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SHIP EVACUATION SIMULATOR

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Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

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16. Abstract

This report outlines the work carried out for Transport Canada to develop a software program for the analysis of ship evacuation arrangements. The real-time simulation program is to be used by regulators and designers to assess the arrangements for evacuating a passenger ship and the degree to which the evacuation will meet target evacuation times set by national and international authorities. The program is to account not only for ship layout and equipment locations, but also for human behaviour, the effect of hazards such as smoke and flooding, and ship heel and motions.

The report summarizes the development work undertaken to achieve this goal and describes in general terms the software program that has been delivered under this project.

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16. Résumé

Ce rapport présente les travaux réalisés pour le compte de Transports Canada en vue du développement d'un programme d'ordinateur permettant d'analyser les procédures d'évacuation d'un navire. Ce programme de simulation en temps réel doit servir aux organismes de réglementation et aux concepteurs à évaluer les procédures d'évacuation d'un navire à passagers et à vérifier dans quelle mesure les délais d'évacuation respectent les limites fixées par les autorités nationales et internationales. Le programme doit modéliser non seulement l'aménagement du navire et l'emplacement du matériel de secours, mais aussi le comportement humain, l'effet d'obstacles comme la présence de fumée et l'envahissement par l'eau, ainsi que la gîte et les mouvements du navire.

Le rapport résume les travaux de développement réalisés pour atteindre cet objectif et décrit les points saillants du logiciel livré dans le cadre du projet.

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- Mr. Ian Denness, Risk Manager of PetroCanada's Terra Nova project for permitting us to participate in the Terra Nova tests;
- The Captains and crew of several vessels on which the project team participated in evacuation exercises.
- All the members of the public who volunteered for tests on SHEBA (Ship Evacuation Behaviour Assessment);
- The software development team at University of Greenwich's Fire Safety Engineering Group, and most importantly the two Client representatives for their guidance, feedback and understanding;
- Mr. Serge Théorêt, Marine Surveyor Transport Canada, Technical Services Division Quebec Region; and
- Mr. Charles Gautier, Senior Development Officer, Transportation Development Centre, Transport Canada.

EXECUTIVE SUMMARY

A project was undertaken to develop a software simulation program to assist marine inspectors in evaluating ship evacuation arrangements. In addition to accounting for the layout and evacuation equipment, the simulation was to account for human behaviour, escape arrangements, ship motions and hazards such as flooding and fire, and to distinguish between crew and passenger behaviour.

The project began with a review of the availability of algorithms, models and data, during which it was noted that there were several established building evacuation models that accounted for human behaviour but there was little data for ship relevant behaviour. Some development work on evacuation simulation was being undertaken internationally and, at the end of the state-of-the-art review stage, it was proposed that the lowest risk approach to achieving the contract goals was to co-operate with a current development effort.

The project was subsequently undertaken in conjunction with the University of Greenwich's Fire Safety Engineering Group in London, whose EXODUS suite of evacuation programs was deemed to be the most suitable for the further development of a ship evacuation model.

Modifications to the model included the addition of abandonment models covering the entrance of personnel into Life Saving Appliances and their subsequent exit from the ship. It was also necessary to modify human performance to account for potential heel angles and motions. There was little available data for the latter, so the project team designed and constructed a portion of a ship (space, corridor and stair) that could be tilted over to 22^o of heel (static). Members of the public of both genders, representing a range of ages and capabilities, were tested in the SHEBA facility in the summer of 2001 to collect data on their speed, etc., at angles up to 20^o. It was not possible to collect motions data and this has not been included in the current model.

Model validation and calibration were undertaken with data taken from several evacuation exercises that were attended on an opportunity basis.

During the project, the International Maritime Organization (IMO) was working on guidelines for such analysis and its attendance at working groups allowed interaction with other developers and an opportunity to ensure the software being developed met future IMO requirements.

The project included manuals, training for Transport Canada staff, case studies and a commercialization plan. Commercialization of the product is already underway with great success.

The deliverable – Version 3.0 of *maritimeEXODUS* – meets 95 percent of the original Transport Canada requirement and exceeds the required capability in many respects. While the approach of international co-operation has reduced the Canadian ownership, the approach represented the lowest risk given the complexity of the problem, the limited data availability and the restricted budget, and has placed Canada in a leading position in this area.

It was concluded that the approach taken to this timely requirement was the optimum one, resulting in a high level of success and a commercially viable end product with a developing market. Commercial agreements and business plans have been put in place.

As a result of this project and a parallel Escape, Evacuation and Rescue (EER) project, Transport Canada has become recognized as a leader in the area of evacuation and should therefore pursue the advantages this brings.

It is recommended that further data collection on the SHEBA rig be pursued at full scale and that Transport Canada do this through co-operative projects such as the forthcoming PRECARN-supported project that is allowing Canadian participation in a European R&D project known as FIREXIT on ship evacuation that will result in an improved *maritimeEXODUS* model.

It is also suggested that future R&D be directed towards addressing the ability to assess the impact of crew/passenger ratios using the model.

SOMMAIRE

Le projet visait à développer un logiciel de simulation qui pourrait aider les inspecteurs maritimes à évaluer les procédures d'évacuation de navires. Outre l'aménagement du navire et le matériel de secours, le programme devait modéliser le comportement humain, les procédures d'évacuation, les mouvements du navire et des obstacles comme l'envahissement par l'eau et le feu, et distinguer entre le comportement des passagers et celui des membres d'équipage.

Une première phase a consisté à faire un inventaire des algorithmes, modèles et données pertinents. Les chercheurs ont alors constaté qu'il existait plusieurs modèles d'évacuation de bâtiment qui prenaient en compte le comportement humain, mais que les données se rapportant au comportement du navire étaient plutôt rares. Des travaux de développement d'un simulateur d'évacuation étaient entrepris à l'échelle internationale et il a été proposé, au terme de cette phase, de coopérer à un projet de développement en cours, cela étant vu comme la méthode la moins risquée permettant d'atteindre les objectifs assignés au projet.

L'équipe de projet a donc uni ses efforts à ceux du Fire Safety Engineering Group de l'Université de Greenwich, à Londres, dont la série de programmes d'évacuation EXODUS apparaissaient les plus appropriés comme bases pour l'élaboration d'un modèle d'évacuation de navire.

Parmi les modifications apportées au modèle, mentionnons l'ajout de scénarios d'abandon, soit le fait, pour les membres d'équipage de monter dans des radeaux de sauvetage et de quitter le navire. Il a également fallu modifier les modèles de comportement humain pour tenir compte des angles de gîte et des mouvements potentiels du navire. Comme il existait peu de données touchant cette dernière variable, l'équipe de projet a conçu et construit une installation représentant une partie de navire (cabine, coursive et escaliers) à laquelle on pouvait donner une gîte (statique) de 22 degrés. Des personnes du public, hommes et femmes, d'agilité physique et d'âges divers, ont participé à des essais dans cette installation (dite SHEBA) au cours de l'été 2001. Des données ont été colligées sur la vitesse de déplacement, etc., des sujets évacuant un navire accusant un angle de gîte maximal de 20 degrés. Comme il n'a pas été possible d'étudier les mouvements du navire, cette variable a été exclue.

La validation et le calage du modèle ont été entrepris à l'aide des données issues de plusieurs exercices d'évacuation auxquels participaient des sujets volontaires.

Pendant que se déroulait le projet, l'Organisation maritime internationale (OMI) travaillait justement à l'élaboration de lignes directrices touchant l'analyse des procédures d'évacuation. Sa participation à des groupes de travail a suscité des interactions avec d'autres chercheurs et a permis de s'assurer que le logiciel en cours de développement respecterait les exigences futures de l'OMI.

Le projet comprend des manuels, des modules de formation pour le personnel de Transports Canada, des études de cas et un plan de commercialisation. La commercialisation du produit a déjà commencé et elle connaît un vif succès.

Le produit à livrer – la version 3.0 du logiciel *maritimeEXODUS* – répond à 95 p. 100 au besoin initial de Transports Canada et dépasse les capacités exigées à de nombreux égards. La méthode retenue pour exécuter le projet, soit la coopération internationale, a réduit la part de propriété du Canada dans le produit final, mais cette méthode était la moins risquée, compte tenu de la complexité du problème, du peu de données disponibles et des restrictions budgétaires. Le Canada se trouve maintenant dans une position de chef de file dans ce domaine.

Il a été conclu que la méthode adoptée pour combler ce besoin était la meilleure dans les circonstances. Elle a débouché sur un grand succès et sur un produit final commercialement viable, pour lequel il existe un marché en expansion. Des accords commerciaux et des plans d'affaires ont été mis en place.

À la faveur de ce projet et du projet Secours, évaluation et sauvetage (SES), mené en parallèle, Transports Canada s'est taillé une place de chef de file dans le domaine de l'évacuation de navire et devrait donc tirer avantage de cette position.

Il est recommandé de continuer à colliger des données à l'aide de l'installation en vraie grandeur SHEBA. Transports Canada devrait, pour ce faire, s'associer à des projets coopératifs, comme le projet à venir appuyé par PRECARN, qui sera l'occasion pour le Canada de participer à un projet européen de R&D sur l'évacuation de navire, connu sous le nom de FIREXIT, et qui débouchera sur une version améliorée du modèle *maritimeEXODUS*.

Il est également suggéré que les travaux de R&D futurs portent sur la capacité d'évaluer, à l'aide du modèle, l'effet du rapport du nombre de membres d'équipage au nombre de passagers.

