPdesign: Some of the progress made in MEPdesign is reported in R9, and the user requirements are drafted in R13. The exercise is documented in R14, the evaluation was based on the version draft version received February 14th.

The report R9 is the software quality assurance plan for the mustering part of the software. Mustering is the process from sounding the alarm to the moment when the passengers are assembled at the mustering stations.

The 4 modules described in the initial project plan have been developed in accordance to the plan.

COMPLIANCE WITH OBJECTIVES:

Comparing deliverables to specific requirements in the plan, the following observations are made:

- Formal requirements to SQAP satisfied. The SQAP, R9, fulfil normal requirements to such quality assurance plans. The document also explains how the user requirements as an interpretation by the other partners of the initial project proposal combined with the research in the referenced work packages are to be implemented in the software.

- Requirements from WP 2a “Guidance” satisfied
Requirements from WP 2b “Design Features” satisfied
Requirements from WP 2c “Group Binding” is simplified. The simplification is a compromise between realism in modelling and computation time.
Global Requirements as specified in SQAP is satisfactory. However, It was found that the input module defining the spaces used for evacuation would not be satisfying as e.g. designers need. The space is allocated on a 0.5 meter by 0.5 meter grid superimposed on the ship drawing. For example corridors are either 0.5, 1.0, 1.5, or 2.0 meters wide (or more in steps of 0.5 meters). SOLAS required minimum 0.8 and 0.9 meters for corridors in crew and passenger areas are therefore arbitrarily represented as 0.5 or 1.0 meters. This is currently not documented as a basic assumption in the software documents. If users are made aware, this is rightly likely to destroy confidence in the model as applied to corridors and stairs and otherwise narrow spaces.
All humans occupy 0.5 meter by 0.5 meter (one grid). The implication is that no passage is possible in corridors of width less than 1 m. This is unrealistic.

POTENTIAL USE: The main intention was that the software could be used for design. For use in design, computation time is important. R9, chapter 7.2 refers to testing of computation time. This is as yet not reported or verified (In the minutes from the 8th PMC meeting 1h computation is reported for one run with 600 passengers for a real mustering taking about 25 minutes. 25 Monte Carlo Simulations would therefore take 25 hours). The requirement in Appendix B, Chapter 1.2, to be able to run cases with 5000 passengers is therefore probably not fulfilled, as the time consumption would be longer than anyone would wish to wait. The relationship between computation time and number of passengers is not documented. As far as the first author understood the algorithm, computation time is expected to increase slightly faster than linear. It is expected, however, that crush conditions will result in computation times that may approach infinity.

R9, Chapter 16 and R14 relate to the mustering exercise at the Kronprins Frederik. The correspondence between predicted and actual mustering time was good. It should be noted, however, that the actual mustering time corresponded also with Scandlines's time schedule for the exercise (25 minutes)—a schedule that was known to the MEPdesign partners well before the exercise. Exact correspondence is not expected. Difference between predicted and actual mustering time are bound to occur because the mustering process is inherently random in nature; the exercise represents only one out of many possible outcomes. Factors that made the prediction easy were the simple geometry of the ship, the absence of group binding, the absence of ship motion and ship list (the list used was too small to influence the passengers; this will be described further). There are also peculiarities with the software prediction. The simulation results are plotted in Figure 3. (The reviewer prepared this based on the data). Whilst the mean value corresponds to the exercise, the distribution is peculiar. An explanation is needed on how a number of normal random input variables produce a distribution that seems to be more uniform. The opposite effect would seem more logical (uniform input to produce normally distributed output.)

One hypothesis offered by the reviewer, in the lack of any explanation from the developer of the software, is: Under crush conditions or almost crush conditions the software try to move one person at the time (the order is determined by which passenger/crew happened to receive the lowest index number). If the person is behind in the queue he cannot move (v=0 for him), if he is in front he can move (v = stochastic input for him). The same argument applies for the next person, and the
next, etc. Therefore, this big difference is an unintentional effect of arbitrary indexing of the passengers and crew. It brief, this has nothing to do with what happens in reality and is a purely an arbitrary and unintentional result of the selected algorithm. However, by “accident” this gives the software credibility – as some uncertainty is demonstrated in the resulting evacuation time.

Another peculiarity is the fact that the normal distribution is used for all random input variables. This implies that there are probabilities that delays, walking speeds etc. are negative\(^1\). Many other distribution functions would be better suited.

![Number of simulation results](image)

**Figure 3: Simulated evacuation time, prepared from R15**

Therefore the EVAC software is not expected to be useful as a design tool. Furthermore, design parameters are not modelled properly. In general is should be observed that the approach selected with focusing on simulation of individuals may be the reason for not ending up with a valuable design tool. This is therefore not criticising the developer of the software. The project was based on this idea. The problem with the idea is that a design tool must focus on modelling design parameters properly. The most important design parameters are related to the general deck-layout, corridor width, public spaces, and width of stairs and doors. Other important resources that need to be allocated relate to manning and crew training. None of these parameters are implemented in a way that make the tool useful for design. The characteristics of a design tool, or more generally a tool for the allocation of resources, is that the design parameters or resources are modelled. The whole idea with such tools is to be able to estimate the effect of changes in the performance (e.g. mustering time) as a function of the design parameters or resources allocated. For example, the income from operating the ship is closely connected to the availability of cabin and public spaces. The ship is therefore optimised in order to maximise useful spaces. To allow for evacuations, this has resulted in prescriptive minimum standards for corridor width in crew and passenger areas of 0.8 and 0.9 meters, respectively. The software cannot represent these values. Another illustration of the importance of

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\(1\) In response to this comment, the developer revealed that the software rejects negative values. This is, however, not documented.
useful spaces is represented by the preference for marine evacuation systems instead of lifeboats. The main reason to prefer marine evacuation systems over lifeboats is the reduced need for space aboard (see R7, page 5).

