Crewing Effectiveness
Modeling Proof of Concept

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ABSTRACT

This project was a proof of concept employing a combination of simulation models with the intent of using a mature version of the combined model to compare crewing levels and automation as a method to investigate crew optimization possibilities. The damage control domain of the Halifax Class Frigate was used as the test environment. Models employed were the Integrated Performance Modeling Environment and the Fire and Smoke Simulation Model. The results of the modeling effort were assessed against measures of effectiveness developed in a previous study. The analysis showed that the combined models could be used to generate useful measures of effectiveness in comparing various crewing levels and a varying probability of reliability for automated sensors and systems.

RÉSUMÉ

Le présent projet était une validation de principe employant une combinaison de modèles de simulation dans le but d'utiliser une version affinée du modèle combiné pour comparer les niveaux de dotation en équipage et l'automatisation comme façon d'étudier les possibilités d'optimisation d'équipage. Le domaine du contrôle des avaries de la frégate de classe Halifax a été utilisé comme environnement d'essai. Les modèles employés étaient l'*Environnement intégré de modélisation des performances* et le *Fire and Smoke Simulation Model*. Les résultats des efforts de modélisation ont été évalués par rapport à des mesurse d'efficacité élaborées dans une étude précédente. L'analyse a montré que les modèles combinés peuvent être utilisés pour produire des mesures d'efficacité utiles en comparant divers niveaux de dotation en équipage et une probabilité variable de fiabilité pour les systèmes et capteurs automatisés.

EXECUTIVE SUMMARY

In January 08, Defence Research and Development – Toronto commissioned a feasibility study in support of the Navy to investigate the use of modeling and simulation as a means to evaluate the effectiveness of proposed crewing levels for ships. The study comprised three main tasks:

1. Task 1 - A survey of crew optimization strategies;
2. Task 2 - Development of a limited-scope damage control model; and
3. Task 3 - Development of a full-scope damage control simulation model.

This document reports on Task 2, development of a limited-scope damage control model.

Task 2 required demonstrating a proof of concept for a chosen modeling approach. This included the development of a simulation model focusing only on the damage control function (rather than all of a ship's functions), and using the Halifax Class Frigate as a test case. Damage control was chosen as the focus because it is often considered a major driver for crewing requirements. Also, it was possible to leverage from previous and ongoing work on Defence Research and Development Canada's Applied Research Project on Optimized Crewing for Damage Control. Specifically, ongoing work on the development of a damage control philosophy should inform the investigation of crew optimization strategies. In addition, previous work on functional modeling of damage control, development of damage control scenarios and measures of effectiveness, as well as ongoing work on the analysis of crew and automation options for damage all serve as useful inputs to the development of the simulation model. During the model development process it was important to ensure that the approach taken to develop the simulation model be capable of application to functions of the ship other than damage control.

Measures of Effectiveness were selected as a method to compare crewing and automation options (including design considerations such as redundancy and construction materials), and varying combinations of the two. Measures of Effectiveness were selected that would be easily understood by domain experts and are comparable to Measures of Effectiveness currently in the Fleet when assessing damage control exercises. The measures are parameters such as 'time to confine a fire', and 'number of compartments affected by smoke'.

Damage and damage propagation was modeled using the Fire and Smoke Simulation Model [1]. It is a network fire model written to specifically simulate the spread of fire and smoke in a naval vessel. An existing platform was used as the development of a Halifax Class Frigate model was too involved for the proof of concept – a model of the Halifax Class Frigate could be developed by Mississippi State University if the next phase of the project is pursued. Critical outputs from the model were the number of compartments affected by fire and smoke given eight different conditions.

The task network modeling tool used to simulate the crew and automation conducting damage control tasks was created with the Integrated Performance Modeling Environment application.

The two models were combined using a Java application as a bridge. Information was exchanged between the application and the Integrated Performance Modeling Environment that affected the overall outcome by reducing the propagation of damage or by allowing smoke and heat to spread into neighbouring compartments. The overall outcome was a model that has the ability to show variation in damage when automation is applied, directly related to previously published measures of effectiveness for damage control. There was a strong correlation between times to extinguish the fire and times to confirm the fire was extinguished (overhaul and adjacent compartment rounds) and the changes in reliability of automation. This proof of concept effectively demonstrated the usefulness of combining a damage propagation model with a task network model to investigate potential automation and crew optimization possibilities.

The following recommendations are made:

Phase III of the research project, including development of an underlying Halifax Class Frigate model, should be continued. The task network model's functionality should be extended to include the tracking of individuals. The usefulness of this model should be extended across all aspects of the ship based on examination of the higher level measures of effectiveness, in order to determine the impact of crewing and automation on the operational capabilities of the ship. Future experiments should also vary the location, intensity, and type of fire in the Fire and Smoke Simulation Model to investigate fully the capabilities of planned configurations of crewing levels and automation, and to consider more complex damage scenarios involving flood as well as fire.

SOMMAIRE

En janvier 2008, RDDC Toronto a commandé une étude de faisabilité pour aider la Marine à enquêter sur l'utilisation de la modélisation et de la simulation comme moyen d'évaluer l'efficacité des niveaux de dotation en équipage proposés pour les bâtiments. L'étude comprenait trois tâches principales :

4. Tâche 1 – Une étude de stratégies d'optimisation d'équipage;
5. Tâche 2 – Développement d'un modèle de lutte contre les avaries à portée limitée; et
6. Tâche 3 – Développement d'un modèle de simulation de lutte contre les avaries à portée maximale.

Ce document fait rapport sur la tâche 2, développement d'un modèle de lutte contre les avaries à portée limitée.

La tâche 2 nécessitait de démontrer une validation de principe pour une approche de modélisation choisie. Cela comprenait le développement d'un modèle de simulation se concentrant seulement sur la fonction de lutte contre les avaries (plutôt que sur toutes les fonctions d'un bâtiment), et utilisant la frégate de classe Halifax comme banc d'essai. La lutte contre les avaries a été choisi comme point de mire, car il est souvent considéré comme facteur important en matière de dotation en équipage. De plus, il était possible d'utiliser des travaux précédents et en cours portant sur le *Applied Research Project on Optimized Crewing for Damage Control* de RDDC. En particulier, le travail en cours portant sur le développement d'une philosophie de lutte contre les avaries devrait opuvoir renseigner les enquêteurs sur les stratégies d'optimisation d'équipage. De plus, le travail précédent portant sur la modélisation fonctionnelle de lutte contre les avaries, le développement de scénarios de lutte contre les avaries et les mesures d'efficacité, ainsi que le travail en cours sur l'analyse d'options d'automatisation et de recrutement d'équipage pour les avaries sont utiles au développement du modèle de simulation. Au cours du processus de développement de modèle, il était important de s'assurer que l'approche adoptée pour développer le modèle de simulation est en mesure de s'appliquer aux fonctions du bâtiment autres que la lutte contre les avaries.

Des mesures d'efficacité ont été choisies afin de comparer les options de dotation en équipage et d'automatisation (y compris les considérations de conception comme la redondance et les matériaux de construction), et diverses combinaisons des deux. Des mesures d'efficacité facilement comprises par les experts du domaine et comparables aux mesures d'efficacité présentement en vigueur dans le parc lors de l'évaluation d'exercices de lutte contre les avaries ont été choisies. Les mesures sont des paramètres comme le temps nécessaire pour circonscrire un incendie et le nombre de compartiments où il y a de la fumée.

Les dommages et la propagation de ceux-ci ont été modélisés à l'aide du *Fire and Smoke Simulation Model* (Floyd et al., 2004a, 2004b; Haupt et al., 2006). Il s'agit d'un modèle élaboré pour simuler la propagation du feu et de la fumée dans un bâtiment. Une plate-forme existante a été utilisée, car le développement d'un modèle de frégate de la classe Halifax était trop complexe pour la validation de principe – un modèle de la frégate de classe Halifax pourrait

être mis au point par l'université Mississippi State si on tente de réaliser la prochaine phase du projet. Des informations essentielles obtenues grâce au modèle sont le nombre de compartiments touchés par le feu et la fumée (huit conditions différentes données).

L'outil de modélisation de réseaux de tâches utilisé pour simuler l'équipage et les dispositifs automatiques en train d'effectuer des tâches de lutte contre les avaries a été créé à l'aide de l'application *Environnement intégré de modélisation des performances*.

Les deux modèles ont été combinés en utilisant une application Java comme passerelle. De l'information a été échangée entre l'application et l'*Environnement intégré de modélisation des performances* et celle-ci eu un effet sur le résultat global en diminuant la propagation des avaries ou en permettant à la fumée et la chaleur de se répandre dans les compartiments environnants. Le résultat global était un modèle qui a la capacité de montrer les variations en matière d'avaries lorsque l'automatisation est appliquée, en lien direct avec les mesures d'efficacité publiées précédemment concernant la lutte contre les avaries. Il y avait une forte corrélation entre le temps nécessaire pour éteindre le feu et le temps nécessaire pour confirmer que le feu est éteint (inspections complètes et des compartiments adjacents) et les changements concernant la fiabilité de l'automatisation. Cette validation de principe a démontré efficacement l'utilité de combiner un modèle de propagation des avaries et un modèle de réseau de tâches pour analyser les possibilités en matière d'optimisation de l'équipage et de l'automatisation.

On fait les recommandations suivantes :

La phase III du projet de recherche, y compris le développement d'un modèle de frégate de classe Halifax sous-jacent, doit se poursuivre. La fonctionnalité du modèle de réseau de tâche doit être étendue à la localisation des individus. L'utilité de ce modèle doit être étendue à tous les aspects du bâtiment à partir de l'examen des mesures d'efficacité de niveau supérieur afin de déterminer l'impact de la dotation en équipage et de l'automatisation sur les capacités opérationnelles du bâtiment. Les expériences à venir doivent aussi varier l'emplacement, l'intensité et le type d'incendie dans le *Fire and Smoke Simulation Model* afin d'enquêter à fond sur les capacités des configurations planifiées des niveaux de dotation en équipage et de l'automatisation, et afin de tenir compte de scénarios plus complexes en matière d'avaries impliquant les envahissements et les incendies.

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SECTION ONE – INTRODUCTION

1.1 GENERAL

Defence Research and Development Canada is providing support to the Navy by investigating the use of modeling and simulation to evaluate the effectiveness of proposed crewing levels for ships. There are many different strategies for optimizing crews, including but not limited to: using automation, re-allocating functions between ship and shore, or re-defining the missions that a ship will or will not perform. Therefore, any simulation model for assessing and comparing the effectiveness of specific crewing levels will need to begin with a clear and meaningful set of assumptions (i.e., policy, doctrine, acceptable risk, and acceptable cost). The simulation model will also need to consider plausible and operationally significant scenarios (i.e., series of events that will be challenging to a ship's crew from a resource perspective, but that the ship will ultimately be expected to manage successfully). The integrated test environment will need to represent the ship as one system, including not just the crew, and not just the technologies, but both; furthermore, the crew needs to be specified not just as an overall number, but as a configuration of specific numbers of crew for specific functions. Finally, the simulation model needs to employ multiple meaningful metrics, so instead of addressing the simple question of which crewing level is best, it should address why and how a given crewing level differs from another, including advantages and disadvantages.

Given the many requirements mentioned above, the simulation model needs to be developed in stages. This contract represents the first stage of this development. Essentially the first stage is a feasibility study to determine whether modeling and simulation can be meaningfully applied to address crewing questions, and if so, to demonstrate how such a simulation model would be built and used.