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GLOSSSARY OF ACRONYMS

AMOG	Australian Maritime and Offshore Group
BMT FTL	British Maritime Technology Fleet Technology Limited
EER	Escape, Evacuation and Rescue
FED	Fractional Effective Dosage
FIREEXIT	Formulation of Immediate Response and Evacuation Strategies through Intelligent Simulation Assessment and Large-Scale Testing
FP	Fire Prevention
FPCG	Fire Protection Correspondence Group
FPSO	Floating Production Storage & Offloading
FSEG	Fire Safety Engineering Group
IMO	International Maritime Organization
IP	Intellectual Property
ISM	International Safety Management
LSA	Life Saving Appliance
MCA	Maritime Coastal Agency (UK)
MES	Marine Evacuation Systems
SES	Ship Evacuation Simulator
SHEBA	Ship Evacuation Behaviour Assessment (facility)
SSL	Survival Systems Limited
TC	Transport Canada
TDC	Transportation Development Centre
TNO	Netherlands Organisation for Applied Scientific Research
U of G	University of Greenwich

1. INTRODUCTION

1.1 Administration

This document reports on the work performed on behalf of the Transportation Development Centre (TDC) of Transport Canada (TC), to develop a ship evacuation simulator (SES). This report constitutes the final deliverable under the contract. Other deliverables include copies of the software and licences, operating and theory documents, and test reports and case studies, not all of which are in the public domain.

The project was directed by Charles Gautier of TDC, with Serge Théorêt of Marine Safety, Quebec Region as "end user". For the majority of the project, the Client was represented by Bill Anderson. The BMT FTL project manager was Ian Glen.

1.2 Background

In the wake of a number of major maritime disasters such as the *Herald of Free Enterprise* and the *Estonia* (as well as a number of offshore rig disasters), and in light of the growth in the numbers of high-density, high-speed ferries and large capacity cruise ships, there is increased attention being paid to escape and evacuation at sea. TC is responsible for certifying evacuation and safety equipment in accordance with international and national regulations. However, a design that meets the regulations in all measurable respects may not meet the evacuation performance requirements, which now include maximum times for evacuating vessels.

While the new High-Speed and International Safety Management (ISM) Codes require some form of risk analysis to support the proposed design arrangements, the procedures for doing this are ill-defined. The result is that the regulations are open to subjective interpretation and inconsistent application. Without suitable tools that can relate the type, size and location of equipment and layout, etc., to the reality of evacuation, there is little scope for a rationally based approach to assessing the effectiveness of design approaches and evaluating their ability to meet the regulatory requirements.

TC Marine Safety recognized the need for improved methods for evaluating evacuation against specified performance standards, and initiated the development of this tool in 2000. During the course of the work, the International Maritime Organization (IMO), through its Fire Prevention (FP) Committee, also recognized the need for improved evacuation analysis for passenger ships. In the time frame of this work, the IMO introduced interim guidelines for the conduct of a simplified evacuation analysis [1] and has more recently introduced guidelines for evacuation analysis using the type of simulation tools developed under this project [2].

1.3 Project Objective

The objective of this project was to develop a simulator to model the emergency evacuation of a vessel, accounting for the available safety equipment, ship layout, evacuation arrangements, routes, nature of the complement and passengers, and prevailing ship and weather conditions at the time of the evacuation.

This objective has been met.

2. PROJECT APPROACH

2.1 Project Overview

The project was required to develop a PC-based simulator program that permits evaluation of evacuation scenarios from a variety of vessel types under a range of ship and weather conditions. The SES software was to be able to represent a wide range of spatial (geometric) configurations, as well as incorporate the effects on the human behaviour models of such factors as low visibility, adverse motions, large angles of heel, etc. The project was to involve the development of a user-friendly computer code using real-time simulation, suitable for use by a ship safety inspector, and which would lend itself to enhancement as data is developed to validate the model.

The project was originally divided into two phases. In the first phase, a review of the state of the art in evacuation simulation was to be conducted to determine what codes existed, the availability of data, and the nature and availability of algorithms, and from that to determine the development path. Following these initial tasks, there was to be a review and a decision on the way ahead.

In effect, during the preparation of the proposal by BMT FTL, two items became clear:

(1) Some development work was going on in this area.
(2) A fully compliant simulation package, developed from the bottom up, would cost much more than the project budget.

In the original proposal by BMT FTL, two approaches were proposed: a fully compliant one and an alternative approach whereby the project would build on an existing development effort, the alternatives being considered following the outcome of the initial review, at which point the project could also be halted.

2.2 Phase 1: Review of Available Models

The result of Phase 1, review of the available algorithms and models, was reported in [3]. This report covers three reviews of available software: a pre-existing one [4] and two that were contracted for under this project [5,6], the latter by BMT FTL's partner with human factors expertise, including an update of the status of some models reported in [4]. The conclusions from these efforts were:

- Validated algorithms for the various human performance and response attributes needed for evacuation in a level building under conditions of smoke, etc., are available.

- Algorithms for the human performance and response to marine-specific situations, including movement on shipboard stairs and ladders, and along angled passageways under motion were not available, but some development work was proceeding in this area.

- Numerous simulation models were available for building and aircraft evacuation that deal with the issues of layout, human interaction, etc., much of which is directly relevant to the marine evacuation scenario.

- About five SES's were at various stages of development, of which two being developed in Australia (EVACHSIP) and UK (EXODUS) provided enough information for us to evaluate the models and a potential future deal.
- Validation of models is a complex subject area, discussed in the literature (e.g., [7]) and, while some validation data was available, the use of full-scale trials is problematic.
- The greatest need, it was proposed, was in the execution of experimental work to collect missing data and to validate algorithms and models that were under development.
- Most existing models dealt with "normal" exit from a building or aircraft as the end point and did not include simulation of that portion of ship evacuation defined as "abandonment", when the passengers actually leave the ship by lifeboats, chutes or slides.

In the course of Phase 1, BMT FTL contacted the Australian Maritime Safety Agency and their contractor, Australian Maritime and Offshore Group (AMOG), which had started to develop a ship evacuation model. The Australians had deduced that none of the available models or algorithms was appropriate [5] and set out to develop their own model.

In Phase 1, BMT FTL had also contacted the University of Greenwich (U of G) Fire Safety Engineering Group (FSEG), which had developed a suite of building and aircraft evacuation models over a period of 10 or so years and had a team of about 20 working in this area full time. Its program, called EXODUS, was well-established and U of G had commenced work on the development of a maritime version [8].

In Phase 1, BMT FTL produced a software requirements document [9] that translated the requirements as expressed in the TC Statement of Work into a functional specification. This was later used to evaluate the two developing software packages that BMT FTL had selected as being suitable for co-operative research. A software test plan [10] was also developed that would be used on completion to measure the degree to which the software met these requirements.

At the end of Phase 1, it was concluded that the best approach to meeting TC requirements was to team with either AMOG or U of G FSEG developers to acquire access to an existing, proven model and to expend the current development effort on much needed data collection, program extension to meet marine evacuation requirements and specifically the TC requirements, and validation.

TC agreed with this approach and the Phase 2 work package was modified to reflect this new direction. One restriction, however, was that the TC contract terms limited the amount of funding that could be spent outside Canada to 20 percent of the project budget, reducing the funding for software development even further.

2.3 Phase 2: Acquisition and Further Development

Initial negotiations were held with AMOG and with U of G FSEG to assess their developing simulation tools. The software requirements document [9] was used to evaluate the two approaches based on information released during the negotiations. The Australian team was not prepared to release sufficient information for BMT FTL to assess the merits of its approach fully, but based on the data made available and deduced, the Australian model did not match the requirements to the same degree as did the software being developed at U of G. Of particular concern was the macro modelling approach in the Australian model, which was subsequently deemed inadequate by the experts at the IMO FP Working Group, which is developing guidelines for these types of models in evacuation analysis.

BMT FTL then approached U of G, which provided sufficient information, and many publications concerning its EXODUS suite of software and its embryonic development of a maritime version, to allow an objective assessment of the degree to which the software met, or could be developed to meet, the requirements of the SES project. The assessment of how the EXODUS suite met or could meet TC requirements was reported to TC. There were many advantages to an arrangement with FSEG, one being that FSEG lacked the marine domain expertise that BMT FTL could supply.

Phase 2 proceeded with a teaming arrangement between BMT FTL and U of G for the development of a ship version of the EXODUS software and the acquisition of data for use in the software.

3. DEVELOPMENT OF THE SIMULATION SOFTWARE

3.1 General

A development contract was given to U of G to develop a maritime version of the existing and successful EXODUS software. This model was developed at the FSEG in the Computation and Math Department of U of G. The EXODUS model had established a solid reputation since its launch in the late 1990s, having over 10 years of research behind it, sales of over 40 units, and a supporting staff of about 10 to 15.

Building on an existing model whose intellectual property rights remained with the developers and whose developer was overseas added some constraints to the project; however, as had been shown earlier, the approach showed promise of meeting all the requirements of TC, limited only by the availability of data for algorithm development and validation. This represented the lowest risk approach to the development requirement, given the relatively limited budget.

The development work included:

- designing and incorporating a new module to deal with the abandonment phase when crew and passengers leave the vessel via lifeboats, life rafts and/or chutes and slides;
- modifying the model to include the effect of heel angle and motions on passenger mobility;
- introducing shipboard procedures such as mustering and donning lifejackets; and
- designing a modern, Windows-based user interface that would meet marine users' needs and, in particular, would be useable by marine inspectors in their assessment of designs.

3.2 New Abandonment Model

The buildingEXODUS model counts the number of people exiting the building. For ship use, the model was required to deal with passengers entering lifeboats, sliding down chutes and slides, etc. This stage was identified as the "abandonment stage". The process of abandoning was itself defined in several steps, such as preparation time for the equipment, passenger hesitation at the entrance to the equipment, moving inside the equipment, engaging the equipment, and time to settle the equipment when the seas are not calm. These definitions were based on observation and discussion with operators. The definitions vary with the type of Life Saving Appliance (LSA).

