REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE (DD-MM-YYY)	2. REPORT TYPE	3. DATES COVERED *(From – To)*
1-October-2009	Technical & Cost Expenditure Status Report	01-Jul-2009 to 30-Sep-2009

4. TITLE AND SUBTITLE

INTEGRATED RECONFIGURABLE INTELLIGENT SYSTEMS (IRIS) FOR COMPLEX NAVAL SYSTEMS

5a. CONTRACT NUMBER

N00014-09-C-0394

5b. GRANT NUMBER

N/A

5c. PROGRAM ELEMENT NUMBER

N/A

6. Author(s)

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)

ONR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

N/A

12. DISTRIBUTION AVAILABILITY STATEMENT

Unlimited Distribution

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The following report details the progress that has been made by ASDL in developing and applying the IRIS concept for the period of July 1 to September 30, 2009. The major task the team focus on is to develop an advanced design process for designing intelligent complex systems with "assess-predict-plan-execute" functions, such as next generation naval ship. The team employed UML to model the design process and various diagrams were created to address the requirements of the design process and represent the design activities. In addition, progress is made on individual tasks, including initial Paramarion drawing for notional ship design, error evaluation in the integration of heterogeneous systems, implementation of resource allocation in high level controller, distributed control development using agent-based control with inference engine, Python-based M&S implementation with the aid of graph-based surrogate modeling, new extension of human in the loop control and method development for improving system effectiveness.

15. SUBJECT TERMS

Modeling & Simulation, Reconfigurability, Integrated & Intelligent, Naval Systems

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Mr. ANTHONY J. SEMAN
U	U	U	SAR	28	19b. TELEPHONE NUMBER *(include area code)* 703-696-5992

QUARTERLY REPORT

(July 1, 2009 – September 30, 2009)

"Integrated Reconfigurable Intelligent Systems (IRIS) for Complex Naval Systems"

Contract #: N00014-09-C-0394

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AWARD PERIOD:
July 1, 2009 to February 21, 2009

September 30, 2009

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Summary

The following report details the progress that has been made by ASDL in developing and applying the IRIS concept for the period of July 1 to September 30, 2009. The major task the team focus on is to develop an advanced design process for designing intelligent complex systems with "assess-predict-plan-execute" functions, such as next generation naval ship. The team employed UML to model the design process and various diagrams were created to address the requirements of the design process and represent the design activities. In addition, progress is made on individual tasks, including initial Paramarion drawing for notional ship design, error evaluation in the integration of heterogeneous systems, implementation of resource allocation in high level controller, distributed control development using agent-based control with inference engine, Python-based M&S implementation with the aid of graph-based surrogate modeling, new extension of human in the loop control and method development for improving system effectiveness.

Task 1: Design of Integrated Heterogeneous Systems

Subtask 1.1: Design Process Development Using System Engineering Approaches

Subtask 1.1.1: Method Development for Complex System Design

Introduction

The Integrated Reconfigurable Intelligent Systems (IRIS) is an initiative employing advanced methods to facilitate the design and operation of complex intelligent systems with an application to a naval ship. These systems are envisioned to perform four critical functions: *assess*, *predict*, *plan* and *execute*. The implementation of these functions involves the extensive use of autonomous decision making to deal with various scenarios. Traditional methods fall short of adequately addressing all the capability requirements within the stipulations of an acceptable cost. Consequently, new design processes must be developed, implementing the methods and tools necessary to design systems with respect to vital global behaviors. In the past few years, the Aerospace Systems Design Laboratory (ASDL) at the Georgia Institute of Technology has developed a Modeling & Simulation (M&S) environment based on a reduced scale demonstrator of the DDG-51 class chilled water system to investigate the system's behavior when coupled to a variety of control and decision making algorithms. This M&S environment is a key enabler that can be incorporated in the design process for analyzing and exploring the design space. After having the M&S environment available, ASDL has initiated plans to develop an advanced design process that will be able to address all the requirements of intelligent complex systems with the implementation of the "assess-predict-plan-execute" functions.