The comparison between Exercise and Simulation, R15, offer insight into the applicability of the software as a design tool. In the report it is noted that much of the assembly times are related to delays. This is obvious, as it is observed that the first passenger arrived at the lifeboat after 4 minutes, whilst the assembling took 24 minutes. A critical question is: did the software modelling predict these delays and the design variables that could be changed to improve the situation. Quoting from the report (a pre-version) R15 we may answer this:

- “There is an initial delay from the moment of an accident to the alarm is sounded from the bridge. This is partly reaction time of bridge crew and partly time to analyse the situation and decide what to do (including the decision to start mustering or not). In the exercise this delay was 2 min.” This delay is not modelled in the software. Further, more crew could improve the situation. Crew actions are not modelled. Better trained crew could also improve the situation. This is not modelled. What is modelled? The answer is that the delay is input. Obviously, if the delay is increased by one minute the assembly time is increased by one minute.

- “Then there is a second delay caused by the time it takes for the crew to react to the call for mustering. The crew assembles first to make sure everybody with assigned duties is present, and they report back to the captain, when they are ready to start the mustering process with the passengers. These first few minutes of an emergency are waiting time for the passengers, where mustering of passengers is not yet started, unless they start evacuating by themselves. In the exercise this delay of crew mustering was between 2 min (for the module-4 assembling crew in restaurant and panorama lounge) and up to 7 min (for module-2 assembling crew from the two shop areas). The mean value for the 4 modules were 3 3/4 min (200 sec.)”. Again this is input to the model.

- “The next phase of an evacuation is the planned evacuation of the different compartments of the ship and assembly of passengers at their muster stations. Delays can here be caused by passengers who might refuse to leave a compartment or who might slow down the process because of walking disabilities. Other delays might be caused by congestion by doors and hallways on the ship, by reduced walking speed on narrow staircases and by counter-streams of passengers.” In a simplified way, this is modelled.

- “At the assembly stations passengers have to put on life-vests. Delays can here be caused by slow distribution of life vests, by problems in putting on the life-vests, or by the lack of crew resources to guide passengers in the process.” These extremely important parameters: number of crew, time to distribute vests time to don vests time to assist passengers, room to assist and instruct are not modelled.

- “Another type of delay at assembly stations is the imposed waiting time in assembly stations at lower decks, where passengers on the upper deck will have to disembark first to make room for passengers from the lower decks. On Kronprins Frederik this is the case with assembly/muster station “A” on deck 5/7, where life vests are handed out” This is not modelled. However, as long as what is happening at the assembly/muster station A is not on the time critical line this is not relevant for the muster time.

- “At embarkation stations there can be further delays if the crew operating the means of evacuation is busy elsewhere. If they are late to arrive on the upper deck because they might have other duties (fire fighting, helping mustering etc.) the disembarkation process might be delayed. In the exercise on Kronprins Frederik some passengers actually arrived on the aft part of deck 9 before there were any crewmembers to show them where the life vests were and how to put them on. These crewmembers were probably delayed in the shop area on deck 5/7, where they assembled a group of passengers and awaited further orders before they went to deck 9. Those passenger who were already close to the disembarkation stations and went directly to deck 9 from deck 8 or who were already on
deck 9 when the alarm was sounded, therefore had to wait a few minutes before any crew members turned up at all.” The task of the crew, which is time critical, is not modelled. With the benefits of hindsight, it may be concluded that the software focused on modelling passengers (which is not a resource and can not be changed\(^2\)), whilst most resources that may be influenced (crew, crew training, available spaces, layout of areas for handing out life-vests, etc.) are not modelled.

In some respect not even trial and error is possible. For example, if a designer wishes to rerun the simulation increasing a corridor width with 20 centimetres there will be a 60% probability that this has no effect according to the software. Still, the predicted evacuation time could be different because of random factors in the simulation.) There will also be a 40% probability that this has a large effect; for the software, the corridor increases 0.5 m.

The EVAC or similar software could in some years be used to approve designs. However, it is well documented that the evacuation time in real incidents/accidents is much longer than in exercises. In FP 45/3/1 a factor of two is indicated. Since the software is more in agreement with exercises than the reality, there is a problem of using both exercises and simulation as the basis for approval. Furthermore, the situation is that many different software packages will be made available. Because they give different results, there could be “competition” to document short evacuation times, because the ship owner paying for the studies generally wishes to prove that the ship is safe. However, the ship owner would generally prefer software over real tests. Mustering exercises must be carried out after the ship is built. It is obviously a nightmare situation to build the ship, then carry out an exercise that fail to meet the required evacuation time; followed by modifications (This is currently a possible scenario for High Speed Crafts). Software may be used to approve the drawings, and the risk of costly design modifications is removed. To accept the use of software there is a need to standardise assumptions and define exactly how the approval could be made.

The EVAC software may be a valuable research tool. The software has included many of the properties of human behaviour from the research in other WPs in the project, and other human behaviour issues may be modelled later. This is very valuable, as there is a need to demonstrate the effect of human factor influences in emergencies.

The EVAC software could also be used in regulatory work, e.g. in an formal safety assessment aiming at formulating prescriptive design rules for design of e.g. escape ways, manning and crew training requirements. Currently, this approach is not followed as IMO has already made a (premature) decision to rely on software; the simplified method described in MSC Circ.909.