The availability of data for the times for these processes was a problem and the project team attended two evacuation exercises (training exercises) on ferries to obtain some data. Data collection is discussed in section 7.

The model's treatment of geometry had to be modified to allow for the definition of the LSA types, capacity and locations. LSAs were initially treated in the same way as "exits" in the original program and had to be modified to introduce a maximum capacity feature, as well as the above-noted performance aspects. An LSA is attached to the hull geometry at the point where passengers embark. In the case of LSAs comprising a chute or slide, which deliver passengers into life rafts or onto platforms, a new feature was developed to represent the slide or chute. These are Transfer LSAs and identify an intermediate step to the final exit device where the counting of evacuated passengers takes place.

3.3 Effect of Heel and Motions

A data search showed little published data for the effect on passenger mobility of an angled floor (deck) or motions. The Australians had collected some data in a simple rig but did not publish useable data [11] and a European-funded program had collected data at TNO (Netherlands) in a motions rig, which only became available at the end of the project [12].

To collect quality data on the effect of an angled deck on passenger mobility, BMT FTL and FSEG designed and constructed a facility at BMT FTL's Kanata site that replicated a portion of a ship and could be tilted up to 20^o (static). The construction of the Ship Evacuation Behaviour Assessment (SHEBA) rig was funded entirely by BMT FTL, with funds from the current project being used to conduct tests on the rig to collect the necessary data. SHEBA is shown in section 7. During the summer of 2001, members of the public volunteered to participate in trials on this rig, and performance data across a range of ages, in group and individual tests, up and down stairs and in contraflow situations was collected. The time for passengers to don lifejackets was also recorded. The range of data collected is provided in Appendix A.

Other data opportunities were taken as they arose and included participating in evacuation tests on a passenger hydrofoil in Montreal, on a Thames River Cruise/dinner boat in London, UK, on the Terra Nova Floating Production Storage and Offloading (FPSO) and on an LSA training rig at Offshore Survival Systems in Halifax.

While the effect of static heel indicated considerable change in speed of personnel at angles beyond 10^o, as a function of age and gender, SHEBA was unable to provide motions (dynamic behaviour). This would have required a more complex system and much longer tests, which were not possible in the project budget and time frame. SHEBA will be outfitted for motions during 2002 for trials required by the European Community (see section 9). In the meantime, the software uses limited data collected under a previous European project at TNO in the Netherlands.

3.4 Shipboard Procedures

Modifications to the model to accommodate such marine-specific activities as retrieving and donning jackets, assembling in a muster station before "exiting", and directing passengers to specific locations such as cabins before going to the exit, were required. In fact, the EXODUS model already permitted individuals to be "tasked" by assigning them to go to a specific location (or locations) and to wait there for a period of time before proceeding to the next location or to the exit. This capability was extremely useful though somewhat cumbersome for large numbers of people.

In the delivered version of the *maritimeEXODUS* program (V3.0), the program permits assignment of tasks to blocks of occupants. The software allows the user to identify a location of lifejackets with each passenger or group of passengers before distributing the passengers to their starting locations, and this action will direct the passengers to return to their lifejacket positions before proceeding to their evacuation stations. In a similar way, the user can identify a location as a muster station to which location all identified passengers will migrate during evacuation.

Other procedural issues include assigning crew to LSAs and preparation times, and ensuring that the LSA is not ready for use by a passenger until the crew is present and the preparation time has elapsed.

It is expected that further development of ship-specific scenarios will be introduced as the program develops and is used.

3.5 User Interface

The contract called for a usual Windows™ interface and this existed in the EXODUS software, but required some refining. As an example of how the interface needed changing, the presentation of multiple “floors” in the building version allowed the floor levels to be “tiled” on the screen using the familiar tile command. The default tiles were somewhat square in presentation, so for example, four “floors” could be shown in the four quadrants of the screen. For a ship however, the deck plan views are invariably long but not deep, and so a more practical presentation of the tiles is as two or three long “windows” with horizontal tiling but no vertical tiling.

Other changes were made to improve the interface, including moving the common tool bar that appeared in every tile to the top of the screen for a single appearance. New “buttons” were introduced for lifejacket and mustering functions, and new dialogue boxes were introduced for new features such as LSA specifications, and heel and trim progression.

To meet the certification application that will be used by marine inspectors and regulators, it is envisaged that there will be predefined “scenarios” in which the distribution of the population (passengers and crew) in terms of numbers and ages, as well as the approximate distribution of these people throughout the vessel prior to the evacuation, will be specified. These scenarios may be a day and a night scenario as this will affect the starting locations and response times, and they will differ with ship type (Cruise, Tourist, Ro-Ro ferry, etc.). These predefined scenarios will be “built in” to the program and will be activated with a pull-down menu after which much of the input data may be bypassed. This feature is ready, but the scenarios have yet to be agreed upon by the international community.

4. THE INTERNATIONAL MARITIME ORGANIZATION

During this project, the BMT FTL project manager, and the FSEG director took an active part in the IMO Fire Protection Correspondence Group (FPCG) that was developing an understanding of the capability of these simulation tools and developing guidelines for their use. This was of great value in assuring that the model being developed for TC would meet IMO requirements. In fact, as it transpired, the model being developed under this contract has become the model to which other developers aspire and by which they measure their success. It is worth noting that the Australian model that BMT FTL investigated would not meet the IMO requirement as it was configured in 2000.

Members of the FPCG include many of the academics and researchers working on simulation models and other aspects of ship evacuation modelling, representatives of regulatory bodies and users, and cruise ship operators. The active participation of project team members in the FPCG (both BMT FTL and U of G staff) has been extremely valuable as it permitted us to:

- monitor activities internationally;
- obtain an early indication of where the regulatory bodies are headed with evacuation analysis;
- influence the direction taken by the regulatory bodies in specifying the simulation capabilities and requirements;
- exchange development and technology ideas with the leaders in the field; and
- compare results and validations.

Later in the project, the IMO FPCG provided example cases for all the developers to analyse with their different models. Results were compared and discussed to determine how the various modelling approaches compared. This offered a form of validation for the modelling approach. Information from this exercise was reported in various papers of the IMO FP46 [13].

5. THE PRINCIPALS OF *maritimeEXODUS*

5.1 Modelling Evacuation

The structure and operation of the EXODUS software and of *maritimeEXODUS* has now been published in a number of papers (e.g., [14], [15]). The information that is public domain is included herein for completeness, but the interested reader may also care to review the references.

To fully assess the potential evacuation efficiency of a ship, it is essential to address the configurational, environmental, behavioural and procedural aspects of the evacuation process [15].

Configurational considerations are those generally covered by conventional methods and involve enclosure layout, number of exits, exit type, corridor width, travel distance, etc. However, as noted above, there are important additional considerations. In the event of fire or flooding, ***environmental*** aspects need to be considered. These include the likely debilitating effects of heat and toxic and irritant gases, and the impact of increasing smoke density and/or water ingress on passengers' travel speeds and way-finding abilities. In addition, for ship-based environments, the sea conditions can affect the environment, causing list or rolling conditions and making egress more difficult. ***Procedural*** aspects cover the actions of the crew, passengers' prior knowledge of the ship interior, emergency signage, etc. Finally, and possibly most importantly, the likely ***behavioural*** responses of the passengers must be considered. These include aspects such as the passengers' initial response to the call to evacuate, likely travel directions, family/group interactions, etc. These four essential elements are incorporated in *maritimeEXODUS* in the form of a program structure that comprises six core interacting sub-models: the geometry, occupant, hazard, toxicity, behaviour and movement sub-models (Figure 5.1). The software describing these sub-models is rule-based, the progressive motion and behaviour of each individual being determined by a set of heuristics or rules.

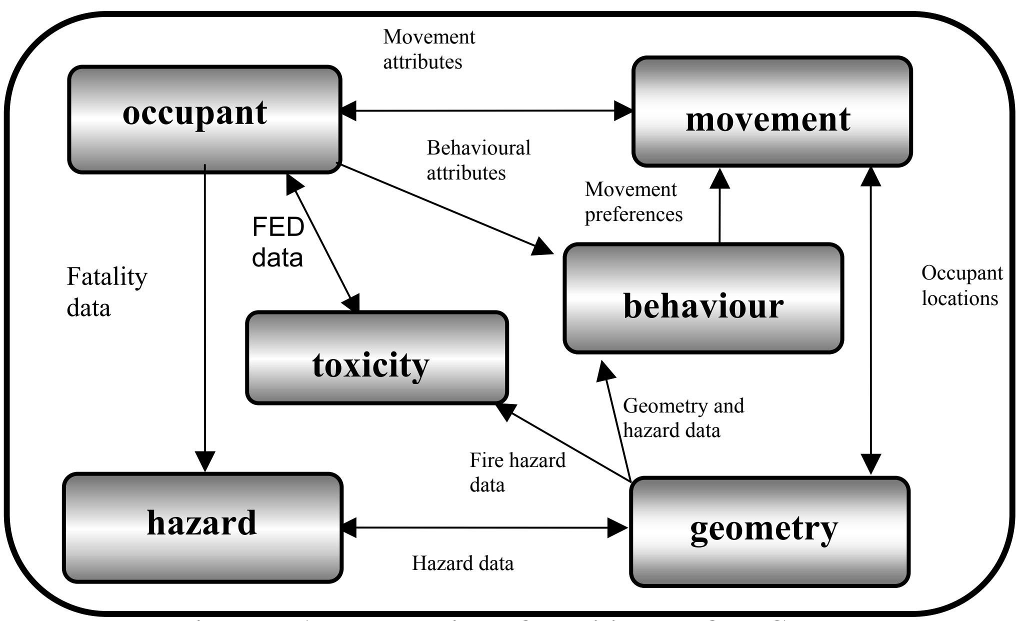

Figure 5.1: Interaction of *maritimeEXODUS* Modules

5.2 Geometry

The two primary parameters in the simulation are *space* and *time*. These spatial and temporal dimensions in the model are spanned by a two-dimensional spatial grid and a simulation clock. The spatial grid maps out the geometry of the structure, locating exits, internal compartments, obstacles, etc. Layouts with multiple decks can be made up of multiple grids connected by stairways, with each deck being allocated a separate window on the computer display. The ship layout can be specified using either a ".dxf" file produced by a computer-aided design package or the interactive tools provided, and may then be stored in a geometry library for later use. The grid is made up of *nodes* and *arcs*, with each node representing a small region of space (0.5 m by 0.5 m) and each arc representing the distance between each node.