Progress

In order to develop an advanced design process for designing intelligent complex systems, the IRIS team has agreed to utilize Unified Modeling Language (UML) as a means to document the systematic approach of the design process. UML is a standardized general-purpose object-oriented modeling language used to specify, visualize, modify,

construct and document the artifacts of an object-oriented software system. In addition, UML is considered as an appropriate tool to describe processes and has been widely used in business process modeling. It is observed that if the process is fully understood and improved before a project is started, the outcome will be achieved in a more efficient and effective manner. As an extension to the business process modeling concept, UML is being employed to formulate the IRIS design process. Unlike other traditional design processes, the IRIS design process will address multiple necessary interfaces actors such as the stakeholders at each design step, the utilization of resources, communications between different steps, interrelations between models, and so on. That is, the IRIS design process put more emphasis on how exactly the activities are accomplished rather than what needs to be accomplished in each design step.

As a first step, a use case diagram was created in active development to capture the functionality and requirements of the IRIS design process. Four high level use cases are currently identified: build system ability set, design architecture concept, establish baseline and build system model, and the actors interacting with these uses cases are identified as well, as shown in Figure 1.

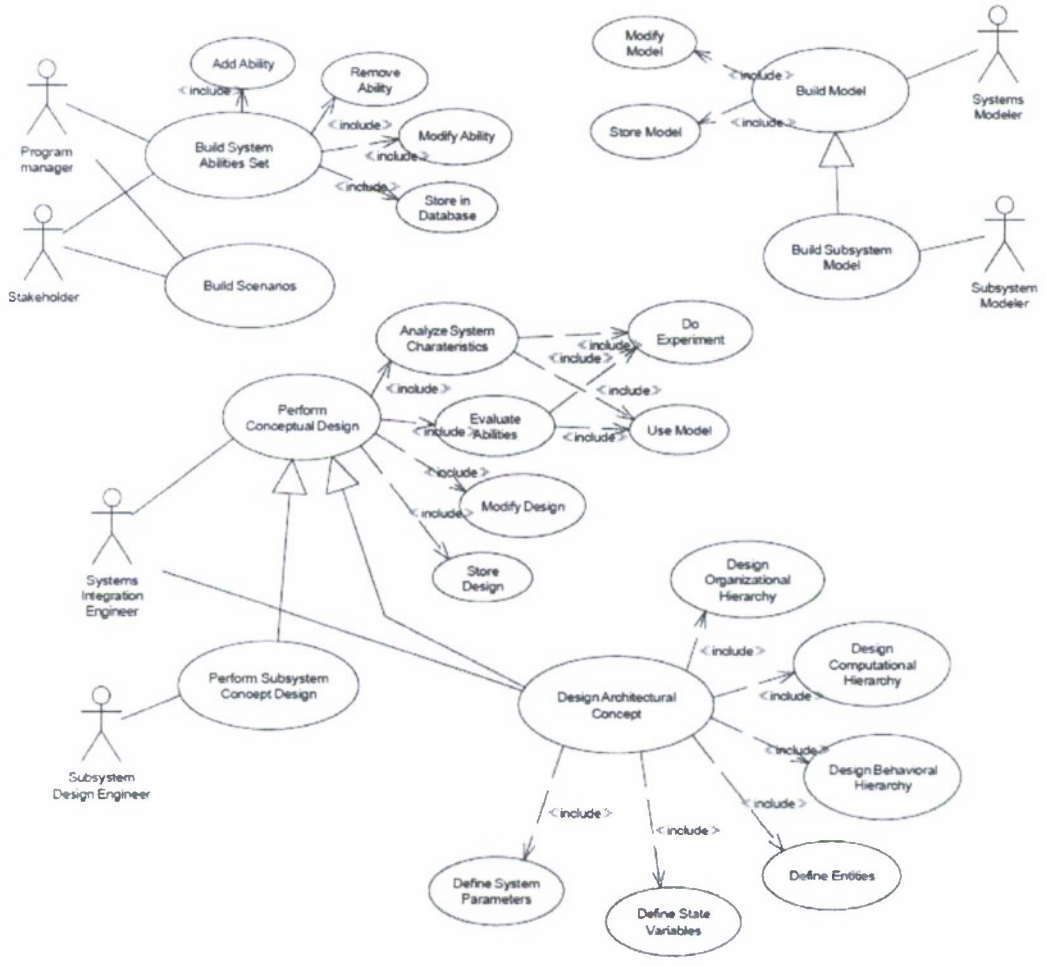

Figure 1: Use Case Diagram for IRIS Design Process

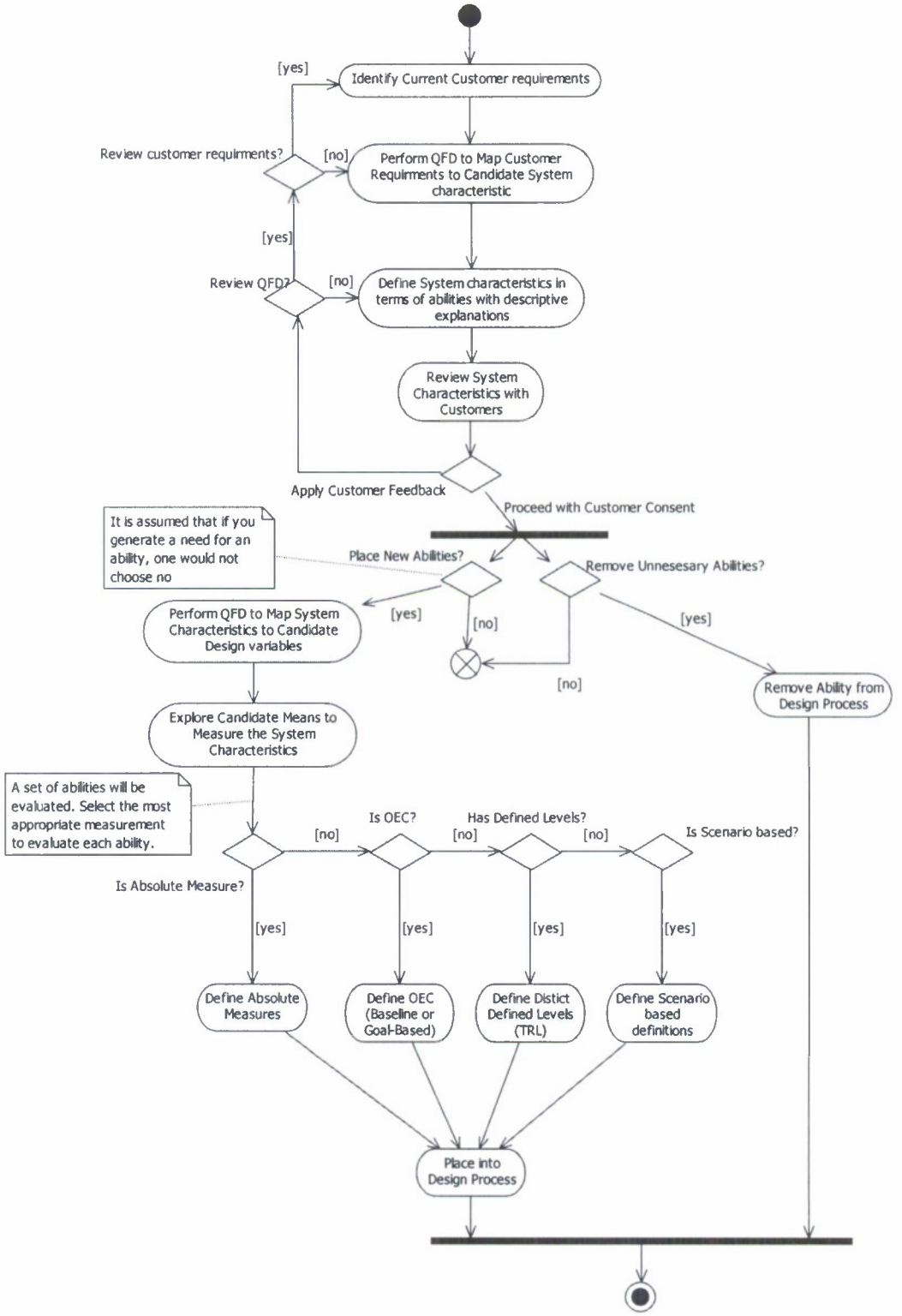

Figure 2: Activity Diagram for "Build System Ability Set"