**WORK PACKAGE 3b, EVACUATION MODEL**

OBJECTIVE: Develop a computer-based evacuation model

BACKGROUND: Evacuation\(^3\) means that lifeboats or other life-saving equipment are boarded by the crew and passengers and launched by the crew. After release the survival craft sail away from the ship. The risks of the evacuation process are modelled to estimate the overall success of evacuation. The risks include (a) incidents during embarkation, (b) environmental and ship conditions that preclude launching

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\(^2\) Some passengers could be trained to be a resource, e.g. regular truck drivers. If they were they could represent resources similar to the crew. Anyhow, such resources are not modelled.

\(^3\) The correct term is abandon ship (normal SOLAS wording)
(e.g., strong listed ship) or (c) damage to the equipment and/or the passengers during launching (e.g., equipment crashed against the ship’s hull) or (d) wreck the equipment when it sails at sea.

ACTIVITIES: The definition module of WP3a should be expanded to be used as the interface for inputting specific life-saving equipment properties (WP2d), and for inputting environmental conditions such as the ship’s list and wind/wave forces. An evacuation module is developed to use the data of the definition module to calculate the temporal course of the different evacuation stages (launching, embarking, and sailing away, or, for other equipment, embarking, launching, and sailing away) and the risk probabilities associated with each stage. The graphical module of WP3a should be expanded to show the evacuation process, including the wave pattern. The final step should be the development of the evacuation-report module.

DELIVERABLES: (a) modified SQAP, (b) a report and a working demonstration model (that is software code) for the prediction of the evacuation process over time

EVALUATION:

PROGRESS MADE WITH MEPdesign: The documentation of the software Lifeboat Launch (LBL) received was a report by Helge Soma and J. Wiklund, dated 7/10-1993 and a draft of R12, received by email March 1st 2001. Earlier versions of the software have also been demonstrated at project steering board meeting.

It is unclear what progress has been made during MEPdesign. The documentation does not indicate use of any input of the MEPdesign project. No validation of the simulation results and results achieved during the tests at KTH (WP2d) has been carried out. The report, R12, describes a general “eye-balling” comparison. Only lifeboat launch is simulated; there is no mention of the slide/raft evacuation system in the documentation.

A draft report, R11, contains plans for the following improvements of LBL:
- Implementation of a 3D model of the ship hull
- Full 3D motion capability of the ship
- Enhanced 3D graphical presentation
- Model of the impact against the ship hull, and the subsequent motion of the boat

In particular the last point is a necessity to be able to extract risk results from the software.

COMPLIANCE WITH OBJECTIVES: The objective is not met, and the documentation is poor or lacking. Based on the information available March 1st. 2001 to MEP partners, the software should be regarded a prototype that needs validation.

POTENTIAL USE: LBL may have users, as it is possible to simulate many aspects of the launch process. The software simulate
- launch from fixed and floating units, with variable height and wire suspension point
- irregular waves
- wind, wind gust, wind direction
- lowering speed
- lifeboat yaw motion
- lifeboat thrust and rudder effect

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4 During the last meeting of the consortium, 27 April 2001, Quasar demonstrated an updated—but undocumented—version of EVAC (WP3a) in which slides and rafts are modelled as fixed additions to the ship’s structure with passengers disappearing as soon as they touch the slide, or the slide modelled as a “black hole”.

5 In a comment (12/5-01) QUASAR refers to use of the software in the offshore sector. Such information has not been considered in this evaluation.
The use would most likely be in connection with improvements of existing lifeboat arrangements. In such cases special adaptation of the software is likely, dependent on the Risk Control Option or other improvements under study. The software is not likely to be used in risk assessment, as this would require running the software a very large number of times. It is more likely that the experimental results from KTH would be used directly in this case. Some relevant factors determining lifeboat launch safety are not included in the software.

- Wave disturbance by the ship. There are wave reflections and standing waves in the area where a lifeboat is launched (as revealed by the studies of KTH). Rather advanced software would be required to account for this. (DNV has developed generic software for modelling such effects: SWAN)
- Risks due to accelerations and human error in handling the equipment (releasing the lifeboat etc.)
- Lifeboat behaviour at sea (e.g. roll effect that may capsize an open lifeboat or PEL)
- Risks during embarkation.

WORK PACKAGE 3c, ASSEMBLY & EVACUATION

OBJECTIVE: Develop a computer model for total evacuation performance
BACKGROUND: For realistic estimates of total evacuation performance, both assembly and evacuation must be simulated at the same time, as embarking life-saving equipment commences after a sufficient number of passengers is assembled at a given muster station. This requires a link between the tools of the previous work packages.
ACTIVITIES: The plan was to develop a link between the assembly module of WP3a and the evacuation module of WP3b, to make them work as one A&E module. The two graphical modules should be integrated for running at once, one window for each module. Finally, the report should be integrated.
DELIVERABLES: (a) modified SQAP, (b) a report and a working demonstration model (that is software code) for the prediction of assembly and evacuation in combination.
EVALUATION:
PROGRESS MADE WITH MEPdesign: The reviewer has not received any of the deliverables.
COMPLIANCE WITH OBJECTIVES: No objective has been met.
POTENTIAL USE: Not applicable

WORK PACKAGE 4a, EXERCISE AT SEA

OBJECTIVE: To validate the predictions of the evacuation model.
BACKGROUND: The evacuation model was tested against an exercise with real people in a ship at sea. The outcomes of the exercise was compared with the

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6 On 26 April 2001, after the review period, Quasar distributed a short note describing an integrated model. This note is not included in the present evaluation.
predictions generated by the tools developed in Phase 3. Due to ethical considerations, the exercise stops short of embarkation in life-saving equipment because this would put lives at risk. During the exercise, events were recorded to measure the same quantities as the ones predicted by the model. Ship motions during the exercise were recorded and given as input to the model to increase its precision of prediction.