The overall study has three well defined tasks: 1) to identify and analyze crew optimization strategies that may be considered by the Navy; 2) to investigate (and demonstrate, if possible) the feasibility and the value of applying modeling and simulation to evaluate the effectiveness of proposed crewing levels for Navy ships by developing a limited scope integrated modelthat focused only on a small number of crewing/automation options and one segment of a damage control scenario; and 3) to extend the integrated model by increasing the number of crewing/automation options and by creating two full damage control scenarios.

The overall purpose of the project supported by the work described in this report was to provide to the Navy with a means of testing the effectiveness of various crewing levels for ships. The project was broken into three tasks, with the first two running concurrently. The work described in this report was in support of the task two. The basis of this work will support a go or no-go decision for the final task.

1.2 PROJECT OBJECTIVES

This portion of the study was a proof of concept for a chosen modeling approach. It included the development of a simulation model focused only on the damage control function (rather than all of a ship's functions). Damage control was chosen as the focus because it is often considered a major driver for crewing requirements. The focus on damage control also allows the project to leverage on previous and ongoing work from Defence Research and Development Canada's (**DRDC**) Applied Research Project on Optimized Crewing for Damage Control. Specifically, ongoing work on the development of a damage control philosophy should inform the investigation of crew optimization strategies. In addition, previous work on functional modeling of damage control, development of damage control scenarios and measures of effectiveness, as well as ongoing work on the analysis of crew and automation options for damage control should all serve as useful inputs to the development of the simulation model. During the model development process it was important to ensure that the approach taken to develop the simulation model would be capable of application to functions of the ship other than damage control.

Given that this Task was a proof of concept, several assumptions and concessions were made in order to progress the modeling simulation effort in a timely manner.

1.3 PURPOSE OF THIS REPORT

This report provides a clear documentation of the methodology employed, describes the results generated from the trial simulation, and provides recommendations for a way ahead. The report will be used by the Scientific Authority and the sponsoring Navy project of the Canadian Forces to determine if a full scope model, with comparison across three crew models and refined testing of automation, should be pursued.

1.4 REPORT OUTLINE

This report consists of the following sections:

a. Section One – Introduction

b. Section Two – Methodology

c. Section Three – Results

d. Section Four – Discussion and Conclusion

The content of each section is self explanatory. Each section commences with a general discussion of the respective contents.

1.5 ACKNOWLEDGMENTS

The project team would like to thank Dr. Fred Williams, Director, Navy Technology Center for Safety and Survivability for providing the Fire and Smoke Simulation Model (**FSSIM**) to facilitate this research, and to both Dr. Williams and Mr. Greg Henley, Research Associate, Cooperative Computing, Mississippi State University for their patience and guidance in supporting our questions about the FSSIM.

SECTION TWO – METHODOLOGY

2.1 GENERAL

The intent of this proof of concept was to combine models in order to investigate the effectiveness of varying levels of crew and automation in a damage control situation. The overall modeling effort was divided into four sections. During the kick-off meeting there was an in-depth discussion regarding which models were to be combined, what was to be the resultant output, and the overall rationale for developing the combined model. It was concluded that the model's output must allow for the comparison between different configurations of crew and automation, for the same damage scenario, in order to support design and build assumptions. Further, to anchor the project's analysis, both a specific damage (fire) and a selection of suitable Measures of Effectiveness (**MOEs**) would have to be developed and agreed upon. A previous study, Torenvliet, G. L., Jamieson, G. A., & Cournoyer, L. (2007), provided a damage scenario and a set of MOEs that were considered appropriate – the specific MOEs are described below in subsection 2.2.

Use of Integrated Performance Modeling Environment (**IPME**) was directed by the Scientific Authority, based on known capabilities of the application as a performance modeling tool. Selection of the damage modeling tool was based on a brief review of existing tools and algorithms for predicting the effects of damage events. The model most familiar to the scientific community, and the only one readily available (important given the compressed schedule) was the Fire and Smoke Simulation Model (**FSSIM**). The FSSIM model and the associated output is described below in subsection 2.5. FSSIM provided some advantageous features to the trial, such as accurate and well-validated results, but also had some drawbacks, such as the lack of a capability to accept modifications during runtime, that needed to be addressed in the conduct of the trial.

Once the FSSIM model was fully understood, including its outputs and its limitations that required workarounds, the construct of the IPME model could be finalized. This is described below in subsection 2.6. The final step was to combine the FSSIM output with the IPME model and generate results. This final step is described in subsection 2.7.

2.2 DAMAGE

It was decided at the commencement of the project to leverage the work conducted in the Functional Modeling, Scenario Development, and Options Analysis to Support Optimized Crewing for Damage Control project for selection of a damage scenario. This project proposed and defined two fire scenarios resulting in different levels of damage, a medium complexity and a high complexity scenario. It was determined, for the proof of concept, to model the medium complexity scenario, with a fire located in the Refrigeration Machinery Space. It was also determined, in consultation with domain experts, that the medium complexity fire would not exhaust the personnel in the Section Base Teams or the manning pools, therefore the IPME model would not require the logic needed to track individual personnel. This is further explained in subsection 2.6.

2.3 HALIFAX CLASS FRIGATE MODEL

The initial intent with this task was to model the Halifax Class Frigate as the location for the scenario to unfold. No such model exists for the FSSIM database. A cursory examination of the ship model fidelity required by FSSIM pointed to the fact that the level of effort to develop even a section of the Halifax Class Frigate (for example all compartments between bulkheads 12 and 20.5) was beyond the scope of the current feasibility study. Further, the specialized nature of FSSIM model development required that the original model developers, Mississippi State University, were needed to efficiently develop a suitable new model. This activity was beyond the scope and timeline of the proof of concept, therefore a decision was made in consultation with the Scientific Authority to use a surrogate compartment from one of the existing FSSIM trial platforms. This is discussed below in subsection 2.5.

2.4 MEASURES OF EFFECTIVENESS

MOEs were selected that would be easily understood by domain experts in that they are comparable to MOEs currently used in the Fleet when assessing damage control exercises. These include items such as time to confine a fire and number of compartments affected by smoke.

The basis of the MOEs was the Torenvliet, G. L., & Jamieson, G. A. (2007) report. The complete list of MOEs from the noted report are included in Table 2-1. The measures selected for the proof of concept are highlighted in the table below and include:

- Time to detect fire (Task 2.1.1)
- Accuracy of fire detection (Task 2.1.1)
- Time to assess impact of fire (Task 2.2.1)
- Accuracy of assessed impact of fire (Task 2.2.1)
- Number of compartments affected by fire spread
- Time to prepare to control fire (Task 3.3)
- Time to extinguish fire (Task 3.4)
- Time to confirm fire extinguished (Task 3.5)
- Time to contain fire (Task 3.1)
- Time to bound fire (Task 3.2)
- Time to shut down ventilation to affected section (Task 3.1.1)
- Number of compartments (besides those with fire) affected by smoke
- Time to isolate power for personnel safety (Task 3.3.3)

Abstraction Hierarchy Node		Measures of Effectiveness
FUNCTIONAL PURPOSE		
1.01	Stability	Ability for personnel to stay on ship Period of ship roll
1.02	Manoeuvrability	Ability to move under own power
1.03	Mission effectiveness	Ability to remain on station

Abstraction Hierarchy Node		Measures of Effectiveness
1.04	Personnel safety	Number of casualties
1.05	Economic stewardship	Overall monetary impact of damage
1.06	Environmental protection	Impact of ship on environment (potentially qualitative)
ABSTRACT FUNCTION		
2.01	Reserve Buoyancy	Volume of the watertight portion of the ship above the waterline
2.02	Structural integrity	Amount of designed structural integrity remaining
2.03	Positive righting arm	Righting arm Righting moment
2.04	List and trim	Amount of list Amount of trim
2.05	Ability to maintain operational speed	Difference between maximum speed possible and operational speed
2.06	Ability to maintain desired course	Available turning rate Available turning radius
2.07	Ability to communicate	Time required to communicate and receive feedback on an internal message Time required to communicate and receive feedback on an external message
2.08	Ability to navigate	Time required to obtain current position Accuracy of position reckoning
2.09	Ability to sense environment	Range of available sensors Time required to obtain position, course, and speed for a contact Accuracy of position, course, and speed reckoning Accuracy of friend/foe determination
2.10	Ability to affect environment	Range of required effectors Capability of required effectors
2.11	Minimize casualties	Number of casualties
2.12	Minimize resource damages	Monetary value of damaged resources
2.13	Minimize resource expenditures	Monetary value of resources expended
2.14	Minimize environmental impact	Impact of ship on environment (potentially qualitative)
GENERALIZED FUNCTION		
3.01	Freeboard	Distance between waterline and the top of the watertight structure of the ship
3.02	Watertight integrity	Total influx of water Amount of shoring or repairs in use to maintain watertight integrity
3.03	Structural strength	Safety margin afforded by overall remaining structural strength

Abstraction Hierarchy Node		Measures of Effectiveness
3.04	Load and balance	Weight/volume of water taken on by flooding Time to detect load and balance problems (Task 2.1.4) Accuracy of detection of load and balance problems (Task 2.1.4) Time to assess impact of load and balance problems (Task 2.2.4) Accuracy of assessment of impact of load and balance problems (Task 2.2.4) Time to redistribute loads across the ship (Task 6.1) Time to remove bilge water (Task 6.2)
3.05	Propulsion	Number of propulsion sources available Amount of time each propulsion source is unavailable due to the effects of damage
3.06	Steering	Availability of steering systems Amount of time steering systems are unavailable
3.07	Internal comms	Availability of internal communications systems Amount of time internal communications systems are unavailable
3.08	External comms	Availability of external communications systems Amount of time external communications systems are unavailable
3.09	Navigation sensors	Availability of navigation sensors Amount of time navigation sensors are unavailable
3.10	Power generation and distribution	Amount of power available Integrity of power network
3.11	Targeting sensors	Availability of targeting sensors Amount of time targeting sensors are unavailable
3.12	Effectors	Availability of effectors Amount of time effectors are unavailable
3.13	Helicopter support	Availability of helicopter support Amount of time helicopter support is unavailable
3.14	Protective measures	(*None*)
3.15	Prompt response	Total time from onset of damage to containment
3.16	Prevention measures	(*None*)
3.17	Spill prevention / containment	Volume of bilge-water expelled from ship
3.18	Resource allocation	(*None*)
PHYSICAL FUNCTION		

Abstraction Hierarchy Node		Measures of Effectiveness
4.01	Flood control	Time to detect flood (Task 2.1.2) Accuracy of flood detection (Task 2.1.2) Time to assess impact of flood (Task 2.2.2) Accuracy of assessed impact of floods (Task 2.2.2) Time to contain flood (Task 4.1) Time to remove / manage source of flood (Task 4.2) Time to remove flood water (Task 4.3) Number of compartments lost to sea due to primary damage Number of compartments lost to sea outside of primary damage zone (or, secondary flooding)
4.02	Structural reinforcement	Time to detect structural problems (Task 2.1.3) Accuracy of structural problem detection (Task 2.1.3) Time to assess impact of structural problems (Task 2.2.3) Accuracy of assessed impact of structural problems (Task 2.2.3) Time to enact shoring (Task 5.1)
4.03	Fire suppression	Time to detect fire (Task 2.1.1) Accuracy of fire detection (Task 2.1.1) Time to assess impact of fire (Task 2.2.1) Accuracy of assessed impact of fire (Task 2.2.1) Number of compartments affected by fire spread[†] Energy release rate for fire[†] Time to prepare to control fire (Task 3.3) Time to extinguish fire (Task 3.4) Time to confirm fire extinguished (Task 3.5)
4.04	Fire containment	*First six MOEs from Fire Suppression plus…* Time to contain fire (Task 3.1) Time to bound fire (Task 3.2)
4.05	Ventilation	Time to shut down ventilation to affected section (Task 3.1.1) Number of compartments (besides those with fire) affected by smoke
4.06	Power isolation	Time to isolate power for personnel safety (Task 3.3.3)
		Number of ship systems affected by power isolation

Table 2-1. Measures of Effectiveness.