Individuals travel from node to node along the arcs. Figure 5.2 shows the grid mesh for a single deck of a sample ship layout and Figure 5.3 is a close-up showing the node arc arrangement. Meshing progresses automatically and rapidly, and logical adjustments are made to cell sizes to fit actual geometries such that all habitable space is covered. Nodes are of different types and have different attributes. The most common node is a "free space" node that allows unhindered movement. Other nodes include boundary nodes that are adjacent to an obstruction, stair nodes, and specialist nodes for seats, LSAs and others. An example of the specialist node is an internal exit node that can be used to "count" the numbers passing over it during the evacuation.

Core attributes common to all nodes include an identifier and location, and a primary attribute is "potential"– essentially the physical distance from the nearest exit, which, combined with the exit attractiveness, forms the "potential map" that controls the movement of occupants. Node attributes also include the environmental factors at the node (temperature, toxic gas or smoke density).

Once the physical configuration of the vessel is defined, the user provides data used by the *maritimeEXODUS* sub-models.

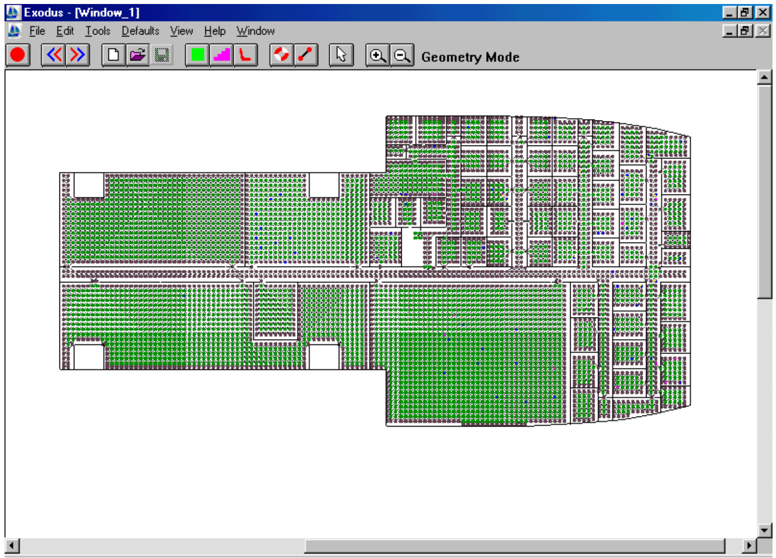

Figure 5.2: Meshing of a Deck Plan

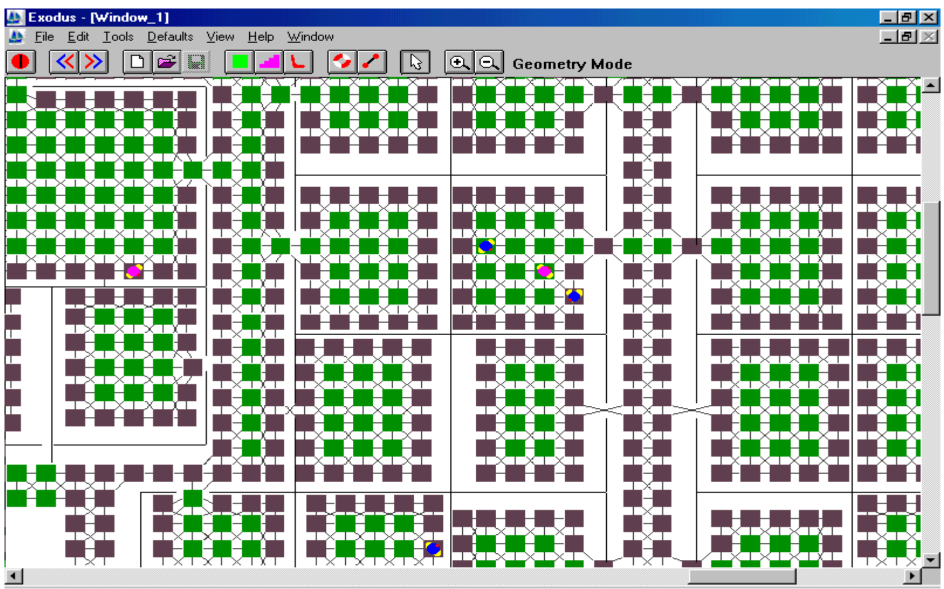

Figure 5.3: Details of Arc-Node Mesh

5.3 Occupant

The **Occupant** sub-model allows the nature of the population of crew and passengers to be specified. This can consist of a range of people with different movement abilities, reflecting age, gender and physical disabilities as well as different levels of knowledge of the ship layout, its escape arrangements, response times, etc. This information can be provided to each occupant individually or in groups. Table 5.1 lists the Occupant attributes considered.

Table 5.1: Occupant Attributes

Gender	Fast Walk Speed
Age	Walk Speed
Weight	Leap Speed
Height	Crawl Speed
Response Time	Up-Stair Speed
Mobility	Down-Stair Speed
Agility	Target Exit
Drive	Familiarity
Patience	Itinerary

- The Mobility attribute allows the introduction of physical disabilities and/or response to the environment such as toxic gases. Mobility is used in conjunction with travel speed and agility.
- The Agility attribute is used in conjunction with the mobility attribute but is a reflection of prowess (e.g., the occupant's ability to leap over a seat or table).
- The Drive attribute is an indicator of an occupant's assertiveness and modifies the behaviour, for example, when competing for possession of a node.
- The Patience attribute is the amount of time an occupant is prepared to wait before considering another action.
- The Response Time attribute is the time the occupant takes between the first sounding of the alarm and reacting. This is a critical value, having a significant effect on the evacuation time.
- The Target Exit attribute allows the user to specify an LSA and to ignore the potential map approach to exiting. This will be used more commonly in passenger vessel evacuation where passengers have a designated LSA and do not merely proceed to the nearest one.
- The Familiarity attribute allows the user to account for the occupant's knowledge of the LSAs. This can either be a single LSA (default) or a list up to all (e.g., Crew member). This influences local behaviour.
- The Itinerary attribute allows the user to specify "tasks". In essence, this lists nodes to which the occupant must go to prior to making for the LSA, and is where one sets the requirement to go to cabins first, to muster stations or to the location of other occupants.

While the scope of the data is comprehensive, much of the data is present by default. Much of the data for these characteristics has been acquired from years of experiments in buildings, but it is here that the data specific to mobility in a ship has been entered based on the experiments carried out. For example, modification of the speed on a stair is required to accommodate steeper stairs and ladders, and is accomplished by modifying the value in the defined characteristic by a modifier that is an attribute of the actual item (stair, ladder) and is also a function of an individual's personal attributes.

5.4 Hazard

The **Hazard** sub-model controls the atmospheric and physical environment in both spatial and temporal terms. In the case of atmospheric environment, this includes the spatial and temporal distribution of fire hazards (CO, CO_2, O_2 depletion, etc.), heat, smoke and water. This model also sets any physical restrictions such as the opening and closing times of doors, etc.

The Hazard sub-model will impose these hazards on the occupants as they move through the model. This sub-model also has the capability to accept experimental data or numerical data from other models. For example, output files from certain fire spread models can be directly read into the program.

An example of manual specification of a hazard would include:

a) Spatial: defining the zones in which the hazard is growing (Zone 1 is stairwell, Zone 2 is corridor and cabins 1 to 4, Zone 3 is cabins 5 to 8, etc.).
b) Temporal:
   For $0<t<10$
      Temperature = ambient + $0.01*^{2}$
   For $10<t<100$
      Temperature = ambient + $0.1*t^{2.5}$

5.5 Toxicity

The **Toxicity** sub-model determines the physiological impact of the environment (hazard) on the occupant. For example, the core toxicity model implemented is Purser's Fractional Effective Dose (FED) model [16]. This model considers the toxic and physical hazards associated with elevated temperature, thermal radiation, HCN, CO, CO_2 and low O_2 and estimates the time to incapacitation. In addition to this behaviour, the occupant is allowed to stagger through smoke-filled environments and is given the ability to select another exit path, based on familiarity with the structure, when faced with a smoke barrier. Furthermore, as the smoke concentration increases and visibility decreases, the travel speed of the occupant is reduced according to experimental data. Movements may slow and eventually result in casualties.

While it is noted that the flooding model will be dealt with similarly, it is still under development and is not included in the Version 3.0 delivery as there is little or no data on which to base the rules.