ACTIVITIES: SCL selected one of its ferries and produced the script for the exercise. The script specified logistics, equipment (including devices recording ship motion), preparation of the ship, procedure for attracting participants, procedures during the evacuation, tasks of investigation team, recording methods, and debriefing session for the participants. The exercise took place in the autumn/early winter. A large number of participants (Plan: 1200, Actual: 600) were attracted as paid volunteers, selected in accordance with the group study carried out in WP2c. The participants were informed in general terms only and were not told that an evacuation exercise should be held. The interview of WP2c was repeated for a some participants. Shortly before mustering commenced, the ship begun to list to one side with the use of the vessel's built-in ballast system. During the exercise, records were kept of the ship motions and list. The number of passengers showing up over time at the muster stations was also recorded, as well as at a number of other points. After the exercise, a description of the ship motion/ship list data was made available to Quasar. Quasar then made the final model prediction. The mustering data are analysed and compared with the model predictions.

DELIVERABLES: (a) subtask1, document on planning of mustering exercise at sea; subtask 2, report on real and predicted mustering including recommendations for future models.

EVALUATION

PROGRESS MADE WITH MEPdesign: The progress made in MEPdesign is reported in R10, R14 and R15.

This document (R 10) is for planning and execution of the mustering exercise to be performed with 600 passengers on board m/f ‘Konprins Frederik’ at sea and to describe it in details as far as possible. The real exercise at sea took place on a round trip from Gedser (Denmark) to Rostock (Germany) on the 28th October 2000. The manual contains information concerning:

- the vessel, general description, passengers accommodation, mustering and evacuation devices: assembly stations, life saving appliances, life jackets,
- the crew, outfit, position and duties during the exercise,
- the passengers, recruiting, check-in procedure, distribution on board, catering,
- the recording of ship movement (motions, list) and passenger flow: functional description of
- equipment, location of recording (counting and video) and observation points, encoding and interpretation of data,
- recording personnel and observers,
- scope of the exercise and time synchronising,
- starting of the exercise (alarm signal for evacuation from the bridge),
- end of the exercise when passengers are assembled to the assembly stations (under captain command) the end of the exercise,
- role of external participants such as SCL emergency group readiness, Marine Authority and Search and rescue Service awareness, MEPdesign partners.

The organisation, execution and interpretation of an exercise to such a level of preparation is rather a new experiment in shipping, specially with all the input of such a consortium like MEPdesign. To our knowledge the ‘heavy means’ required and
brought to disposal by the recording, particularly the counting of passengers (data collected by the combination of them), identified in different social groups, at different location on board a roro passenger vessel was never done before. In the exercise 594 real passengers were recruited for this special trip specially arranged at the occasion of this exercise.

COMPLIANCE WITH OBJECTIVES. The exercise on board the roro vessel Kronprins Frederik aimed at collecting appropriate data on the conditions under which passengers actually proceed from their initial positions to the mustering stations.

The document issued by SCL provides detailed analysis of the procedures allowing to obtain factual information on the passengers’ behaviour including time to arrive at mustering stations, walking speed, identification of bottlenecks, etc..

It specifies the time schedule of the different phases of the exercise, the roles to be played by the crew, how passengers will be identified and classified, the locations of counters, the ways by means of which the proper information will be captured and processed.

The trials have been carried out following the provisions of the report, demonstrating ipso facto that the document, prepared with great care and accuracy, complies with its objectives.

POTENTIAL USE: The document can be considered as a reference for the organisation in the future of either new experiments or even at the occasion of tests that IMO would make mandatory. In the latter case there would be a need for refining the specifications of the experiment to be used for measurements on board ships.

In brief the document is a most valuable methodological tool. However it may be noted that the exercise itself that took place at the occasion of the project was not rich in conclusions.

This is due to the fact that:

- the weather was fine and the sea state calm,
- the ship’s static list was less than 2°.

This made it impossible to measure the influence of the ship’s list and motion on some parameters such as the walking speed.

The result of the exercise is clearly of interest to all developers of software for simulation of the assembly process. In principle this and other exercises or real evacuation experience may form a set of tests the software would have to pass in order to be accepted for use. Fortunately, this exercise is well documented, including the limitation. The results should therefore be publicly available.

WORK PACKAGE 4b, EVALUATION

OBJECTIVE: Evaluate the pragmatic value of the whole project.

BACKGROUND: In the initial project plan two potentials end-users of the MEPdesign results were perceived: (a) regulatory bodies and (b) ship designers and ship builders. The maturity of the MEPdesign results should be assessed as a guideline for a new IMO submission and as a guideline for class notations (class certification) to be used by ship owners on a voluntary basis. Secondly, the maturity of the MEPdesign results should be assessed as a design tool. In the latter case, the rules and regulations will be treated as 'functional requirements' leaving it up to the ship owner to document by the use of the simulation tool that the functional requirements were met.
ACTIVITIES: An ongoing activity has been to guide the project with regard to risk assessment and formal safety assessment with an eye on preparing a proposal for new rules/regulations or the removal of ineffective ones. The second activity is to produce a written evaluation of contribution of the MEPdesign.