The Tasks identified in parentheses after each MOE are fully described in Torenvliet, G. L., & Jamieson, G. A. (2007). The tasks are the same damage control tasks used in the IPME model and form the basis of the crew and automation damage control effort.

For the proof of concept it was decided that only MOEs from the Physical Function level of the abstraction hierarchy would be tracked. MOEs from higher levels of the abstraction hierarchy could be the subject of future work, but such an investigation was considered beyond the objectives of the current proof of concept. This would require linking the damage control effort to specific resources, and linking the association between compartments lost to damage with the resultant effects on operational capabilities of the ship. For example, losing the Fire Control Equipment Room #1 will reduce certain warfare capabilities, specifically anti-air and anti-surface capabilities. MOEs from higher levels of the hierarchy that might be considered are: 2.10 – Ability to affect environment, 3.07 – Internal Communications, 3.08 – External Communications, 3.10 – Power generation and distribution, and 3.11 – Targeting sensors. This future activity could offer interesting perspectives on the overall assessment of crewing impacts in terms more relevant to operational effectiveness.

2.5 FIRE AND SMOKE SIMULATION MODEL

To provide validity to the model the 'physics-based' FSSIM was used as the basis for the propagation of damage from a predetermined fire. FSSIM is a network fire model written to simulate the spread of fire and smoke in a naval vessel. It is a well documented model with a recently updated Graphic User Interface (**GUI**). FSSIM has passed through a rigorous validation and verification program with the United States Navy, under the direction of Dr. Fred Williams, Director, Navy Technology Center for Safety and Survivability. Documentation supporting FSSIM is noted in the References section.

FSSIM is designed to be deterministic (if the initial conditions are identical the outcome will be the same each time it is run) and cannot be interrupted or stimulated with probabilistic events during runtime. Because it is deterministic it is only necessary to run it once for each configuration to generate the output required for interaction with IPME. This characteristic, however, posed an issue for the current trial, in that the means to feed output from IPME back to FSSIM during execution did not exist. In order to represent the success or failure of containment and assessment tasks, therefore, the FSSIM model was run a number of times with different initial conditions. Thus when IPME indicated an event during execution of the scenario, there was a means to relate the event to the effect on fire and smoke propagation.

An initial issue with FSSIM was selecting a ship or platform to use for the trial. Use of the Halifax Class Frigate, or a portion of the ship, was investigated. Conversations with MSU made it readily apparent that the creation of the relational database, a Structured Query Language (**SQL**) accessed file, is only possible with the support of the developers at MSU. The requirement to extract information from AutoCAD diagrams and then check the validity of the data is beyond the capability of developers not completely familiar with the schema of the relational database. The project was also faced with the problem of availability of the Halifax Class Frigate AutoCAD diagrams and the uncertainty of the precision of the drawings. The SQL relational database requires the bulkheads / decks / and fittings to be aligned precisely or the FSSIM model will allow smoke and heat travel. For these reasons an alternate solution was required for the proof of concept phase.

Once it was determined that the model of the Halifax Class Frigate would not be available in the time frame required for the proof of concept the only option were the four databases (platforms) provided with the trial FSSIM program. These platforms / options were:

- Confined_Space – a submarine;
- Ship_A – the aft portion of a frigate / destroyer sized warship;
- Building_1 – a single floor office building; and
- Shadwell_Forward – the forward portion of USN Shadwell.

The “confined space” FSSIM model was selected for the proof of concept because it provided the greatest functionality – controllable ventilation, ventilation isolation valves (framebays), and doors and hatches. The only additional functionality found in the Halifax Class Frigate but not represented in the Confined Space model was fitted fire fighting systems (this functionality is accounted for in the IPME, and the added realism of having it in the FSSIM will be investigated in Phase 2 of this project).

The surrogate space in the Confined_Space model that best represented the Refrigeration Machinery Space (from the medium complexity fire in Torenvliet, G. L., & Jamieson, G. A. (2007), as discussed in subsection 2.2) was compartment 3-74-2, the Torpedo Room. This space allows for the simulation of confining or not confining isolation valves (framebays are a surrogate for isolation valves). The same fire was set for each run, with a power of 1000 KW and was allowed to run for 500 seconds. Figure 2-1 provides a list of all the space in the “confined space” FSSIM model.

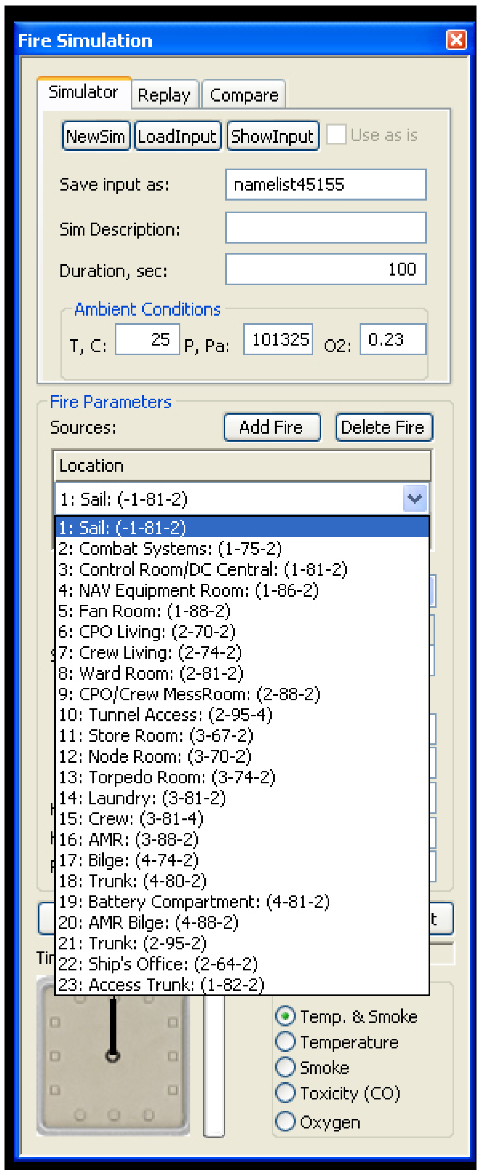

Figure 2-1 Simulation Set-up Interface

The second major issue that had to be overcome was the lack of interaction with IPME at runtime. It was determined that the use of output files from several unique conditions that related to the successful completion or failure of specific tasks could overcome this problem. These tasks and the corresponding FSSIM configurations are documented in Table 2-2. This was only one of the possible methods to overcome the lack of runtime communications between FSSIM and IPME. Other communication methods could be investigated in future iterations of the overall model.

The FSSIM model allows for any combination of doors, hatches and scuttles to be open or closed. This is significant as it allows for the simulation of successful or unsuccessful confinement by the Rapid Response Team (**RRT**) or automation. The specific doors, hatches and scuttles are operator selectable. For the proof of concept the openings selected are indicated in footnotes to Table 2-2. In the proof of concept, the configuration was all or none. Future studies could look at the openings with more fidelity.

The following table lists the initial set-up of each of the FSSIM model runs and the reasoning behind each run. It also lists when the ventilation will be set to be activated. Note: The tasks (e.g., 3.1, 3.1.1, etc.) mentioned here are described in Table 2-3.

Run Number	Confinement (3.1.2 and 3.1.3)	Ventilation shut down (3.1.1)[1]	Notes – information must be provided by IPME to select the proper FSSIM output file
1	Full	5 seconds	No failures of confinement tasks 3.1
2	Full	60 seconds	Failure of task 3.1.1 – requirement to shut down at switchboard
3	Isolation valves left open in vicinity.[2]	5 seconds	Failure of task 3.1.2
4	Isolation valves left open in vicinity.[2]	60 seconds	Failure of task 3.1.2 and failure of task 3.1.1 – requirement to shut down at switchboard
5	Doors / hatches in close proximity left open.[3]	5 seconds	Failure of task 3.1.3
6	Doors / hatches in close proximity left open.[3]	60 seconds	Failure of task 3.1.3 and failure of task 3.1.1 – requirement to shut down at switchboard

[1] Ventilation nodes 87 and 90 will be activated.

[2] Isolation failure is modeled by including framebays.

[3] Door numbers 32, 35, and 36 are left open, hatches 50 and 51 are left open, and scuttles 66, 69, and 70 are left open.

7	Isolation valves / doors / hatches in close proximity left open. [2&3]	5 seconds	Failure of tasks 3.1.2 and 3.1.3
8	Isolation valves / doors / hatches in close proximity left open. [2&3]	60 seconds	Failure of tasks 3.1.2 and 3.1.3 and failure of task 3.1.1 – requirement to shut down at switchboard

Table 2-2 FSSIM configurations

The running of FSSIM in these configurations yields (at the time when bounding is complete) the number of compartments on fire or at a temperature that precludes bounding by people – thereby affecting the time to extinguish the fire (3.4). As an example, if the fire is not completely bound in IPME until 346 seconds and there has been a failure in closing isolation valves, with success of all other confinement tasks, then output file 3 is polled. The resulting number of compartments with excessive heat and smoke at 346 seconds is returned to IPME by the Java bridge application, affecting the time to extinguish the fire and conduct adjacent compartment rounds. The FSSIM output file also provides smoke levels (kg soot / kg air) and toxicity (kg CO / kg air) at specific times, in specific compartments that could be used to affect the confinement and bounding tasks in IPME in future experiments. The current model employs probability of failure triggered by IPME and does not consult FSSIM (this may not affect the outcome as both will be probabilistic).

Prior to the start of each FSSIM run a number of variables are selected. They are listed below:

1. duration of each run – 500 seconds for proof of concept;
2. ambient conditions - 25°C, 1013.25 KPa, and 23% oxygen (O^2);
3. location of the fire – Torpedo Room (3-74-2);
4. Fire type – constant or TBD (constant was selected);
5. Power of fire – 100 or 1000 kW (1000 kW was selected); and
6. The remaining variables; yield per kg of fuel were left with the FSSIM default values as was the heat of combustion, heat of vaporization and pyrolysis temperature.

Details of these variables are included with the FSSIM documentation.

It would take further engineering studies to change these values; however they could prove very useful when making design decisions. In follow-on work, SMEs should be consulted to ensure the numeric values are validated prior to running the model.

An interface is provided by the FSSIM for the set-up of these initial conditions, an example is provided shown below.

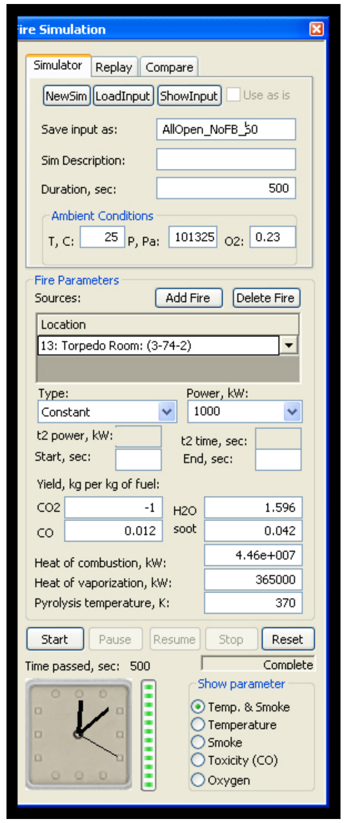

Figure 2-2 FSSIM setup GUI – example

Further parameters can be set at runtime. In this model, Confined_Space, the inclusion of the framebays and the stopping of ventilation could be ordered. The figure below depicts the set-up for FSSIM for condition 8, no confinement or isolation and failure of remote ventilation crash stopping (therefore requiring ventilation to be stopped at the switchboards – taking on average 60 seconds (a value to be validated in any follow-on research).