5.6 Behaviour

On the basis of an occupant's personal attributes, the **Behaviour** sub-model determines the occupant's response to the current situation and passes its decision on to the **Movement** sub-model. The model has the capability of implementing two behavioural regimes: **Normal** and **Extreme**. Under **Normal** behaviour, an occupant is prepared to wait until it is possible to make the desired move. Under the **Extreme** regime, an occupant will wait patiently until a period of time equal to the user-defined "patience attribute" has been met before taking actions that could result in jostling around or possibly recommitting to another course of action.

The **Behaviour** sub-model is the most complex module and incorporates adaptive capabilities that include structural knowledge, reaction to communication, affiliative behaviour, occupant motivation and a stochastic element to the queuing recommitment behaviour. The basis of the model is a series of rules.

The **Behaviour** sub-model functions on two levels. **Global** behaviour involves implementing an escape strategy that may lead an occupant to exit via the nearest serviceable exit, an assigned exit, or most familiar exit. As noted above, the occupant's familiarity with a particular ship layout may be set by the user prior to commencing the simulation, thus enabling a distinction between crew and passenger. This important feature can be used to examine, for example, the effect of crew/passenger ratios. Also, as noted, it is possible to assign an occupant with an itinerary of tasks: for example, visit a predefined location such as a cabin (to fetch lifejackets) that must be completed prior to evacuation. This is an essential feature if one is to simulate crew who must take up duty stations during an evacuation. Finally, each occupant or a group of occupants can be assigned a specific muster station or LSA for their target exit.

As an example of how the exit strategy is modelled, in the case where the occupant is exiting via the nearest exit, the occupant follows the potential map that is formed around the exits, moving always to a lower potential, sidestepping to a node of equal potential if no lower is available, and waiting if only higher potentials are available. The potential (or attractiveness) of exits can be changed to reflect the occupant familiarity, available signage or visibility of the exit.

Note that the features added in Version 3.0 whereby occupants are globally assigned to an assembly station or to cabin locations using the graphical interface modifies the global behaviour.

Local behaviour includes such considerations as determining the occupant's initial response to the call to evacuate (i.e., will the occupant react immediately or after a short period of time, or display behavioural inaction, conflict resolution, overtaking or the selection of possible detouring routes?). The manner in which occupants will react to local situations is determined in part by their attributes. As certain behaviour rules, such as conflict resolution, are probabilistic in nature, the model will not produce identical results if a simulation is repeated.

5.7 Movement

The **Movement** sub-model is the main simulation engine in which the movement of the occupants is calculated using the information from all the other modules. The calculation is carried out at time steps of $^1/_{12}$ second. The **Movement** sub-model delivers the output of the location of all occupants at each time step using a series of complex algorithms and rules governed by the other models.

5.8 Abandonment with LSAs

The abandonment model includes the definition of LSAs (survival craft and Marine Evacuation Systems (MES) such as chutes and slides), their location, type, performance data and status. Passengers may be assigned to an LSA or left to find the nearest one. Crew are also assigned to an LSA and the state of readiness of the LSA can be changed with the arrival of a crew member. Therefore, if a lifeboat requires crew to be present before it can be operated, this criterion must be met before the device is operational. Again, these options are dealt with by defaults that can be overridden by the user if desired. The current version of the program does NOT allow the redirection of passengers by crew members, but this is under development for a later version.

MES such as slides and chutes, with their accompanying platforms and life rafts, are treated at component level (i.e., the slide has performance criteria, as does the platform at the bottom, etc.) This approach has two major benefits:

(1) The program can readily accommodate the wide range of configurations of MES, including any which may emerge in the future.
(2) The program can be used to assess the "design" of such systems (e.g., the impact of a double slide / single platform versus a single slide / single platform on evacuation times, or the effect of having six life rafts deployed around a "mother" platform versus four).

Figure 5.4 is the LSA dialogue box and shows the characteristics that must be specified for LSAs, the "Active" characteristics being dependent on the type of LSA defined. This dialogue box includes such items as hesitation at the top of a chute, system preparation time and, for lifeboats, the lowering speed and the height. All are defined in the *maritimeEXODUS* Quick Reference Guide. It is here that default data from manufacturers and from trials will be inserted, and the collection of the data for these devices is the subject of a European/Canadian project in 2002.

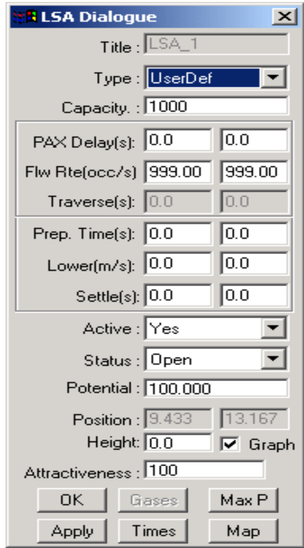

Figure 5.4: Specifying the LSAs

6. PROGRAM OUTPUT

maritimeEXODUS produces a range of output, both graphical and textual. Interactive two-dimensional animated graphics are generated as the software is running (see Figure 6.1). Output times for individuals, total time to muster and evacuate, and graphs of numbers evacuated versus time are produced at each LSA and overall for comparison against prescribed standards. The user can observe the evacuation as it takes place and can interrogate occupants and events. A "population density" mode provides immediate indication of points of congestion. A data output file is produced containing all the relevant information generated by the simulation, including a copy of the input data. This file can be used, for example, to determine the waiting time of any individual or group of individuals and this can assist in comparing procedures or layouts. The track of any individual, the longest track, etc. can be shown. To aid in the interpretation of the results produced by the model, several data analysis tools have been developed. These are intended to be used once a simulation has been completed and enable large data output files to be searched and specific data selectively and efficiently extracted.

In most cases, such as certification runs to meet IMO requirements, the desired output will be statistical and a large number of program runs will be required. As noted earlier, since the selection of many of the parameters is statistical (e.g., a value chosen from a distribution between an upper and lower bound), the same initial scenarios will not generate identical results. Thus it is desirable to make a statistically significant number of runs of the program. In this respect, *maritimeEXODUS* is superior to all of the other developing programs in that it has a "batch mode" set-up and the speed of the analysis allows multiple runs to be conducted in a reasonable time frame. (The time for a simulation run is, of course, a function of the number of personnel in the run and the size of the vessel.)

Interpreting such results would involve selecting an acceptable level of exceedence and comparing this with whatever standard is being used. For example, the response may be that the time to evacuate the whole ship will be less than the rule time 95 percent of the time (5 percent chance of excedence).

In addition, a post-processor virtual-reality graphics environment has been developed (vrEXODUS), providing an animated three-dimensional representation of the evacuation (see Figure 6.2). This presentation is most useful for demonstrating where counterflow is causing problems in passageways. One of its features is that individuals who carry out the "fetch lifejacket" task are shown to change upper body colour (to yellow) when they are wearing their lifejackets.

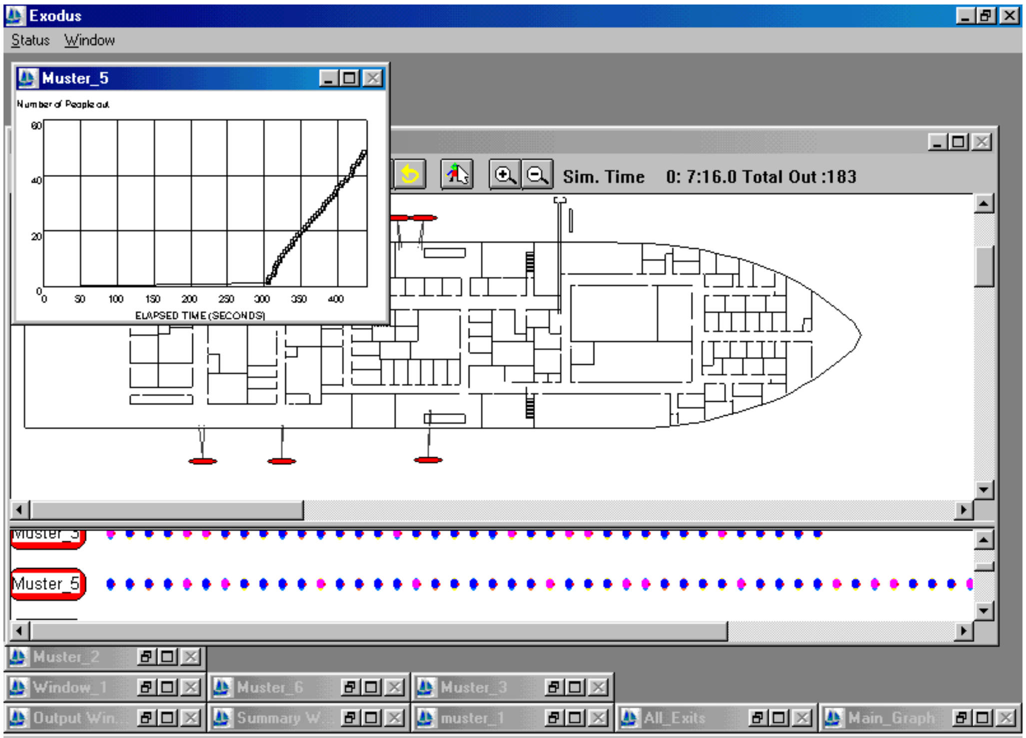

Figure 6.1: Interactive Two-Dimensional Animated Graphics

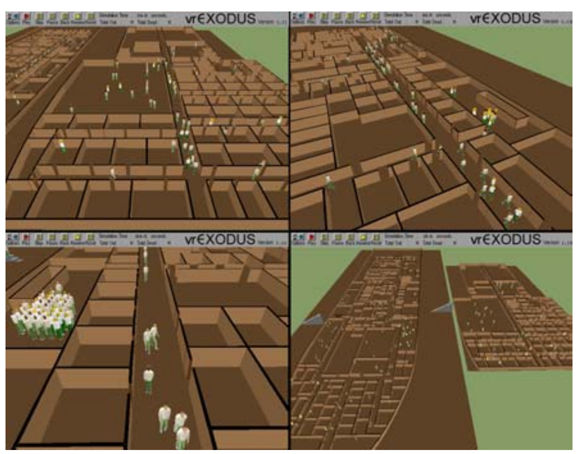

Figure 6.2: vrEXODUS Representation of *maritimeEXODUS* Predicted Ship Evacuation

7. DATA COLLECTION

7.1 SHEBA Facility

Part of this project was to collect data for inclusion in the model where such data was not available. As noted earlier the project team designed and built a facility which modelled a section of a ship at full scale and which could be used to collect mobility data in passageways and on stairs at angles up to 22 degrees of lateral tilt (heel). The facility is known as SHEBA and is shown in Figures 7.1 and 7.2

The SHEBA simulator consists of a small room (3.65 m x 2.4 m) at one end (muster station) attached to an 11 m long corridor. The corridor is connected to a flight of stairs ascending 2 m to a platform and exit. The corridor and stair dimensions (and stair slope) are based on standard sizes found on passenger vessels. Railings were also fitted in the corridor and along the stairs according to standard ship sizes. The corridor is 1.89 m wide (1.63 m between railings). The staircase is 1.53 m wide (1.30 m between railings). The staircase has a total of 9 steps. The vertical distance between each step is 200 mm with a step run of 230 mm.