DELIVERABLES: Written evaluation of the pragmatic value of MEPdesign, including the prospects for regulators and designers: The current report.

EVALUATION: See conclusion at the end of the report.

6.2 Other ongoing Research with aims similar to MEPdesign

The interest in software for simulation of mustering time is large, and growing because of the new requirements in SOLAS II-2, Regulation 28.1, Paragraph 3. The following are examples. There may be other ongoing activities that are not known to the authors. During the duration of the MEPdesign project contacts have been made with all the projects listed, except the Canadian.

Australian Research Project

The Australian research is quite similar to MEPdesign in many ways, e.g. including simulation of movement of individual persons, HF research, and a large-scale evacuation exercise. This research has been reported in MSC 72/12/1, and a series of papers, Brumley A. T., Koss (1997,1998, 2000a, 2000b).

Japanese Project

The Japanese research has been presented as part of the huge Japanese FSA project with results implemented in MSES (Marine Safety Evaluation System), MSC 72/INF.17. Also the Japanese use simulation of individual persons, and the project has carried out a large evacuation exercise, reported in FP44/INF.9. The Japanese project and software seems to be less focused on HF.

French Project and Exercise

The SPECS project

SPECS is a project developed by the « Institut de Recherche de la Construction Navale » in co-operation with the University of Plymouth. This is a 2 years (+), 1st year development, together financed by the French ministry of Industry and private firms such as: Chantiers de l’Atlantique, Bureau Véritas.

Study: Crowd movements simulation when evacuating passengers ships. There is a potential market for urgent passenger ship evacuation study for future and existing passenger ships by anticipating IMO future regulation. Objective: movement of crowd has to be studied on board vessel because of the fast development of large capacity passenger vessels. For this purpose it is a need to collect information and data to be entered within a reliable computer model for the simulation of technical devices of the ship’s structure and also basic human behaviour appearing in emergency situation at sea.

1/ Why simulate evacuation of vessels?
To fulfil international rules concerning EVAC devices,
* Safety on board is one of the most important criteria for ‘Quality’ for such passenger ships,
* Most of the present regulation don’t require calculation but only spaces and flow checking including safety coefficient,
* Simulation could allow to optimise the paths and procedures for evacuation,
* Simulation is used in other industrial resorts.

2/ What can be simulated?
* Data concerning the state of the ship : list, trim, the passengers and their behaviour,
* Expected results : time to evacuate and quality of the passages ways (corridors, stairs), bottleneck, fluidity, access facilities, wayfinding marking.

3/ Simulation tools
Simulation model is based on multi-agent techniques, the concept is : one object = one passenger.
Agent attribute : perception, condition (health, motivation, stress)
Agent method : movement, planning choice,
Agent interaction and antagonist needs.
Multi-level planning structure : deducted from data from the shipyard or,
Constructed around the public accommodation and evacuation paths.
Definition and build-up of the human behaviour model :
In a crowd, group binding,
Level of stress (exercise or real evacuation),
Health condition,
Quality of the individual world perception,
Quality of the choices for evacuation,
Motivation…

4/ Present state of the project :
mock-up of the simulation model under elaboration,
definition of the overall architecture,
basic definition of the agents,
supervisor profile definition.

The FRENCH EXERCISE SECNAV ZONAL

Date : 26 September 2000
OBJECTIVE :
➢ Validate the co-ordination of the rescue at sea and on shore,
➢ Test the medical chain,
➢ Identify the victims ,
➢ Control media aspect of the event and the information of the families,
➢ Test the functional relations and appreciate the flow of the information.
BACKGROUND : The target of the rescue exercise to naufragés was the salvage of an important number of passengers on board a roro passenger ship.
PARTICIPANTS and MEANS :
200 participants provided by the marine military authorities, Civil and military maritime organisations and others authorities including European Community observers, photo/video team and private TV team.
The roro passengers ship « Ile de Beauté » chartered to SNCM, playing the role of the damaged ship.
Maritime assistance : 5 ships from the French navy and custom department
Air means : several helicopters and observation planes, from marine, air and civil safety departments.
CONCLUSION : reports are still confidential and not opened to public consultation.
The main objective of the exercise was to verify on wide scale co-ordination and information procedures between military and civil authorities from land and sea.

Canadian Coastguard and UK’s Maritime and Coastguard Agency project carried out by BMT Reliability Consultants and Canadian company Fleet Technology Ltd.

In Lloyds List Tuesday September 26 2000, a new study commissioned by the Canadian Coastguard and the UK’s Maritime and Coastguard Agency is described. It is said to provide a radical rethink of safety equipment installations on board vessels.
Quote:

*The study will focus on simulating evacuations on Class 5 leisure passenger craft operating along the River Thames and the St Lawrence Seaway. Its recommendations could have ramifications for design throughout the passenger-shipping sector.*

*The study will build on 'Promodel', the predictive logistics software package designed to quantify possible hazards in transporting the Space Shuttle's solid rocket boosters, which will be adapted to predict passenger behaviour during emergency conditions.*

*The package will be used to calculate the risks involved in evacuating a ship and the final study will make recommendations concerning new and existing vessel designs, and how evacuation procedures might be improved to achieve higher survival rates.*

*The project is being developed by UK-based BMT Reliability Consultants and Canadian company Fleet Technology.*

*The evacuation process is itself a hazard and it is thus not possible to undertake lifelike evacuation trials.*

*Crews can run through the evacuation procedure slowly and deliberately in training, but this does not necessarily prepare them for the way passengers behave during a real emergency.*

*The simulation data analysed will include the physical location of safety equipment, the paths via which passengers can escape, the capacity of those escape routes, the location where passengers are most likely to take decisions over their escape and the probability of their taking decisions in a range of circumstances.*

*The 'factor x', requiring the simulation to be run a number of times to establish an average evacuation success rate, will be random behavioural data. Certain passengers may be 'natural survivors', for example, where others are not.*
It is just this type of vagary that the package's designers are attempting to incorporate.