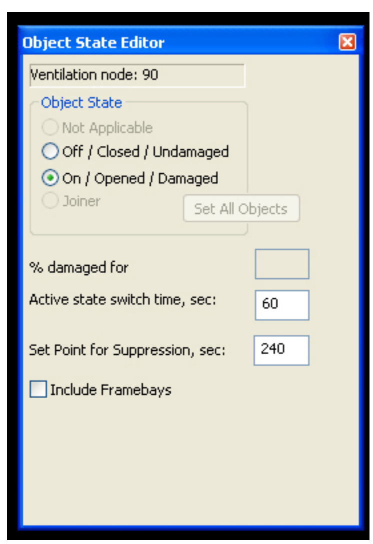

Figure 2-3 FSSIM set-up for configuration #8

The *Set Point for Suppression* as shown in Figure 2-3 above is not applicable to the Confined_Space model. Any model created for further study should include this functionality.

2.6 INTEGRATED PERFORMANCE MODELING ENVIRONMENT

The Integrated Performance Modeling Environment (**IPME**) is a Linux - and Windows - based integrated environment of simulation and modeling tools for answering questions about systems that rely on human performance to succeed. The Windows based version was used in this experiment and run on the Microsoft Vista Operating System. The system was run in the administrator mode to allow for IPME to communicate with the bridge application. IPME provides:

- A realistic representation of humans in complex environments;
- Interoperability with other models and external simulations; and
- Enhanced usability through a user friendly graphical user interface.

IPME provides a full-featured discrete event simulation environment built on the Micro Saint Sharp simulation engine. Additionally, it provides added functionality to enhance the modeling of the human component of the system. Finally, it has a number of features that make it easier to integrate IPME models with other simulations on a real-time basis including TCP/IP sockets and tools for developing simulations that adhere to the Higher Level Architecture (**HLA**) simulation protocols that are becoming standard throughout the world. These capabilities will help practicing professionals solve their problems by providing answers to questions involving human performance.

The IPME model was solely based on the probabilistic times to conduct the tasks in a pre-planned method (tasks included in Table 2-3) and with a probability of failure for that method. Failure of individual tasks either gave a time penalty to that task or affected the choice of subsequent task branches. In the Halifax Class Frigate baseline model the majority of tasks were performed by crew, and a low failure rate was adopted in the model, consequently the penalty was not as severe. Each task time was programmed to have a normal variation of 10% of its base time. The task time variation can be varied by task and should be verified by SMEs for follow-on modelling efforts.

In order to examine the performance impact of the robustness and redundancy requirement of each automated task, the IPME model was created in such a way that the probability of failure associated with each automation feature could be adjusted easily.

In the proof of concept the size and complexity of the damage (fire) would rarely cause the Section Base Teams or manning pools to exhaust their resources. The forward and after Section Base Teams in the Halifax Class Frigate are required to have a minimum of 18 personnel whereas the manning pool, with the ship at Emergency Stations will typically have 30 personnel ready to support the damage control effort. Given the number of available crew for the modelled scenario the application of an array to track crew was not required. This was considered appropriate to keep the IPME model as simple as possible for the proof of concept. The model has been developed to be easily modified in the future to account for individual crew through an array.

An IPME model was developed using the tasks described in Torenvliet, G. L., & Jamieson, G. A. (2007)14.[5].

Table 2-3, below, lists each task and the logic/assumptions associated with them. Timings were provided by a domain expert; however they have not been validated by Subject Matter Experts. Since the intent of this study was to prove the concept of using simulation for addressing crewing options, it was deemed acceptable to use reasonable but unverified timings in the model.

The percent chance of failure for full automation is listed as 'XX%'. This value was varied in the IPME model with the results presented in Table 3-2.

Task	Canadian Patrol Frigate baseline			Full automation		
	time	note	assumptions	time	note	assumptions
Monitor ship spaces (1.1)	These tasks were not included in the proof of concept. They could be considered for inclusion in follow-on work.					
Detect Fire (2.1.1)	Represented by tasks 2.1.1.1 through 2.1.1.3					
Detect fire location (2.1.1.1)	120 sec	Actual location is confirmed by Rapid Response Team (**RRT**)	15% of time fire too intense for tasks 2.1.1.2 and 2.1.1.3*	10 sec	Every space is fitted with sensors	Heat sensor failure – XX % chance – requires RRT – 50% penalty (180 seconds)
Detect fire type (2.1.1.2)	Same as 2.1.1.1	Conducted by RRT	If RRT unable to enter compartment due to fire intensity (15% probability) the planning task is affected 2.2.1.3 (25% degradation)*	Same as 2.1.1.1	Conducted by gas sensors	Gas sensor failure – XX % chance. If fails – affects planning tasks 2.2.1.3 (25% degradation)
Detect fire intensity (2.1.1.3)	Same as 2.1.1.1	Conducted by RRT	If RRT unable to enter compartment due to fire intensity (15% probability) the planning task is affected 2.2.1.3 (25% degradation)*	Same as 2.1.1.1	Conducted by change in heat /	Heat sensor failure – XX % chance. If fails – affects planning tasks 2.2.1.3 (25% degradation)
Assess impact of damage		Conducted by Damage Control			Conducted by HQ1 supported	

Task	Canadian Patrol Frigate baseline			Full automation		
(2.2.1)		Headquarters (**HQ1**) and Command			by 'crash cards'. If 2.1.1.1 – 2.1.1.3 fail then information is entered into system manually.	
Assess impact of fire on ship's functional purposes (2.2.1.1)	60 sec	Conducted by HQ1 – command is briefed	Will not fail	30 sec	Conducted by HQ1 supported by 'crash cards'	XX% failure – if system fails then revert to CPF baseline with 50% penalty.
Assess impact of fire on accessibility to ship spaces and equipment (2.2.1.2)	30 sec	May have to consider a communications failure between HQ1 and command.	Will not fail	15 sec		XX% failure – if system fails then revert to CPF baseline with 50% penalty.
Assess potential for fire to spread to adjacent spaces(2.2.1.3)	30 sec		Will not fail, however will be affected by failure in tasks 2.1.1 network	15 sec		XX% failure – if system fails then revert to CPF baseline with 50% penalty.
Assess impact of fire to spread to adjacent spaces using criteria in 2.2.1.1 – 2.2.1.3 (2.2.1.4)	30 sec		Will not fail	15 sec		XX% failure – if system fails then revert to CPF baseline with 50% penalty.
Contain fire (3.1)			This task also confirms location of fire to HQ1			
Shut down ventilation system to affected section (3.1.1)	5 sec	Performed by Damage Control Operator (**DCO**)	2% failure – if shut down fails backup is to shut down ventilation from switchboards – 60 seconds.	2 sec	Performed by system	XX% failure – if system fails then revert to CPF baseline task 3.1.1 with 100% penalty to the standard time – resulting in a 10

Task	Canadian Patrol Frigate baseline			Full automation		
						second task time.
Close bulkhead isolation valves (3.1.2)	45 sec	Performed by RRT	5% failure - unable to access valves – this will affect the FSSIM model. (model must reflect condition of containment)	10 sec		XX% failure – if system fails then revert to CPF baseline task 3.1.2 with 100% penalty.
Close all relevant doors and hatches (3.1.3)	30 sec	Performed by RRT	5% failure - unable to access valves – this will affect the FSSIM model. (model must reflect condition of containment)	30 sec	Performed by RRT – safety considerations preclude having automated doors and hatches	XX% failure - unable to access valves – this will affect the FSSIM model. (model must reflect condition of containment)
Bound fire (3.2)		For a fire in the refrigeration machine space			In auto mode triggered by task 2.1.1	
Set and maintain boundary above fire (if possible) (3.2.1)	120 sec	Boundaries in Crew's Cafeteria, Crew's Lounge and Dish Washing Compartment		10 sec	With water mist – monitored with sensors in same compartments as baseline.	XX% failure – if system fails then revert to CPF baseline task 3.2.1 with 100% penalty.
Set and maintain boundary aft of fire (if possible) (3.2.2)	60 sec	Boundaries in Forward Auxiliary Machinery Room		10 sec	With water mist – monitored with sensors in same compartments as baseline.	XX% failure – if system fails then revert to CPF baseline task 3.2.2 with 100% penalty.
Set and maintain boundary forward of fire (if possible) (3.2.3)	120 sec	Boundaries in Sonar Instrument Space and Gyro Room No. 1		10 sec	With water mist – monitored with sensors in same compartments as baseline.	XX% failure – if system fails then revert to CPF baseline task 3.2.3 with 100% penalty.
Set and maintain boundary below fire (if		N/A		10 sec	With water mist – monitored with sensors in	XX% failure – if system fails then number of compartments for

Task	Canadian Patrol Frigate baseline			Full automation		
possible) (3.2.4)					shelter station 1, beer stores and dry provision stores.	adjacent compartment rounds – task 3.5 is increased.
Set and maintain boundary port of fire (if possible) (3.2.5)		N/A – port hull			N/A	
Set and maintain boundary starboard of fire (if possible) (3.2.6)		N/A – stbd hull			N/A	
Prepare to control fire (3.3)	Represented by tasks 3.3.1 through 3.3.3					
Chose strategy to control fire (3.3.1)	60 sec	Triggered by 2.2.1.4. However, must know status of confinement (3.1) before final strategy is set – model will ensure at least 30 seconds transpire after the completion of 3.1.3 before this task can be completed.		45 sec	Operators must read and consider the direction provided by the system – consider the L3 'kill card' system in the Dutch Frigate	XX% failure – if system fails then revert to CPF baseline task 3.3.1 with 100% penalty.
Ensure availability of fire control resources (3.3.2)	60 sec			30 sec		XX% failure – if system fails then revert to CPF baseline task 3.3.2 with 100% penalty.
Coordinate personnel safety for chosen strategy (3.3.3)	180 sec	If a fire is to be fought by humans, this task would include power isolation.		30 sec		XX% failure – if system fails then revert to CPF baseline task 3.3.3 with 100% penalty.

Task	Canadian Patrol Frigate baseline			Full automation		
Extinguish fire (3.4)	1 space – 6 minutes 2 spaces – 9 minutes 3 spaces 12 minutes 4 spaces – 18 minutes 5 spaces – 25 minutes	Triggered by 3.3.3. However there must be a minimum of 120 seconds between the completion of 3.3.1 and the start of 3.4. As the number of compartments that were too hot to place a boundary increases so does the time to perform this task. The FSSIM model output will be queried to provide input to this task. Also must place sentry.	There was no analytical reasoning for the timings, as a proof on concept it was considered adequate to show the ability to have varying times for the number of compartments affected.		30 sec – triggered by 2.1.1 – uses water mist system	XX% failure – if system fails then revert to CPF baseline task 3..4 with 50% penalty.
Confirm fire extinguished (3.5)	1 space – 2 minutes 2 spaces – 4 minutes 3 spaces 6 minutes 4 spaces –8 minutes 5 spaces – 10 minutes	Fire is not extinguished until adjacent compartment rounds are complete. This will relate to the number of compartments inside the boundaries set in task 3.2.	Two minutes per space that is not confined. The calculation of a confined space will come from the temperature, smoke, or toxicity of the compartments at some time during each IPME run.	1 space – 3 minutes 2 spaces 6 minutes …	This is the same task in each	Three minutes per space that is not confined. The calculation of a confined space will come from the temperature, smoke, or toxicity of the compartments at some time during each IPME run.