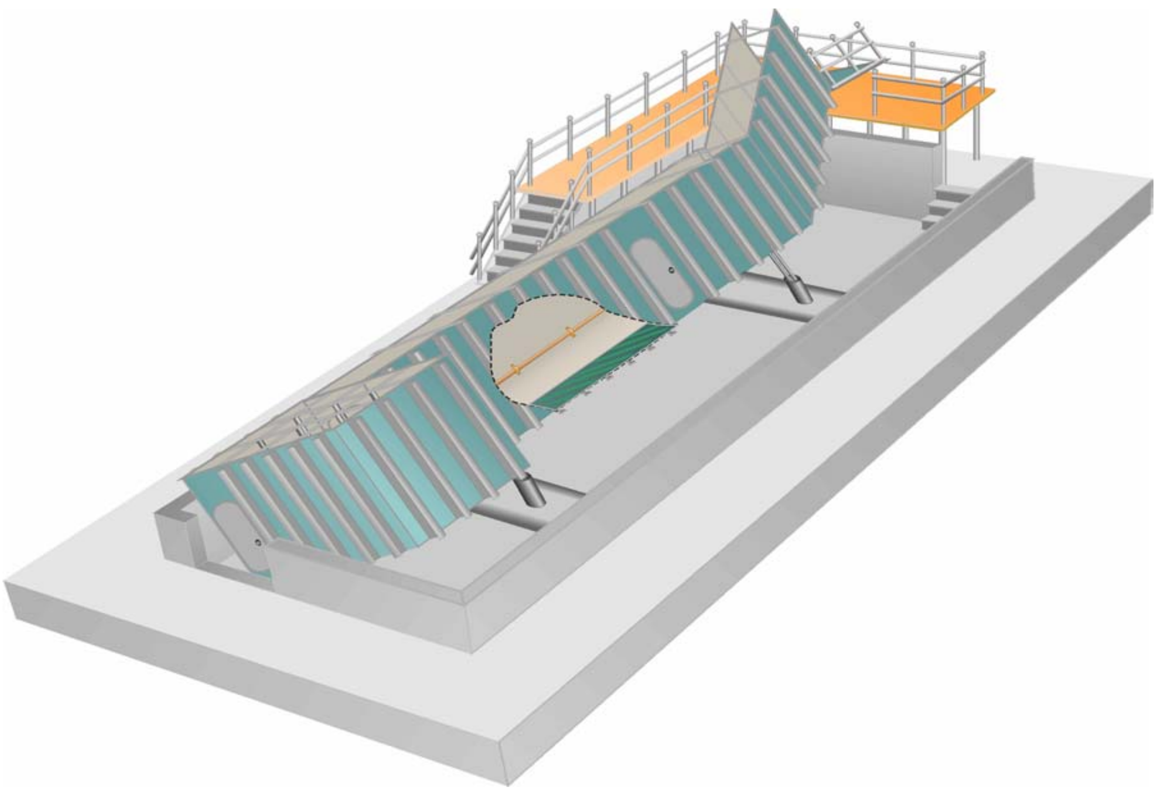

Figure 7.1: Artist's Rendering of SHEBA Rig

Figure 7.2: The SHEBA Simulator

To measure the speed of individuals in the passageway, there are three optical sensors connected to a data acquisition computer. The sensors are spaced 4.6 m apart and are approximately 1 m from the floor (see Figure 7.3). The first sensor is approximately 1 m from the mustering room, while the last sensor is about 1 m from the bottom of the stairs. This was done to eliminate the acceleration and deceleration phases of movement in the passageway. A custom program was used to calculate the time intervals between the first and second, and second and third sensors. Speed on the stairs was also measured with optical sensors.

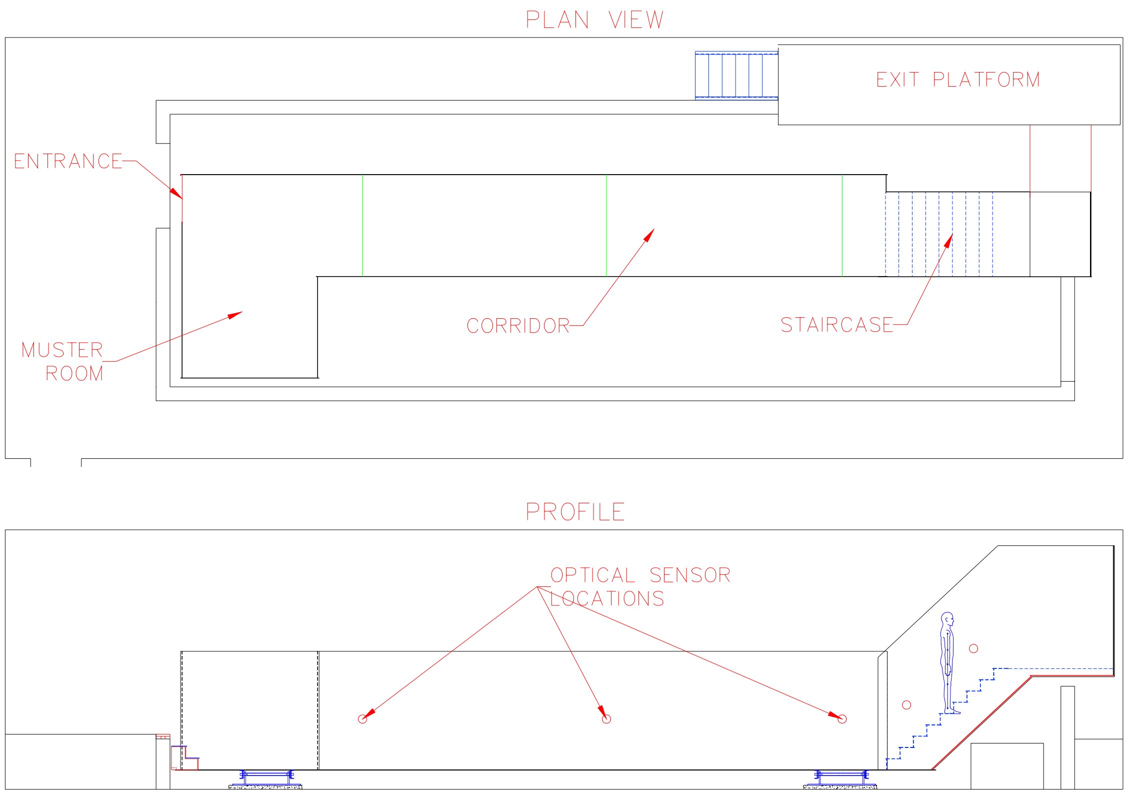

Figure 7.3: Profile and Plan Views of SHEBA Simulator

The speed and behaviour of groups were analysed from video recordings taken from six cameras positioned overhead in the passageway and stairs (Figure 7.4). The locations for recording the times (and the locations of the optical sensors) were shown by black lines marked on the floor and walls of the facility. The black lines were easily visible in the video recordings even when a large number of people were in the passageway.

Each of the video cameras recorded to its own dedicated video cassette recorder, each with a synchronized digital timer that recorded onto the tape for measuring times of individuals and groups to $^{1}/_{100}$ s.

Part of the study using the SHEBA facility was to determine the flow rate of people through a typical silled ship doorway. Tests were done at a range of angles and with and without lifejackets. Three test groups were used for the door tests.

Members of the public, in groups of about 15, were processed through the rig over a period of several weeks in summer 2001. The test plan was such that test personnel did not “adapt” to increasing angle. Times to don lifejackets were also measured.

The data from these tests was used in Version 3.0 of *maritimeEXODUS*, along with limited published data from a smaller rig used for experiments at TNO in the Netherlands.