According to BMT Reliability marketing manager, Michael Starling, it is a mistake to believe that passengers panic during evacuations: "Objectively, passengers may appear to be behaving irrationally, but their actions will generally be logical from their point of view. Parents will run towards a fire to rescue their children, for example."

Passengers will also defer to figures of authority, even when they are wrong, according to Mr Starling. "The King's Cross fire demonstrated that people responded to the police and ignored London Underground staff, even though it was the LU staff who were in the right."

Leisure passenger craft can present further complications. Certain people aboard (DJs, for example,) cannot really be classed as either crew or passengers. Again, the demographic attributes of river cruise passengers vary: safety requirements will be different if all of the passengers are children, or pensioners, or disabled.

BMT is due to make its final report within four months, while Fleet Technology will deliver next year.

Unquote.

Comment: Unclear what human factors information this project provides, and how the model will be validated.

Strathclyde/Deltamarin project on evacuation simulation

The project has recently been described in a paper by Vassalos et al.(2001). This paper focuses on the software modelling techniques that are used.

The paper outlines a mesoscopic (i.e. between microscopic/individual behaviour as MEPdesign and macroscopic as described in MSC Circ.909) passenger evacuation simulation model, based on multi-agent techniques and a multi-level planning structure, developed by SSRC in collaboration with Deltamarin Ltd. The code is called Evi (Evacuability index), it uses a virtual environment for enhanced effectiveness of evacuation performance evaluation. It represents the a computer simulation-based capability for the prediction of passenger mustering and evacuation involving a number of escape and rescue scenarios (abandon ship, transfer to refuge centres or a combination of these) in a range of incidents (fire, collision, progressive flooding, cargo shift, foundering) whilst accounting for ship motions in a sea environment. Unlike earlier models, Evi has been developed from the outset for application to passenger ships in a sea environment, including the largest cruise liners and Ropax. Uncertainty in all the parameters that may affect evacuation times and the ability to play back a given scenario as video are included Typically; simulation of 5,000 passengers mustering on a 15-deck vessel can be achieved at real time. This implies that the software may be used as a design tool. The SSRC/Deltamarin activities does not include HF research and focuses on preparing software that may include results from HF research.
United States Project - Guidance for computer-aided evacuation analysis tools

The U.S. proposes that a uniform approach to the development of the microscopic methodologies is needed to establish rules, assumptions, input parameters and validation criteria. Two core principles are proposed:

1. A common definition be established for the sequence of events that are encompassed by the evacuation process,
2. The computer analysis should be fully documented outlining the procedure and using drawings of the vessel being analysed.

The inventory of the minimum elements that should be included in a microscopic evacuation model could be summarised as follows:
- capacity to simultaneously mimic all the selected input parameters to define the respective ship environments during an evacuation,
- iterative determination of various counterflow, merging, crossflow scenarios, including corridors and stairways; impact of passengers travelling the fore and aft, the port to starboard directions and vice-versa;
- use of the fine network approach to map the evacuation process which subdivide the ship in a fairly uniform network of tiles and nodes;
- regarding the passenger population, use of an individual approach having differing physical limitations;
- consider the behavioural perspectives of the passengers: interactions, decision-making, …
- agreed input parameters to be developed;
- use of the risk assessment techniques mainly for analysis related to fire and smoke impact; iterative calculation to identify improvements in the design of the evacuation system;
- capacity to simulate fire growth and smoke spread with reference to validated fire models;
- use technically recognised research data based on actual ship evacuations exercises;
- validation of the methodology by comparing its results to actual shipboard evacuation data when developing.

German Project - «Draft Guidelines for a microscopic evacuation analysis of ro-ro passenger ships and High Speed Passenger Craft»

Purpose: to provide information on how to execute an evacuation analysis based on a microscopic and stochastic approach intended as a basis for a computer simulation and use its results.

Method of evacuation analysis:
- description of the system: floor into grid of cells, escape routes, assembly and embarkation stations,
- individual parameters to be considered: physical person and perceptual abilities,
- assumptions: overtaking allowed, disabilities accounted, no change permitted in escape routes, 100% of passengers, ship’s motions accounted, all persons in the simulation act once within a second,
- scenarios: night and day,
- data for preparation, embarking, launching times….
• Simulation of the evacuation process: one grid of cell = one person, performing according to the rules,
• Standard of performance,
• Identification of congestion: density, queues,…
• Flexibility arrangements: closed corridors, stairways, embarkation non available, structural damage, fire…
• Time distribution/number of persons evacuated…
Corrective actions if necessary to the design, passages…

6.3 Overall Evaluation MEPdesign

A first accomplishment of the project was the recommendations for new concepts, where the photoluminescent strips with arrowheads proved to be effective.

A second accomplishment of the project was demonstration of the risks and ineffective standards for the abandon ship phase, and the potential for improving this.

Both these achievements demonstrate that systematic work is necessary for improving safety, that improvements are not easy, and that both costs and benefits of the improvements must be considered. A procedure like formal safety assessment should be used for final recommendations.

A third achievement is the large amount of HF information relating to the assembly/mustering phase. Some of this information is of general applicability in any type of evaluation of effectiveness in mustering. The specific data must, however, be implemented in software to be directly useful.