*in future iterations FSSIM may provide output that affects these tasks.

Table 2-3 IPME Tasks and Assumptions

It is assumed that with the modern design and rigorous testing of smoke and heat sensors the Mean Time Between Failure will be large for damage control sensors selected for warships. While this by itself yields high reliability, the likelihood of battle damage or second/third degree consequences that might cause connectivity with sensors to be lost will decrease reliability. The consequences of failure are noted in the table above and the IPME model is well documented with the implications of each task failure. In a higher automated system operators may take some time before a failure is noticed, therefore, the mean time to complete certain task could be longer than that when the task was done in the baseline mode. This has also been accounted for in the model.

The FSSIM model was run for 500 seconds for each trial run. The time to extinguish the fire in IPME is generally in excess of 500 seconds. In the next phase, therefore, the FSSIM should be run for longer periods to capture all potential propagation of damage before the fire is extinguished.

2.7 FSSIM TO IPME MODEL BRIDGE

The bridge between the FSSIM output and the IPME model was a Java application. The bridge is used to determine which of the eight FSSIM output files is polled in order to generate the results that are applied against the predetermined MOEs. Critical to the decision of which FSSIM output files to use are the failures of tasks 3.1.1 - Shut down ventilation system to affected section, 3.1.2 - Close bulkhead isolation valves, and 3.1.3 - Close all relevant doors and hatches. Knowledge of the task success or failure state allows the bridge program to poll the appropriate FSSIM output file and return the number of compartments with high temperatures and high levels of smoke. This information is then used as input to select subsequent IPME tasks and also to output as MOEs directly to the results file. As an example, if ventilation is crash stopped successfully by automation but the RRT does not get the bulkhead isolation valves closed due to smoke or heat (% failure noted in the IPME Tasks and Assumptions table), FSSIM run #3 (Table 2-2) will be polled by the bridge application for information.

Table 2-4 highlights some of the output from the bridge application. It captures the IPME clock time when specific tasks are completed, the duration of specific tasks for that run, and the number of compartments affected by smoke and heat. It also records when tasks fail. In the example above the highlighted cells show that at 45 seconds an attempt was made to close the bulkhead isolation valves. The initial attempt was recorded as a failure, therefore the RRT had to move back (possibly due to smoke) and close the valves further from the fire. This one failure led to the final result of 4 compartments being affected by smoke and 2 by heat – above the average for this configuration.

	Task Number	Task Start Time	Task Duration	Compartments Affected by Smoke	Compartments Affected by Heat
STARTING RUN 30		0			
shut down ventilation system to affected section	3.1.1	6.1	5.8	0	0
close bulkhead isolation valves	3.1.2	45	38.9	1	1
close bulkhead valves fail		45.1			
close bulkhead isolation valves	3.1.2	90.71	45.6	2	1
close relevant doors and hatches	3.1.3	118.98	28.26	2	2
detect fire intensity completed	2.1.1.3	119.36	119.16	2	2
detect fire type completed	2.1.1.2	143.82	143.62	2	2

	Task Number	Task Start Time	Task Duration	Compartments Affected by Smoke	Compartments Affected by Heat
detect fire location completed	2.1.1.1	164.51	164.31	2	2
assess impact of fire on ship's functional purpose completed	2.2.1.1	226.57	62.06	3	2
assess impact of fire on accessibility to ship spaces and equipment	2.2.1.2	261.23	34.66	3	2
assess potential for fire to spread to adjacent spaces	2.2.1.3	288.89	27.67	3	2
choose strategy to fight fire	3.3.1	311.2	17.88	3	2
assess impact of fire spread to adjacent spaces using criteria in 2.2.1.1 to 2.2.1.3 completed	2.2.1.4	318.3	29.41	3	2
Power Isolation completed		321.04	9.65	3	2
power isolated		321.05	0.01		
coordinate personnel safety for chosen strategy	3.3.3	342.51	31.21	3	2
ensure availability of fire control resources	3.3.2	348.3	30	3	2
set and maintain boundary aft of fire completed	3.2.2	480.89	60	4	2
set and maintain boundary forward of fire completed	3.2.3	540.89	120	4	2
set and maintain boundary above fire completed	3.2.1	540.89	120	4	2
extinguish fire completed		823.78	215.8	4	2
confirm fire extinguished completed		1099.46			
END RUN 30		1099.46			

Table 2-4 Sample Bridge Application output

In order to determine if spaces were affected by the propagation of fire and smoke several assumptions were made. These assumptions were solely for the purpose of this proof of concept and have not been validated. They can easily be changed for the next phase with perhaps more realistic values, or values agreed upon as realistic by Subject Matter Experts.

It was decided, for the proof of concept, to set the trigger for the maximum temperature acceptable for setting boundaries at 60°C or 333 K.

Smoke or kg soot / kg gas has, for the proof of concept, been set to trigger a condition of extensive smoke damage at 1 x 10-4 kg soot / kg gas. In the FSSIM model the smoke detectors have been set to activate at 2.07 x 10-5 kg soot / kg air. These levels populate the Measure of Effectiveness ‘Number of compartments affected by smoke’.

The raw output data is manipulated in excel as follows. Every failed task is highlighted. The output is sorted by task. The task duration of the individual failed tasks are combined. Each group of tasks is analyzed for the average (mean) duration or time to completion and the standard deviation. This is a time consuming effort and should be automated or streamlined in the next phase. Results of this analysis effort are shown in Table 3-2.

SECTION THREE – RESULTS

3.1 GENERAL

The results from the proof of concept were output into data files. The data was then manipulated in Excel and analyzed. The model was not tested for sensitivity for specific variables as the reason for the proof of concept was solely to investigate the feasibility of combining IPME with a companion tool – in this case FSSIM.

3.2 FSSIM OUTPUT

The output generated from FSSIM was in two parts. There is the graphic representation of the propagation of fire and smoke – as shown in the figure below – and the numeric output as shown in the Table 3-1.

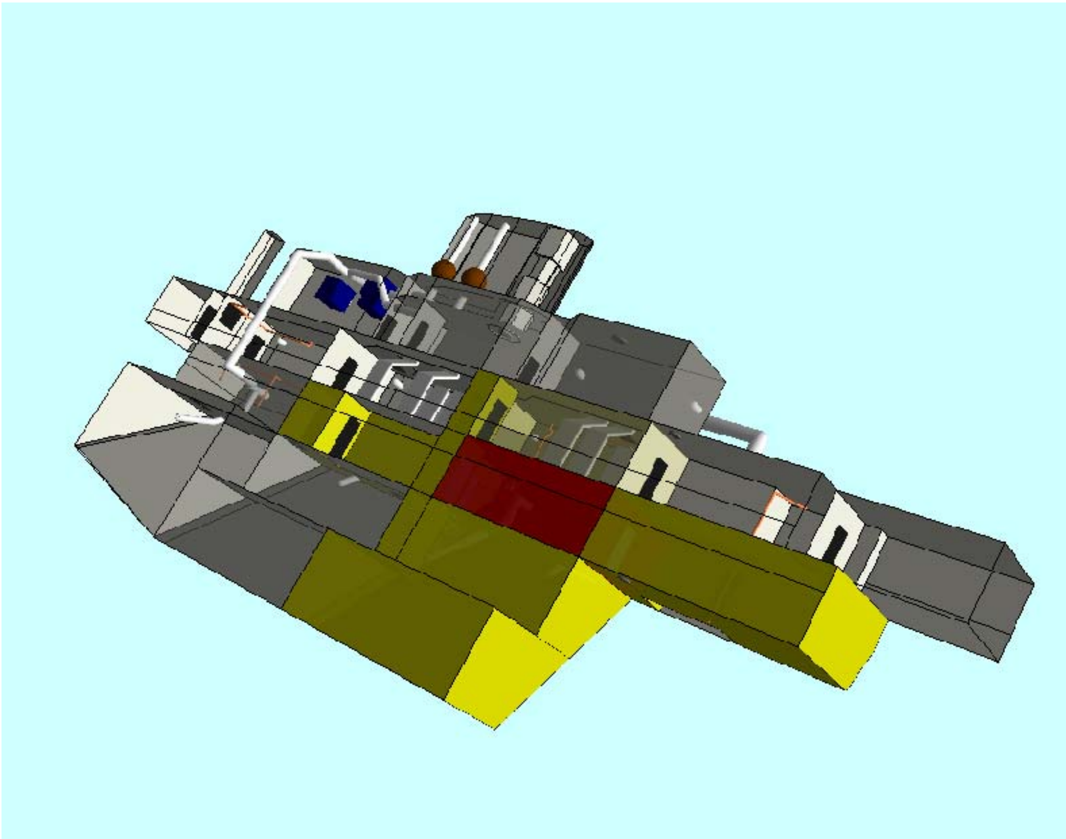

Figure 3-1 Propagation of Fire and Smoke – condition #8

As shown in the figure above FSSIM uses a colour schema to depict temperature and smoke in each compartment. The default colour map for temperature is as follows:

- Below 40C (default units are Celsius C) -- no color is shown (only default compartment surface color) as the conditions do not impact activities of humans.

• Between 40C and 60C -- color intensity increases from default surface color to yellow, i.e. transition between a safe region and a region where humans need protective equipment.
• Between 60C and 165C -- color stays constant yellow. In this region the color does not show any differences to varying temperatures, as long as the values are in the range where humans with protective equipment are safe.
• Between 165C and 185C -- color goes from yellow to red (transition between the limited access and no access regions).
• Above 185C -- color remains at saturated red indicating uninhabitable areas for humans.

The default colouring was used for the proof of concept.

The numerical output from FSSIM is structured such that at each model step (approximately 1 second) the following information is printed to the output file:

1. time (seconds);
2. temperature (degrees Kelvin);
3. pressures (Pa);
4. oxygen (O^2/kg gas);
5. toxicity - carbon monoxide (CO/kg gas);
6. smoke - soot (kg soot/kg gas);
7. heat release – presence of fire (kW); and
8. fire size (kW).

Table 3-1 shows the output from FSSIM runs #1 and #8. Both are for model step 360. For reasons of brevity Table 3-1 has been vetted to only show the step number, the run time, compartment temperature, and compartment soot level as the remaining values were not used in the analysis or results and have been left out.