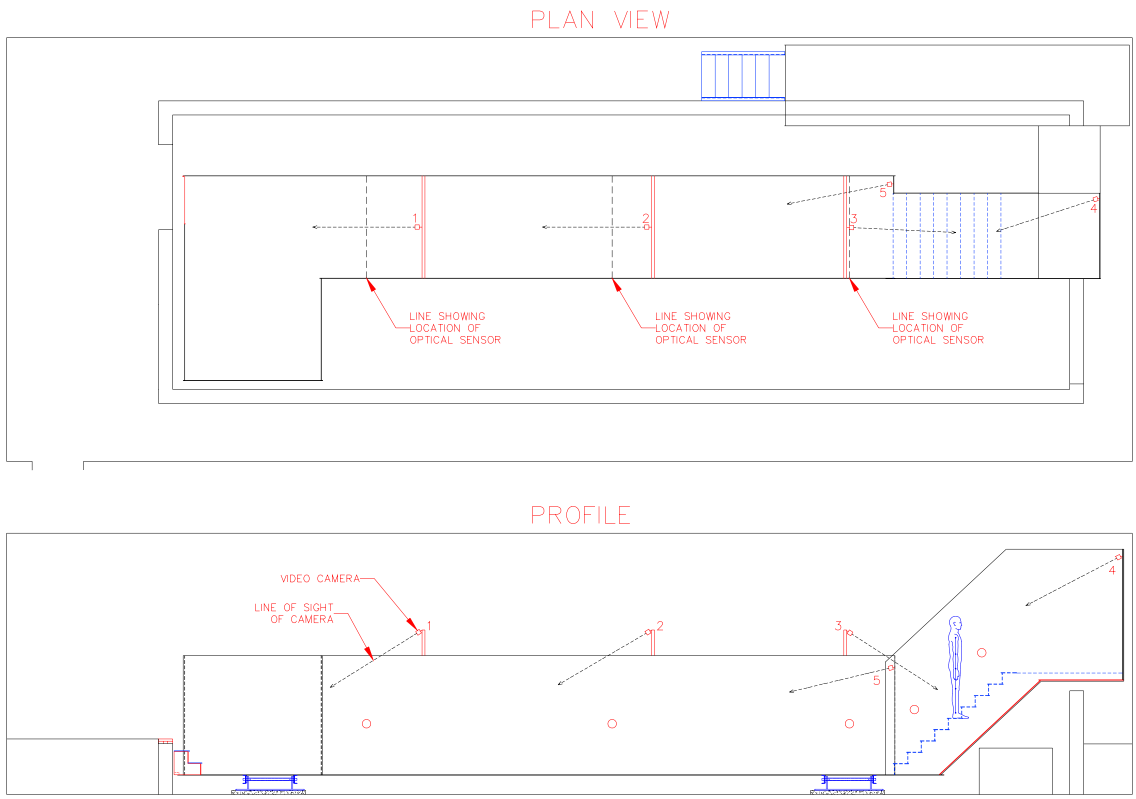

Figure 7.4: Location of Cameras in SHEBA

7.2 Full-Scale Trials

During the project, a number of full-scale trials, with participation on an opportunity basis, provided some useful data for model development and validation.

7.2.1 Evacuation Trials from Small Passenger Vessels

Two evacuation trials from small vessels were attended. The project leader was fortunate to participate in an evacuation exercise from the Thames River dinner cruise vessel MV *Naticia* in London, UK, in June 2001, conducted for the UK Maritime Coastal Agency (MCA). Controlled evacuation tests were conducted from the vessel, tied up alongside the wharf, with volunteers representing about half of the full capacity of the vessel. Times were recorded and video records made. An early version of *maritimeEXODUS* was used to predict the response times, given the distribution of the population, with excellent results (see Figure 7.5 taken from [17]). The report of these trials [17] was not released to the public by MCA.

This acted as a validation of the program for a relatively simple evacuation from a small vessel, but it was shown that behaviour such as an evacuee redirecting to an alternative exit on the basis of the size of the waiting group at the destination exit was reproduced by the *maritimeEXODUS* algorithms.

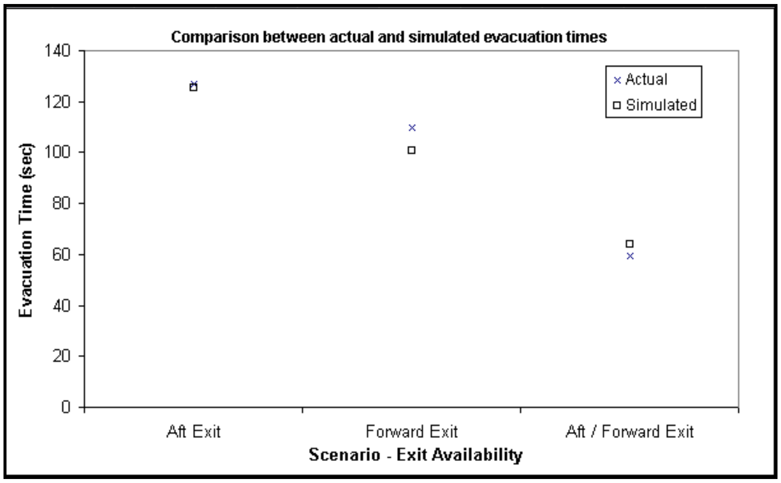

Figure 7.5: Comparison of Trials and *maritimeEXODUS* Results for MV *Naticia*

The project team also participated in an evacuation trial from a passenger hydrofoil, destined for a Montreal-Quebec City run, while docked in the Port of Montreal. Again, half of the capacity of the vessel was populated with a good range of ages and both genders. On the command to abandon ship, lifejackets were donned, a life raft on the water side was inflated and passengers entered the life raft. Timing of the process was recorded and video was made. This data has not yet been compared with any *maritimeEXODUS* runs.

7.2.2 LSA Tests on Ferries

BMT FTL Project team members attended two LSA tests on Ro-Ro ferries. These tests are carried out either for crew training or for LSA installation certification. Neither test involved passengers and was generally not carried out in an "emergency" environment.

Video and timed records of the activities were noted and allowed the project team to understand the stages of the process, define the components of the LSA simulation and collect some basic timing data. As an example of the issues to be dealt with, during exercises involving a chute, only one person is allowed in the chute at a time. This may not be the case in a real emergency.

7.2.3 The EER Project

A parallel Escape, Evacuation and Rescue (EER) research project is being funded by TC [18] and this provided opportunities to collect data and validate the model on two occasions.

On one occasion, at the invitation of Survival Systems Limited (SSL) of Dartmouth, NS, the project manager attended a series of tests carried out with Dalhousie University students in which various evacuation events were timed. Times for individuals and groups to transit passageways (in the SSL offices), including clearing through a silled door, and to don survival suits were recorded. Later, the test team moved to SSL's LSA test facility over Dartmouth harbour where they were timed climbing and descending ladders, and descending a chute system (Skyscape).

This data was reported and compared with SHEBA data. However, it was felt that the control of the tests for these experiments was not adequate and the numbers of test personnel insufficient to provide the quality of data required for a program such as *maritimeEXODUS*. This is not a criticism of the EER tests, but rather a reflection of the fact that *maritimeEXODUS* distinguishes age groups, genders, familiarity, etc., attributes that were not measured in the EER trials. Nevertheless, as spot checks on some of the data in *maritimeEXODUS*, the exercise was useful. It was particularly useful in providing information on the use of a chute and in assisting with developing correct testing procedures.

The second associated project was an opportunity to attend tests on board the Terra Nova FPSO. In this project, timed evacuations from various locations on the ship to the Temporary Safe Refuge were combined with detailed measurement of distances along escape routes. Test personnel included a male and female student and male crew members. The tests gave an opportunity to measure the speed of people on vertical ladders and steep stairs as well as on the flat deck. This data was used first to *calibrate* values in *maritimeEXODUS* (from some runs) and then the program was used to *predict* the results for other locations with very satisfactory results. These tests were useful in validating the mobility models and adding new data for speed on vertical ladders. However, the evacuations were simply from a starting position to a finishing position along a prescribed route and therefore the behaviour models in *maritimeEXODUS* were not exercised. The results were reported to Petro-Canada in a brief report [19] from which Table 7.1 is extracted.

Table 7.1: Terra Nova FPSO – Typical Route Evacuation Times

Case	Trial(s)	Simulation	Delta
Male 45	114	114	0%
Male 38	126	110	-12.7%
Male 32	105	107	1.90%
Female 24	155	132	-14.84%
Average Error			-6.41%

It is noteworthy that there is some significant overlap between this SES project and the EER project, although they were initially run apparently without knowledge of each other. The project teams have tried to maintain contact and there is potential for future joint efforts in some areas.

8. DELIVERABLES

The deliverables under this project included:

- Software and licences;
- Documentation;
- Project reports;
- Project website;
- Test cases;
- Training course;
- Commercialization plan.

8.1 Software and Licences

The SES software to be delivered under this project is called *maritimeEXODUS* and is a development of an established product developed by the U of G FSEG, with whom the Intellectual Property (IP) rests. The delivery of the software is under an agreement between BMT FTL and U of G, and four copies of the software were delivered under the licence. Following Beta testing, the delivered version was V3.0. A single copy of the vrEXODUS post-processing software was also delivered.

8.2 Documentation

Documentation delivered under this project includes restricted documentation that is tied to the ownership of the software licence and project documentation.

8.2.1 Software Documentation

The software was delivered with a comprehensive manual that includes the user manual, the theory manual and a tutorial.

In addition, a "Quick Reference Guide" was developed to assist the user with the more commonly used procedures.

These documents are not referenced because of their confidentiality.

8.2.2 Project Documentation

A number of documents were produced under this project in addition to project progress reports. These documents initially referred to the project as "MES, Marine Evacuation Software". This is not to be confused with MES – Marine Evacuation Systems.

Interim reports were produced as follows:

FTL 5101C.IR1	After the initial phase, Task 3), which reported on the findings and provided the rationale for the change in direction
FTL 5101C.IR3	SHEBA Data Acquisition Methodology

Project documents produced were:

Project Management Plan	FTL 5101-001
Software Development Plan	FTL 5101-002
Software Requirement Specification	FTL 5101-003
Software Functional Test Plan	FTL 5101-004
Plan for the Acquisition of Experimental Data	FTL 5101-005
Commercial Plan for Ship Evacuation Simulator	FTL 5101-007*
Specification for the Submission of Data for Review of Ship Evacuation Using Ship Evacuation Analysis Software	FTL 5101-008

* Commercial Confidential

In addition, regular weekly and monthly progress reports and milestone reports were produced.