To the extent documentation is available, it should be clear from the detailed evaluation that the developed software is not particularly useful in design. The assembly module may have some merit, but it is quite unrealistic that this may gain widespread use. The idea that designers, builders, and shipowners may use all accomplishments to assess the safety of existing and new ships, and to explore the safety gains (less casualties) of a new guidance system, of refurbished escape routes, more muster stations, etc. is in reality unrealistic, whilst possible in theory. It was also said in the project plan that because effects of ship motion are included, the idea was that designers could also explore the safety gains of better stabilisers and use of a different ballast system. Obviously this is unrealistic, as numerous reanalysis would be required in a design loop that is already quite complicated. In practice only very effective software or design formulas will be of use in such cases.

Is it seen from the detailed evaluation that the following general conclusion is justified

“The project has been largely successful, but does not fulfil all stated goals”.

Formally the successes may be summed up as:
➢ Formal requirements to each tasks have been met, with only small deviations
➢ Detailed knowledge of group binding effects from the work of DMI
➢ Detailed experimental results on wayfinding errors at TNO
➢ Detailed experimental results on walking speed at TNO
➢ Demonstration that HF data may be produced by carefully designed HF research
➢ Software that may be used in HF research and maybe in a future risk assessment (formal safety assessment)
Generally the work demonstrates that by using the research results systematically evacuation time may in theory be reduced with at least 20%. However, it is not clear how the results should be implemented in practice.

The project demonstrates that current evacuation analysis is overly optimistic.

The lack of success are related to:

- The approach for the software was unrealistic as a design tool or as a response to the SOLAS II-2, Regulation 28-1, Paragraph 3. The software can not yet be used for design or as basis for approving ship design
- The project demonstrates that current evacuation analysis are overly optimistic, but has failed to come up with an alternative
- The data of the abandon ship process can be read from tables rather than by using the software
- There is no easy way to implement the project results, as new insights demonstrate that evacuation is slower and less reliable than implicitly assumed in current regulations

6.4 Gap List

Most of the work in MEPdesign has focused on evacuation in emergencies where the initiating event of the accident scenario is collision, grounding, foundering etc. If the initiating event is a fire, exposition, arson, sabotage etc. with smoke and burning material in the cabins, corridors, public spaces or mustering area this is not covered in MEPdesign. Another series of tests would be required to build up databases for these scenarios.

All parts of MEPdesign have focused on how to evacuate people fast and safe. It should be observed that about ½ of the evacuations are preventive, and passengers may need to get safely back to the ship. This is not dealt with, and it is not dealt with in any regulation. It is not unlikely that this will become an issue in the IMO work group on large passenger ships, which convened the first time during MSC 73, in December 2000. Passenger ships with 3000 to 5000 people are cruising to Arctic/Antarctic. Even a preventive evacuation of 5000 passengers in arctic regions is a nightmare with the current life saving appliances.

A large number of projects are currently ongoing relating to the development of software tools. At this stage of the development it is not clear that the development of software will produce benefits to the industry, and it is not clear which method is most suitable for implementation. This relates both to the modelling techniques (e.g. macroscopic, mesoscopic, microscopic) and the basic philosophy. Furthermore, if effective software was made available the scenarios that should be simulated and the associated acceptance criteria need to be specified, e.g. in an appropriate IMO instrument. The current requirements lack necessary specificity.

Whilst many of the tools and the knowledge base developed in MEPdesign and in other projects may be useful in a risk assessment, a risk assessment or FSA has yet to be carried out. The first case could relate to the work in the “Large passenger ship” Work Group at MSC, where the agreed work program opens up for the use of FSA. It is not likely that much will happen in that respect unless someone volunteers to carry out the work, by establishing a joint industry project.
Note that this gap list is limited to high level issues. On a detailed level the gap list could be extended. Such gap lists are to some extent included in the individual reports, or limitations that could be removed by future research are mentioned.
## 7 LIST OF REPORTS AND PAPERS

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<td>R2</td>
<td>DMI “Design Features-A proposal for New design features on board passenger ferries” WP 1b</td>
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<td>R3</td>
<td>DMI “Ship Motions- Ship motions for Passenger Ferry M/F Kronprins Fredrik” WP 1c</td>
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<td>T1</td>
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8 OTHER REFERENCES

5. FP (Fire Protection sub-committee to Marine Safety Committee documents at International Maritime Organisation. All documents are available at the web: http://www.imodocs.imo.org/, but password is necessary. All national maritime administrations and NGOs have access.)
7. MSC (Marine Safety Committee documents at International Maritime Organisation. All documents are available at the web: http://www.imodocs.imo.org/, but password is necessary. All national maritime administrations and NGOs have access.)
ANNEX: Development of FSA since 1999

At MSC 71 (May 1999) the joint MSC/MEPC work group on HE and FSA discussed the following issues (considered unresolved in the IMO FSA Guideline):

- use of the regulatory impact diagram;
- use of expert views/judgements; and
- determination of risk acceptance criteria/levels.

The joint HE/FSA work group also took into consideration the draft Guidelines for practical application of FSA to the IMO rule-making process, set out in annex 5 to document MSC 71/WP.15/Add.1, having agreed that these new Guidelines should become an appendix to the FSA Interim Guidelines.