	Step #	360		
All Close – Run # 1	Configuration / Run #			All open - no isolation Run # 8
time				
seconds				seconds
3.53E+02				3.54E+02
compartment temperatures	Compartment Name			compartment temperatures
	In the FSSIM model temperatures delineate different states for operators - above 60 C or 333 K protective clothing is required			
°K				°K
2.98E+02	Sail			2.99E+02
3.00E+02	Combat Systems			3.10E+02
3.00E+02	Control Room/DC Central			3.08E+02
2.99E+02	NAV Equipment Room			3.04E+02
2.99E+02	Fan Room			3.00E+02
2.99E+02	CPO Living			3.00E+02
3.05E+02	Crew Living			3.14E+02
2.99E+02	Ward Room			3.01E+02
2.99E+02	CPO/Crew MessRoom			3.00E+02
2.98E+02	Tunnel Access			3.00E+02
3.01E+02	Store Room			3.60E+02
2.98E+02	Node Room			3.00E+02
3.76E+02	Torpedo Room			5.05E+02
2.99E+02	Laundry			3.04E+02
3.00E+02	Crew Living			3.63E+02
2.99E+02	Auxiliary Machinery Room			3.00E+02
3.02E+02	Bilge			3.68E+02
3.02E+02	Trunk			4.05E+02
2.98E+02	Battery Compartment			3.00E+02
3.06E+02	Auxiliary Machinery Room Bilge			3.00E+02
2.98E+02	Trunk			2.99E+02
2.99E+02	Ship's Office			2.99E+02
2.98E+02	Access Trunk			2.99E+02
compartment soot	Smoke detector trip value in the USS Shadwell is 2.07E-05. In the proof of concept the value of 1.0E-04 was used as the trigger task failure – a compartment that had too low a visibility to enter. This value can be varied depending of the visual sensors in use.			compartment soot
kg soot/kg gas				kg soot/kg gas
1.17E-08	Sail			4.26E-08
6.90E-05	Combat Systems			1.12E-04
7.88E-05	Control Room/DC Central			1.20E-04
2.46E-05	NAV Equipment Room			1.19E-04
8.69E-06	Fan Room			2.64E-05

3.13E-07	CPO Living	2.56E-06
2.86E-05	Crew Living	1.05E-04
3.40E-05	Ward Room	2.70E-05
2.73E-05	CPO/Crew MessRoom	4.29E-05
9.01E-08	Tunnel Access	2.04E-07
1.10E-05	Store Room	6.93E-04
4.14E-07	Node Room	1.02E-05
1.38E-03	Torpedo Room	1.01E-03
9.48E-07	Laundry	4.49E-05
9.51E-06	Crew Living	7.06E-04
5.26E-06	Auxiliary Machinery Room	6.45E-05
3.75E-06	Bilge	7.13E-04
8.73E-06	Trunk	9.62E-04
1.28E-05	Battery Compartment	7.52E-05
4.14E-06	Auxiliary Machinery Room Bilge	3.18E-05
2.10E-07	Trunk	4.71E-07
1.57E-09	Ship's Office	1.65E-08
1.94E-06	Access Trunk	5.93E-06

Table 3-1 Representative FSSIM Output

In this example, if there had been a complete failure of confinement – tasks 3.1.1, 3.1.2, and 3.1.3 – and the fire was not bound until 354 seconds after fire initiation, the returns to the output file would be fire damage to 5 compartments and smoke damage to 9 compartments as shown in the right-most column of Table 3-1.

In the model a compartment's soot value that was used to trigger the failure of certain tasks was greater then that required to trigger a smoke detector alarm (as used in the USS Shadwell trials). The reason being is that the soot level was set high enough to deter the RRT (without breathing apparatus) from performing confinement known to be greater than that required to trigger an alarm. Further work can be done to determine the actual level at which RRT would not enter a space without self contained breathing apparatus.

3.3 COMBINED OUTPUT

Because of the probabilistic nature of the IPME model the combined model was run 50 times for the Halifax Class Frigate Baseline run and 50 times for each automation failure rate run (0%, 10%, 25%, and 50%). These are the values that are substituted for the 'XX%' listed in table 2-3. The model output represents the output from a Monte Carlo simulation. It was intended to run the models for more iterations, however the time to run just one configuration was over 6 hours. This is due to the number of queries being performed by the bridge application for each IPME runtime second; possible solutions to the slow speed of the model will be investigated in the next phase.

Model Output Table					
Measure of Effectiveness	Halifax Class Frigate Baseline	Automation with Figure of Reliability - % failure			
		0 %	10 %	25 %	50 %

Model Output Table					
Measure of Effectiveness	Halifax Class Frigate Baseline	Automation with Figure of Reliability - % failure			
		0 %	10 %	25 %	50 %
Time to detect fire (Task 2.1.1) – see subtasks below					
Time to detect fire location (Task 2.1.1.1)	123 ± 17	9.98 ± .96	11.2 ± 3.3 (6 failures)	12.3 ± 4.2 (11 failures)	14.2 ± 5.1 (21 failures)
Time to detect fire type (Task 2.1.1.2)	122 ± 15	10.2 ± .98	9.90 ± .95	9.97 ± 1.1	10.1 ± .1.0
Time to detect fire intensity (Task 2.1.1.3)	113 ± 27	9.71 ± 2.0	10.5 ± 1.9	9.95 ± 2.1	10.1± 1.8
Assess impact of detected fire (Task 2.2.1) – see subtasks below					
Assess impact of fire on ship's functional purpose (Task 2.2.1.1)	60.4 ± 5.1	30.2 ± 3.0	41.2 ± 31 (6 failures)	52.8 ± 41 (13 failures)	69.2 ± 45 (22 failures)
Assess impact of fire on accessibility to ship spaces and equipment (Task 2.2.1.2)	30.0 ± 3.2	15.3 ± 1.7	18.6 ± 11	23.1 ± 14	27.2 ± 15
Assess potential for fire to spread to adjacent spaces (Task 2.2.1.3)	29.8 ± 3.0	15.1 ± 1.2	18.9 ± 11	23.0 ± 14	37.3 ± 26
Time to contain fire (Task 3.1) – see subtasks below					
Time to shut down ventilation to affected section (Task 3.1.1)	5.01 ± .50	2.02 ± .19	3.15 ± 3.1 (6 failures)	4.91 ± 4.6 (15 failures)	6.87 ± 5.1 (21 failures)
Time to close bulkhead isolation valves (Task 3.1.2)	46.4 ± 10.1	9.87 ± 1.1	13.2 ± 16 (2 failures)	32.3 ± 38 (13 failures)	52.4 ± 46 (23 failures)
Time to close all relevant doors and hatches (Task 3.1.3)	30.7 ± 5.1 (1 failure)	32.7 ± 8.5 (4 failures)	30.8 ± 5.6 (1 failure)	30.3 ± 2.8 (0 failures)	29.7 ± 6.1 (1 failure)
Time to bound fire (Task 3.2)	No useful output due to logic errors were present in the model				
Time to prepare to control fire (Task 3.3) – see subtasks below					
Choose strategy to fight fire (Task 3.3.1)	20.2 ± 2.3	19.8 ± 2.4	20.0 ± 2.2	19.5 ± 2.0	20.0 ± 2.1
Ensure availability of fire control resources - (Task 3.3.2)	No useful output due to logic errors were present in the model				
Coordinate personnel safety for chosen strategy *time to isolate power* (Task 3.3.3)	No useful output due to logic errors were present in the model				

Model Output Table					
Measure of Effectiveness	Halifax Class Frigate Baseline	Automation with Figure of Reliability - % failure			
		0 %	10 %	25 %	50 %
Time to extinguish fire (Task 3.4) – from start	905 ± 113	505 ± 75	637 ± 75	749 ± 141	862 ± 159
Number of compartments affected by heat spread	1.12 ± .59 max # 5	1.32 ± .59 max # 5	1.12 ± .59 max # 5	1.26 ± .44 max # 3	1.54 ± .71 max # 5
Number of compartments affected by smoke	3.16 ± .86 max # 9	3.22 ± .86 max # 9	3.10 ± 1.0 max # 9	3.42 ± .61 max # 4	3.74 ± 1.5 max # 10
Time to confirm fire extinguished (Task 3.5)	1213 ± 95	787 ± 125	929 ± 182	1043 ± 156	1166 ± 172

Table 3-2 Mean Time for Task Completion or Number of Compartments affected related to automation reliability

The table above is the proof of concept results table. It relates the MOEs listed in the left hand column to the mean time or number of compartments for each 50 runs of IPME for a given reliability of the automation. For the proof of concept the automation reliability was stepped as shown on the top row. The automation reliability steps were large in order to show the large scale affects of reliability. All times in the table above are seconds.

The logic errors listed for tasks 3.2, 3.3.2, and 3.3.3 have been tracked to the IPME model and will be corrected prior to subsequent modelling. These errors did not affect the overall outcome of the proof of concept and are an indication or the complexity of the damage control problem with even a simple scenario.

All MOEs related to timings are generated by the IPME model. Two of the MOEs (highlighted in yellow in Table 3-2), number of compartments affected by heat spread and number of compartments affected by smoke, are extracted from the FSSIM output by the Java bridge application. The MOEs without results listed in the table – times to bound, availability of fire control resources, and coordinate personnel safety for chosen strategy, were outputs with logic errors – these should be addressed prior to the next phase; however this problem did not affect the overall outcome of the proof of concept.

The results indicate that the model shows a correlation between reliability of automation and time to extinguish the fire and time to confirm the fire is extinguished (highlighted in green in Table 3-2). There are still a few logic errors that must be corrected before the next phase; however they were identified during the proof of concept and are addressable.

Of note with respect to the specific results; in each crewing and automation configuration the runs resulting in the most smoke and heat damage to compartments were a result of failure of closing doors and hatches.

It must be noted that the fire size, type, and location was not varied – this would be an interesting experiment to investigate if the fire burned itself out on the occasions when confinement was completed (as witnessed in the configuration run for the proof of concept). For example, if the Halifax Class Frigate model is developed in a future phase, the investigation of a fire in the main cafeteria or other large compartment with more fuel would be an interesting experiment.

SECTION FOUR: DISCUSSION AND CONCLUSIONS

4.1 GENERAL

The discussion and conclusions are based on the work conducted and results from the proof of concept.

Many variables can be modified in the models in order to 'tune' a hypothesis being investigated in future studies. For the proof of concept the IPME timing variables were held constant and only the tasks probability of failure was changed. The failure variables were changed for the entire model, not just select tasks or groups of tasks such as the three 'Detect' tasks. The subsection below lists the variables that can be adjusted in the combined model. As noted in subsection 3.3 the FSSIM variables were not changed – specifically the fire location, intensity and type.

Overall the proof of concept can be considered as successful. The integrated model performed as designed. It provided output in terms of MOEs that allowed for comparison between crewing / automation levels. There was also a strong correlation between times to extinguish the fire and time to confirm fire extinguished (overhaul and conduct adjacent compartment rounds) with a change in reliability in automation. These conclusions are clearly shown in the results at Table 3-2.

The combined model also showed the ability for IPME to communicate with FSSIM, through a bridge application, increasing the validity of the output as the propagation of damage was based on a validated physics based model. It is recommended to continue with the next phase with the involvement of MSU to support development of the Halifax Class Frigate relational database and with SMEs to validate the damage control assumptions. The IPME model should also be extended to track the usage of personnel.

The objective of the proof of concept report was to supply a set of methodological issues and recommendations – both follow in section 4.3 and 4.4.

4.2 VARIABLES

The two models, IPME and FSSIM, have a number of variables that can be adjusted. The following table lists the variable and the potential hypothesis (affect) that can be tested.

Model	Variable (unit)	Hypothesis
IPME	Task times (seconds)	Crew tasks take longer allowing damage to propagate.
	Task failure penalty (multiplication factor)	Ship's with greater automation will have greater consequences with failure.
	Probability of failure of crew tasks (%)	Critical tasks can be identified and training / procedures / automation can be developed to increase probability of success.
	Probability of failure of automation (%)	Automation of certain damage control tasks have a greater return on specific

Model	Variable (unit)	Hypothesis
		MOEs.
FSSIM	Fire location (compartment)	Fires in particular compartments pose a greater risk to higher level MOEs. These compartments should be protected with enhanced automation / design features.
	Ventilation stop time (seconds)	Smoke damage is directly related to ventilation.
	Fire intensity	Construction materials affect outcome.
	Fire Type	
Bridge Model	Temperature trigger for heat damage (°C or °K)	Equipment design can affect usability – change higher level MOEs.
	Soot trigger for smoke damage (kg soot / kg gas)	Equipment design can affect usability – change higher level MOEs.