8.2.3 Project Website

A project website was established to allow all qualified parties to access information as it was developed. The website was accessed through the BMT FTL website and was protected by passwords. Documents, pictures, status reports and minutes of meetings were posted there on a regular basis.

8.2.4 Test Cases

Two real cases were used for testing and training. These involved the two Quebec-based ferries, *Camille du Four* and *Cavalier Maxim*.

8.2.5 Training

BMT FTL staff provided two days of training for four Marine Safety personnel at their Quebec City offices when the program was delivered.

8.2.6 Commercialization Plan

Part of this requirement was to develop a commercially viable product, and one of the deliverables was a commercial plan. The commercial aspects of the project were considered throughout. A licence agreement has been signed between BMT FTL and U of G for the commercialization of *maritimeEXODUS*, in which FTL and its sister company, BMT Seatech in the UK, will act as sole agent for software sales and consulting. The BMT network of clients in the shipping regulatory and military agencies is worldwide.

During the project, a number of papers were given by BMT FTL and U of G that introduced the *maritimeEXODUS* software. The reception it got was very positive; indeed, it was clear that the market existed before the product was ready. While promotion of the product has been active since October 2001, when it was introduced at the annual Society of Naval Architects and Marine Engineers show in Orlando, Florida, no products will be made available until the completion of the Beta testing, acceptance of this product by TC, completion of the manuals, etc.

Further presentations were given at the cruise industry's biggest show in Miami, Florida, in March and again, the product received good reviews. Specific presentations have been given at a rate of about one per week to individual cruise companies, ferry operators and naval defence contractors, as well as regulators including UK MCA and Lloyd's Register.

There have been several articles featuring the program in international magazines, including *New Scientist*, *Lloyd's List*, *Fairplay International* and others, and a number of television stations have broadcast features covering the software and the SHEBA rig, including Discovery Channel, CBC and CTV in Ottawa, and German and Italian state TV.

Brochures have been produced for both the software and the SHEBA rig.

Expenditure by FTL alone on commercialization has exceeded $40,000 to date, with equal contributions from BMT Seatech and U of G.

9. FUTURE PLANS

Towards the end of the project, a proposal was submitted to the European Parliament Fifth Framework R&D program by FTL – with its new parent BMT, a number of European organizations and U of G – for funding support to take *maritimeEXODUS* to the next level. The work scope includes integrating a smoke/fire spread model, incorporating ship motions, integrating with the world's most used ship design software (TRIBON), and using a post-processor for optimizing designs based on the evacuation results using artificial intelligence methods. This project, known as FIREEXIT, included Canadian participation using SHEBA for smoke and motions data collection, the Institute for Marine Dynamics for data on performance of LSAs in a seaway and the Marine Institute for data on LSA performance using full-scale equipment. Some of this proposed work parallels the activity with the EER program.

The European funding does not cover Canadian organizations, but a program known as PRECARN can be used to support joint Canadian-European research and PRECARN has accepted a proposal for the Canadian work. These programs cover about 40 percent of the required funding.

Thus, over the next few years, more work on the LSA and on ship motions data collection (a requirement of this project that was not achieved) will be carried out and TC will benefit directly as the software is updated.

IMO is discussing the possibility of organizing full-scale ship trials with a large number of passengers. UK MCA is also considering such a project, allowing competing simulation developers to co-operate in the data collection.

In Canada, there is scope for closer co-operation and integration of the EER work with this model.

10. CONCLUSIONS

(1) TC's requirement to develop an SES was an ambitious and timely one. The structure of the project allowed an assessment of the feasibility of developing such a tool, from the base up, to be made early on and thereafter permitted redirection of the project to satisfy the requirement within the constraints imposed by budget, lack of data, etc. This approach, and the flexibility that it demonstrated, has proven to be very effective in this development, benefiting all parties.

(2) The project to develop an SES to TC's specification, including human behaviour and interaction, fire, smoke and flooding, and ship heel attitude and motions has been completed with achievement of some 95 percent of the requirements as specified. This was achieved by building on development work being carried out in the UK on an established building evacuation simulation program.

(3) The decision to embark on international co-operation in the development of the program, while reducing the IP assets of TC and the Canadian participants, has resulted in the development of a program that has international credibility because of its pedigree and the reputation of its developers, has achieved international recognition and acceptance in the marine community, and is backed by a full-time development team.

(4) The shortfalls in the performance and scope of the delivered software are due to lack of data to support the development of the specified features. These will be addressed in future developments of the program to the benefit of TC.

(5) In the course of the project, and motivated by the demands of the project, a facility to collect missing data on the behaviour of persons in non-level deck conditions was designed and constructed by the project team (SHEBA). Some project funding was directed to the conduct of tests in this rig and the data has been incorporated in the program. This is a unique data set and the facility is a unique facility.

(6) Validation of the program was based on a combination of previous validations for the code in the building and air modes, plus limited validation of the marine version from controlled evacuation trials on a Thames River Dinner Boat and the Terra Nova FPSO. Additional effort to carry out full-scale validation is needed and international co-operation in this is preferred. This is currently being discussed at IMO and with cruise line operators.

(7) In addition to delivering a fully documented software package, a quick reference guide and a specification for the submission of data for analysis by the program were developed to assist the Marine Safety Inspector users.

(8) A commercial agreement between the partners and a commercialization plan have been activated and the commercial activity is underway on a broad front with outstanding success.

(9) Limited liaison with a parallel TC initiative took place and benefited this project. Future work is planned for the EER and for the further development of *maritimeEXODUS*.

11. RECOMMENDATIONS

(1) There can never be enough quality data for validation and algorithm refinement and if there is future funding, then this can best be directed towards full-scale data collection. Full-scale data collection on ships with real people is, however, expensive and co-operative approaches are essential. It is recommended that TC keep abreast of IMO and UK MCA initiatives in this area and that it participate in these through part funding. With leading expertise in ship evacuation, including the conduct of trials here in Canada, such funding could be directed towards Canadian activity.

(2) The European/PRECARN project is only funded at 40 percent, requiring the participants to contribute considerably. TC could support parallel activity, data analysis, funding of “volunteers”, etc. to support this effort and reduce the burden on the participants.

(3) A feature of the program that was desired by TC but not satisfactorily achieved in Version 3.0 was to allow the exploration of the effect of crew/passenger ratios on the evacuation. A full understanding of how this would be defined and then modelled was not readily achieved, and the development of a comprehensive feature of this type remains outstanding. TC could fund the specific development of this feature that would require functional definitions, algorithm development and program changes.

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APPENDIX A

SCOPE OF TESTS CONDUCTED ON SHEBA

APPENDIX A: SCOPE OF TESTS CONDUCTED ON SHEBA

A.1 Candidate Statistics

Table A.1: Total Number of Candidates Used for Testing

Candidate Gender and Age	Number
Total Males and Females	145
Males (all ages)	83
Females (all ages)	62
Males (5-17)	7
Males (18-29)	17
Males (30-50)	27
Males (51+)	32
Females (5-17)	7
Females (18-29)	12
Females (30-50)	25
Females (51+)	18

Table A.2: Candidates in Passageway and on Stairs Wearing Life Jackets (Individual Runs)

Heel Angle	Males	Males	Males	Females	Females	Females
(degrees)	18-29	30-50	51+	18-29	30-50	51+
0	8	16	16	8	8	7
5	3	0	6	2	1	4
10	12	13	16	9	17	7
15	2	10	6	0	3	5
20	4	8	8	7	13	3

Table A.3: Candidates in Passageway and on Stairs Without Lifejackets (Individual Runs)

Heel Angle	Males	Males	Males	Females	Females	Females
(degrees)	18-29	30-50	51+	18-29	30-50	51+
0	7	8	9	3	11	4
5	0	0	0	0	0	0
10	2	2	4	0	2	5
15	1	3	4	0	1	3
20	6	5	5	3	10	1

Children were also used as test candidates but the data from them was not fully analysed as Exodus does not currently use people under the age of 18.

Table A.4: Test Candidates under the Age of 18

Group Number	Gender	Age
3	Male	15
3	Female	13
3	Female	14
3	Female	5 (see Note A)
4	Male	16
6	Female	7
7	Male	9
7	Male	5
7	Male	12
7	Female	14
9	Male	14
9	Female	14
9	Female	13
9	Female	8
9	Male	11

Note A: The 5-year-old girl was accompanied by her mother during the tests and is not included in other statistics. Her mother was candidate number 7 on day 3.

Table A.5: Numbers of Candidates Used by Angle

A.5(a) With no door opening

Type	0^o	5^o	10^o	15^o	20^o
Group	60	15	30	31	34
Individ.	46	16	49	31	32
Contra.	29		16	30	33
Group No jackets	16		18	16	16
Individ. No jackets	34		16	16	
Contra. No jackets	16		18	32	15

A.5 (b) With door opening in place

Type	0^o	5^o	10^o	15^o	20^o
Group	35		19	19	16
Individ.			35		19
Group No jackets	34		35	19	15
Individ. No jackets	35				35

In the above tables, it is apparent that only a small number of candidates were used at 5 degrees. Following the initial testing at 5 degrees, it was noted that speeds of individuals did not significantly change when compared with zero degrees. In a few cases, individuals were faster at 5 degrees than at zero. As a result, the test plan was revised to concentrate on the higher angles.