In plenary at MSC 71 it was also agreed that the Committee should further:

- discuss the use of the regulatory impact diagram, using as a reference the regulatory impact diagram given in annex 6 to document MSC 71/WP.15/Add.1;
- consider the issue of experts views and judgement, using the preliminary Guidance note for the use of experts in an FSA trial application, given in annex 7 to document MSC 71/WP.15/Add.1, with a view to incorporating Guidance into the FSA Interim Guidelines;
- discuss risk acceptance criteria aiming at the development of a definition of such criteria, which might, in future, be included in the FSA Interim Guidelines; and
- consider the draft Guidance on human reliability analysis (HRA) within the formal safety assessment, as contained in annex 8 to document MSC 71/WP.15/Add.1 (The IACS HRA in FSA document), with a view to incorporating it, as an appendix, into the FSA Interim Guidelines.

At MSC 72, the following documents were reviewed relating to FSA:
- Norway (MSC 72/16), in the context of the issue of risk acceptance criteria;
- United Kingdom (MSC 72/16/1) on the use of the regulatory impact diagram attaching a summary on how the diagram fits into the FSA process;
- United States (MSC 72/16/2) expressing concerns with regard to the integration of the Guidance into the FSA process and proposing a framework for ensuring that the human element is taken into consideration and that FSA process is used where needed and appropriate; and
- Japan (MSC 72/INF.17) presenting a method for reduction of the number of accident scenarios and an example of the trial calculation of cabin fire risks.

The Terms of reference of the Joint MSC/MEPC Working Group on HE and FSA, relating to formal safety assessment at MSC 72 was:

to further develop amendments to the FSA Interim Guidelines on the basis of the texts contained in annexes 5 to 8 of document MSC 71/WP.15/Add.1 and in the light of relevant decisions of MSC 71 (paragraphs 14.2 to 14.14 of document MSC 71/23) taking into consideration the comments and proposals made in the documents submitted to the session;
to ascertain the outstanding work to complete this work programme item and the significance and importance of this work in the FSA process as well as in the related work of the Organisation; and to advise on an appropriate work plan to carry out the urgent or essential remaining work; and to consider the need of a correspondence group to deal with the FSA matters intersessionally and, if so, to prepare draft terms of reference for such a group.

It was agreed that the following should be included in the IMO FSA Guideline:

- guidelines on practical application of FSA to the IMO rule-making process (MSC 71/WP.15/Add.1, annex 5);
- guidance on the use of experts in the FSA application (MSC 71/WP.15/Add.1, annex 7); and
- guidance on the use of human reliability analysis (HRA) within formal safety assessment (MSC 71/WP.15/Add.1, annex 8).

With regard to the regulatory impact diagrams (RID) the group had agreed that RID may be used in qualitative terms for assessing the influence of regulations in respect of effective prevention of accidents. However, to be confident about the possible use of this technique, more information on the practical application was needed. In that respect, the joint group amended the draft revised FSA Guidelines by deleting the relevant paragraph and included the use of regulatory impact diagrams (RID) as a new appendix to the guidelines, to be considered as a basis for further discussions. The majority was clearly in favour of simply permanently remove the reference to RID, e.g. as no need for it has been identified.

The Committee noted the opinion of the joint group that, in the light of continuous FSA applications being developed, further improvements to the FSA Interim Guidelines should be discussed as a matter of priority at the group's next session and that further improvements to the Guidelines should include the integration of the human element into the FSA process; and, as advised by the joint group, decided to establish an intersessional Correspondence Group on FSA under the co-ordination of Japan, with the following terms of reference:

- to develop further improvements to the Interim Guidelines for the application of formal safety assessment (FSA) to the IMO rule-making process (MSC/Circ.829-MEPC/Circ.335), taking into account the proposals set out in document MSC 72/WP.7, annex 7;
- to develop further guidance on the use of regulatory impact diagrams (RID) and provide relevant examples of their application;
- to consider the possible application of risk evaluation criteria, taking into account proposals in document MSC 72/16;
- to consider the integration of the human element into the FSA process;
- to consider any further proposals arising from the trial applications of the FSA Interim Guidelines, inter alia, the studies on bulk carrier safety being developed by the International Collaborative Formal Safety Assessment Study co-ordinated by the United Kingdom (MSC 72/INF.18 and MSC 72/4/3) and by Japan; and to submit its report to the Committee at its seventy-fourth session.

The observer from IACS advised that, in response to the need for the standardised training package identified in document MSC 71/WP.15/Add.1 (paragraph 31), IACS had developed an FSA training package for the establishment of a basic understanding
of FSA methodology. The Committee welcomed an offer from IACS to make the training package available to MSC 74. (This is now developed by an IACS project team7)

At MSC 74 (May 30th – June 8th, 2001) the plan is to:

➢ finalisation of the improved draft revised FSA guidelines for their continuous application and the consequent ending of the period of trial applications;
➢ further integration of the human element and FSA into the IMO decision-making process; and
➢ development of risk evaluation criteria with regard to maritime safety and the protection of the marine environment. (as proposed in MSC 72/16 by Norway8)

In this context, MSC 72, in order to facilitate the development of risk evaluation criteria for the protection of the marine environment, taking into consideration the desirability of their integration in the “precautionary approach”, invited Member Governments to include experts on protection of the marine environment in their delegations attending MSC 74.

The Committee approved the following work plan of the joint group relating to FSA:

➢ consideration of the outcome of the intersessional correspondence group on FSA with a view to finalising the improved Guidelines;
➢ consideration further of the integration of the human element and the FSA into the IMO rule-making process;
➢ development of risk evaluation criteria with regard to maritime safety and the protection of the marine environment; and
➢ development of a training package for the establishment of a basic understanding of the FSA process.

7 Rolf Skjong has developed many of the modules
8 Rolf Skjong has represented Norway in FSA WG and was the principal author