Table 4-1 Variable List

4.3 METHODOLOGICAL ISSUES

It is concluded that as a proof of concept this has been a successful project. The lessons learned have been:

1. FSSIM is a deterministic, physics based model, which cannot be interfaced at runtime with IPME;
2. The FSSIM is a fully verified and validated model that predicts the propagation of fire smoke in any properly defined platform;
3. The FSSIM relational database, based on AutoCAD drawings, can only be developed by Mississippi State University (**MSU**). MSU writes extraction utilities to retrieve compartment data for the ship's AutoCAD to store in a relational database. MSU is reluctant to share the database schema making it almost impossible to create, without their direct involvement, a working FSSIM model of the Halifax Class Frigate;
4. The ease of developing the FSSIM relational database is based on the quality of the AutoCAD drawings – for instance, one consideration is whether the bulkheads align perfectly within the drawings;
5. IPME can only be made to communicate with the output from FSSIM with the use of a third party application – the FSSIM to IPME bridge program;
6. In order to have a single IPME task network model, logic must be embedded in each task to simulate a specific manning / automation level – reducing the overall number of tasks while keeping the model complex enough to simulate the damage control problem area;
7. The configuration of the IPME task network model must be planned to compliment the output files from FSSIM in order to assess the results against predetermined MOEs. Effectively all three aspects of the integrated model must be considered during development of any one portion;

8. The values used to trigger events, both in FSSIM and IPME, were selected only as a proof of concept and can be easily modified for future analysis or research; and
9. To invoke MOEs at the higher levels of abstraction than at the physical level, a linkage is required between resources / operational capabilities and the damage sustained in each model run.

4.4 CONCLUSIONS AND RECOMMENDATIONS

The paragraph numbers in parenthesis indicate the basis of each conclusion or recommendation. The following recommendations are made:

1. Prior to further work a relational database of the Halifax Class Frigate compartment information should be developed for use with FSSIM (2.3);
2. Follow-on models could expand the interaction between the IMPE model and FSSIM to consider toxicity and smoke concentration for the rapid response teams / confinement tasks (2.5);
3. Implement a 'crew array' in IPME to account for Section Base Team or manning pool personnel in more advanced scenarios (2.4);
4. Subject Matter Experts should be engaged to validate the timing assumptions and the probability of failure (reliability) for all tasks and all automation levels (2.4);
5. Determine realistic smoke (soot), temperature, and toxicity (CO) levels that would hinder confinement by precluding the setting of boundaries in the desired compartments –values used by the United States Navy may be available as part of the DC ARM literature (3.1);
6. Extend the Measures of Effectiveness to include measures from the abstract and generalized function levels in the functional model of damage control. This will require the linkage of the damage control effort to specific resources and/or the association between compartments lost to damage and operational capabilities of the ship – such as losing the Fire Control Equipment Room #1 will reduce certain warfare capabilities (2.2);
7. Consider the inclusion of the 'Monitor ship spaces' tasks in the follow-on work (2.4);
8. Increase the statistical analysis conducted on the output(2.3);
9. Future studies should improve fidelity of confinement assessment with respect to number, location and state of controllable openings(2.3);
10. In IPME the times to extinguish the fire are generally in excess of 500 seconds, therefore in the next phase the FSSIM should be run for longer periods to capture all potential propagation of damage before the fire is extinguished (2.4);
11. Data manipulation of the output from the bridge application should be automated or streamlined in the subsequent phase (2.5);
12. The fire size, type, and location should be varied to determine the affect on outcome (3.3);
13. Possible solutions to the slow speed of the model should be investigated in the next phase (3.3); and
14. Logic errors in the IPME and Bridge application must be corrected before the next phase (3.4).

SECTION FIVE – REFERENCES

[1] Floyd, J., Hunt, S., Williams, F., and Tatem, P., *"Fire + Smoke Simulator (FSSIM) Version 1 – User's Guide,"* NRL/MR/6180-04-8806, 31 March 2004.

[2] Floyd, J., Hunt, S., Williams, F., and Tatem, P., *"Fire + Smoke Simulator (FSSIM), Version 1 – Theory Manual,"* NRL/MR/6180-04-8765, 16 July 2004.

[3] Tomasz A. Haupt, Greg Henley, Bhargavi Sura, and Robert Kirkland, *"User Manual for Graphical User Interface Version 2.4 with Fire and Smoke Simulation Model (FSSIM),Version 1.2"*, NRL/MR/6180--06-9013, 18 December 2006.

[4] Torenvliet, G. L., Jamieson, G. A., & Cournoyer, L. (2007). *Functional Modeling, Scenario Development, and Options Analysis to Support Optimized Crewing for Damage Control - Phase 1: Functional Modeling (Revision A)* (Contract Report No. CMC Document 1000-1370 / DRDC Toronto CR 2006-090). Ottawa, Ontario: CMC Electronics.

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ANNEX A
GLOSSARY OF TERMS AND ACRONYMS

ANNEX A: GLOSSARY OF TERMS AND ACRONYMS

CPF	Canadian Patrol Frigate - equivalent to Halifax Class Frigate
DCO	Damage Control Operator
DRDC	Defence Research and Development Canada
FSSIM	Fire and Smoke Simulation Model
GUI	Graphic User Interface
HLA	High Level Architecture
HQ1	Damage Control Headquarters
IPME	Integrated Performance Modeling Environment
MOE	Measures of Effectivenss
MSU	Mississippi State University
RRT	Rapid Response Team
SQL	Structured Query Language

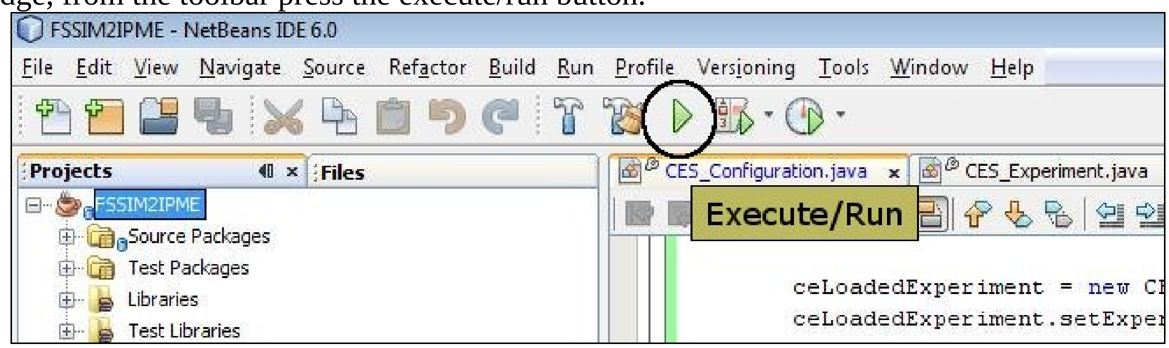
ANNEX B
EXECUTING THE CREWING EFFECTIVENESS STUDY IPME / FSSIM MODEL

B.1. Executing the Crewing Effectiveness Study IPME / FSSIM Model

The following describes the steps required for the experimenter to execute the Crewing Effectiveness Study IPME/FSSIM damage control simulation model.

On the project laptop, first start up the IPME application. Once IPME has finished loading, load the CES_DC_Model.prx project file. To do so, in IPME, select from the **File** menu the **'Load from file'** entry, and browse to the 'Crew Effectiveness Study' directory. Then, select the CES_DC_Model.prx file and press open. After the model has loaded, execute the model. The model now should be waiting for the FSSIM to IPME bridge application to connect. Next, open the Netbeans application from the shortcut provided on the desktop.

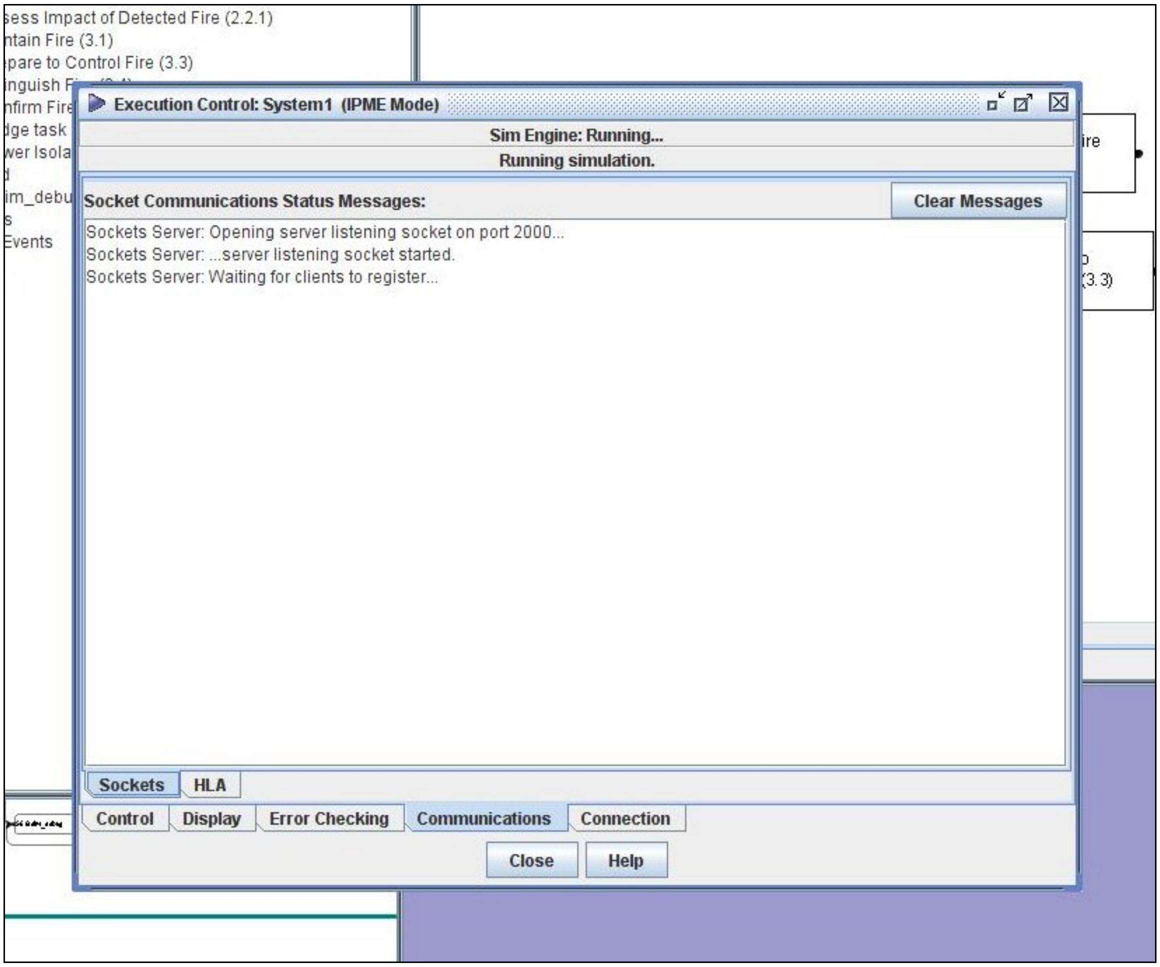
Once the Netbeans application has started up verify the FSSIM2IPME project is set as the default project (The project name should show up in the project explorer in a bolded font. If it is not, right click on the project and select **'Set as main project'**). To start the FSSIM2IPME bridge, from the toolbar press the execute/run button.



Once the FSSIM2IPME user interface has started, set the following fields to the following:

- IPME Address: localhost
- JDBC Connection String: jdbc:mysql://localhost/fssim_rundata
- Database Username and Password: just enter 'ces'
- Number of Runs: 50
- Client Name: ipme_test_client

Before connecting to the IPME model, verify that the IPME model has been started and is waiting for a client to connect. View the communication log (Available from the Execution Control window) to view the status that the IPME model is currently in.



Once the IPME model has been started and is waiting for the external bridge application, you can proceed to press the connect button on the FSSIM2IPME bridge UI to start the execution of the IPME model.

B.2. Crewing Effectiveness Study IPME Model Setup

The model as currently implemented in IPME, allows the experimenter to define the level of automation and the probability that automated tasks will fail via IPME network variables that can be initialized in the **ces_dc_initialize** function. These are explained in the following sections.

B.2.1. Automation Control

The automation of the detection, containment, bounding, power isolation, and extinguishing of fire task networks are controlled by boolean variables representing the state of automation for those task networks. If a particular automation control variable (for example, **bBoundingAutomation** for the Bound Fire task network) is set to true, then the tasks for that particular task network are now set to simulate the execution of the tasks via automated processes. If the automation control variable is set to false, then those tasks will be completed manually via crew member(s) if any are available.

Currently, the following boolean network variables represent the state of automation for the various task networks.

- bAssessImpactAutomation
- bBoundingAutomation
- bContainFireAutomation
- bDetectFireAutomation
- bPowerIsolationAutomation

B.2.2. Failure Control

The probability of failure for automated tasks is handled with the IPME network variable **dAutomationFailChance**. This variable stores a double value in the range of 0.0-1.0 to be used in calculations determining whether or not a particular network task has failed.

B.2.3. Model Variables

The CES DC IPME model is also dependent on the variables listed at the end of this document. These variables control everything from the bounding fire times, to the crew allocation and status. All variables should be initialized from the ces_dc_initialize function which is called upon with each new run of the model

B.3. Crewing Effectiveness Study IPME Model Output

Output generated from the CES_DC_Model IPME model is saved to the comma seperated value (CSV) file named output.csv found in the C:\Crew Effectiveness Study directory (the path of the output file is currently stored in the **sOutputFilePath** network variable). It is important to note that every time the model is executed, the model output data is appended to the end of the output file. So, after each group of runs of the model, the experimenter should move the output file to another directory on the machine before running the model in a subsequent experiment.
The columns within the output CSV file denote the following. Column one contains the description of the task, column two contains the IPME task ID, column three indicates the time the task ended, column four contains the duration of the task, column five indicates the number of compartments effected by soot, and column six indicates the number of compartments currently on fire.

B.4. Crewing Effectiveness Study FSSIM Database

As FSSIM does not have an API to allow external applications to access the resulting fire and smoke data produced by the FSSIM model at runtime, another method must be approached. For this project, the FSSIM output data is stored in a relational database (MySQL) and queried during IPME model execution via the FSSIM2IPME bridge application. Before being able to run the CES DC IPME model, the database must first be populated with the appropriate FSSIM output data files run previously on FSSIM under various conditions (i.e., doors open, ventilation off, etc). In order to import a FSSIM output file, in the FSSIM2IPME user interface, select the **FSSIM->Import** menu item. In the resulting dialog box, enter the path to the FSSIM output file to import, enter the JDBC connection string (jdbc:mysql://localhost/fssim_rundata), the database username/password (just enter ‘ces’) and a description of the FSSIM output file – Table 3-1 is an example. Click on the import button to import the FSSIM data into the relational database. In the current iteration of the FSSIM2IPME application, there does not exist any functionality to allow the experimenter to enter the conditions required for the FSSIM2IPME model to reference the imported FSSIM data files (such as indicating whether or not ventilation was active, doors were open or closed, etc). This will be addressed in the upcoming version of the FSSIM2IPME application. The current method around this problem is to directly edit the fssim_rundata.run_determination table directly via the MySQL Administrator and set the columns shutdownVentilationFail, closeBulkheadIsolationValveFail, closeDoorsHatchesFail, and ventilationShutdownTime to appropriate values best describing the imported FSSIM output data. Values for a full scale model will be provided by Subject Matter Experts for each specific damage condition. The table columns noted above are used by the FSSIM2IPME bridge to determine which FSSIM output data to query at runtime depending on the columns associated conditions which are sent by the IPME CES DC model at runtime. These conditions received from the IPME CES DC model include if the crew/automation closes doors and the time it occurred, whether or not ventilation was shutdown, whether or not the fire was properly bounded, etc.

B.5. Crew Effectiveness Study IPME Model Network Variables Definition

These values are set in each IPME task and are probabilistic in nature. Given the particular damage in this proof of concept Subject Matter Experts provided estimates of times or probability of success for each task and a standard deviation.

B.5.1. aiBoundWallTimesForCompartment

This two dimensional array contains the times required to bound the walls in various compartments found on the CPF. If an array location contains -1, then that indicates the particular wall of the compartment does not have or require a need to be bounded. The array is indexed as follows: The first dimension indexes the compartment, and the second dimension indexes the wall requiring to be bounded. Second dimension index is used to locate a wall bounding time for the forward(0), port(1), starboard(2), aft(3), above(4), or below(5) walls.

B.5.2. aiBoundedWalls

This two dimensional array is used to keep track of which wall for each compartment is currently successfully bound. First dimension indexes to a particular compartment from 0-98. The second dimension index is used to locate a wall bounded flag for the forward(0), port(1), starboard(2), aft(3), above(4), or below(5) walls. If the flag for a particular wall is set to 1, then the wall is successfully bounded. Otherwise a zero indicates failure.

B.5.3. aiCrew

This two dimensional array stores up to 99 (or more if needed) crew teams. Each crew team can contain up to 99 crew members and each member status flag can be set to either BUSY (0) or READY (1). This provides a possibility of up to 9801 crew members (99 teams x 99 crew members / team). The first dimension of the array indicates a crew team, while the second dimension of the array indicates a crew member within a particular team, and the value of the variable represents the crew member’s status.

B.5.4. aiMaxCrewMembersPerGroup

This one dimensional array is used to store the maximum number of crew members per team. This is used with the **aiCrew** array above to allocate and de-allocate a maximum defined number of crew members per team during runtime of the model.

B.5.5. atBoundWallTasks

This one dimensional array of task identifiers is used to store the associated bounding task identifiers per each bound wall task defined in the **bound fire** subnetwork. This array is used to handle potential automation failures and crew member re-allocations during runtime.

B.5.6. bAssessImpactAutomation

This boolean variable enables or disables the automation for the **Assess Impact of Detected Fire (2.2.1)** subnetwork.

B.5.7. bBoundFireFail

This boolean variable is used to indicate whether or not the automation for the **Bound Fire (3.2)** subnetwork has failed.

B.5.8. bBoundingAutomation

This boolean variable is used to either enable or disable the automation in the **Bound Fire (3.2)** subnetwork.

B.5.9. bConfineDone

This boolean variable is used to indicate that confinement of the fire has been successfully completed.

B.5.10. bConfinementInfoAvail

This boolean variable is used to indiciate that confinement data is available for the continuation of the **Prepare to Control Fire (3.3)** subnetwork.

B.5.11. bContainFireAutomation

This boolean variable is used to either enable or disable the automation in the **Contain Fire (3.1)** subnetwork.

B.5.12. bDetectFireAutomation

This boolean variable is used to either enable or disable the automation in the **Detect Fire (2.1.1)** subnetwork.

B.5.13. bPowerIsolated

This boolean variable stores the status of the power isolated task.

B.5.14. bPowerIsolatedAutomation

This boolean variable is used to either enable or disable the automation in the **Power Isolation** subnetwork.

B.5.15. bPowerIsolationDone

This boolean variable indicates the completion status of the **Power Isolation** subnetwork.

B.5.16. bPrepareToControlFireAutomation

This boolean variable is used to either enable or disable the automation in the **Prepare to Control Fire (3.3)** subnetwork.

B.5.17. bShutDownVentAutomation

This boolean variable is used to either enable or disable the automation of the ventilation shutdown tasks in the **Contain Fire (3.1)** subnetwork.

B.5.18. dAssessImpactTimeMult

This double variable stores the multiplier to be applied to the tasks within the **Assess Impact of Detected Fire (2.2.1)** if automation happens to fail. Initailized to 1.0.

B.5.19. dChooseStrategyMeanTime

This double variable is used to store the mean time precalculated for the tasks 37.4 and 37.6 in the **Assess Impact of Detected Fire (2.2.1)** subnetwork.

B.5.20. dContainFireAutoFailTimeMult

This double variable stores the multiplier to be applied to the tasks within the **Contain Fire (3.1)** subnetwork if automation happens to fail. Initailized to 1.0.

B.5.21. dDetectFireAutomationFailMult

This double variable stores the multiplier to be applied to the tasks within the **Detect Fire (2.1.1)** subnetwork if automation happens to fail. Initailized to 1.0.

B.5.22. dDetectFireMeanTime

This double variable is used to store the precalculated meantime to synchronise the starting and ending of tasks 36.1, 36.2, and 36.3 in the **Detect Fire (2.1.1)** subnetwork.

B.5.23. dFailExtendTimeMult

This double variable stores the multiplier to be applied to the tasks within the **Bound Fire (3.2)** subnetwork if automation happens to fail. Initailized to 1.0.

B.5.24. dShutDownVentAutoFailTimeMult

This double variable stores the multiplier to be applied to the tasks within the **Contain Fire (3.1)** subnetwork if automation happens to fail. Initailized to 1.0.

B.5.25. sOutputFilePath

This string variable stores the location of the output file to be written to during runtime. This file must have a valid path on your own machine. Also, remember to rename or delete the output file before each model run as it will append to the file if it currently exists.

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Crewing Effectiveness Modeling Proof of Concept (U)
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(U) This project was a proof of concept employing a combination of simulation models with the intent of using a mature version of the combined model to compare crewing levels and automation as a method to investigate crew optimization possibilities. The damage control domain of the Halifax Class Frigate was used as the test environment. Models employed were the Integrated Performance Modeling Environment and the Fire and Smoke Simulation Model. The results of the modeling effort were assessed against measures of effectiveness developed in a previous study. The analysis showed that the combined models could be used to generate useful measures of effectiveness in comparing various crewing levels and a varying probability of reliability for automated sensors and systems.

(U) Le présent projet était une validation de principe employant une combinaison de modèles de simulation dans le but d’utiliser une version affinée du modèle combiné pour comparer les niveaux de dotation en équipage et l’automatisation comme façon d’étudier les possibilités d’optimisation d’équipage. Le domaine du contrôle des avaries de la frégate de classe Halifax a été utilisé comme environnement d’essai. Les modèles employés étaient l’Environnement intégré de modélisation des performances et le Fire and Smoke Simulation Model. Les résultats des efforts de modélisation ont été évalués par rapport à des mesurse d’efficacité élaborées dans une étude précédente. L’analyse a montré que les modèles combinés peuvent être utilisés pour produire des mesures d’efficacité utiles en comparant divers niveaux de dotation en équipage et une probabilité variable de fiabilité pour les systèmes et capteurs automatisés.

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(U) crewing; damage control; modelling; simulation