As the use case diagrams are created, they will be analyzed and described using UML activity diagrams. Activity diagrams illustrate *what* needs to be done in a logical succession. Because each activity diagram is presented in a relatively more detailed manner, one can observe all the dependencies between activities in a graphic form, and enhance the ability to spot where changes and improvements must be done. Figure 2 presents the activity diagram for "build system ability set" use case. To complete this use case, the customer's requirements are identified first, and then the Quality Function Deployment (QFD) technique is utilized to map customer's requirements to system characteristics. Then the system characteristics will be defined in terms of abilities and reviewed with customer. If changes need to be made to the ability set, activities will be taken to add or remove abilities. After the system ability set is built, the abilities will be transferred to the next design step to aid further design decisions. The final design solution will be evaluated against these abilities. The activity diagrams created for the other three use cases are listed in the Appendix, showed in Figure 17 to Figure 21.

Activity diagrams model the logic supporting a use case or usage scenario and shows the overall work flow. However, it is not capable of showing the detailed interactions between classes and the message flows between objectives. This information can be represented in communication diagram in which it combine the information from class, sequence and use case diagrams to describe both the static structure and dynamic behavior of the process. We also created communication diagrams for each use cases and they are illustrated in Figure 3, Figure 4 and Figure 5.

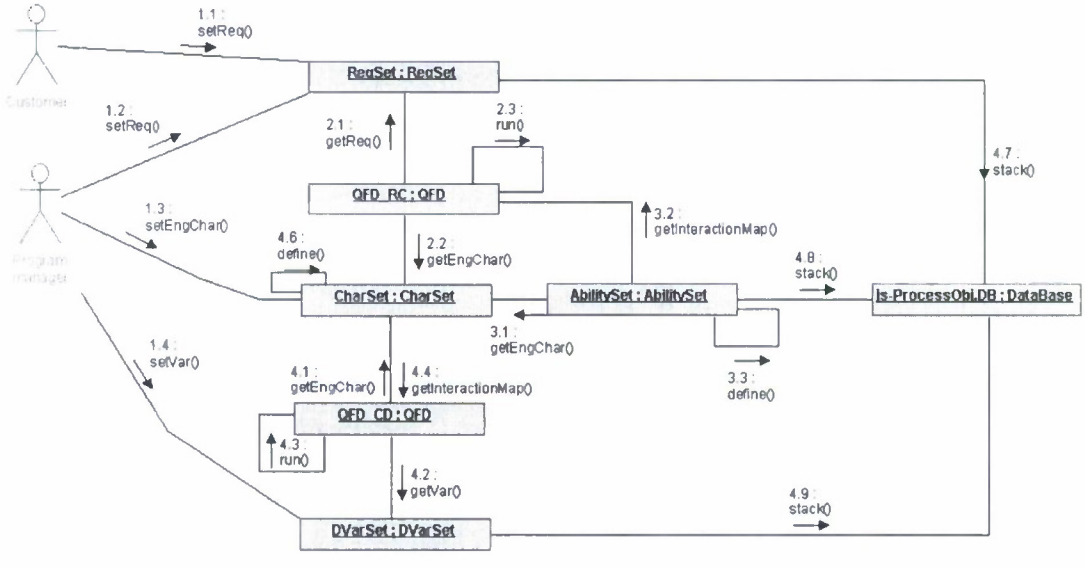

Figure 3: Communication Diagram for "Build System Ability Set"

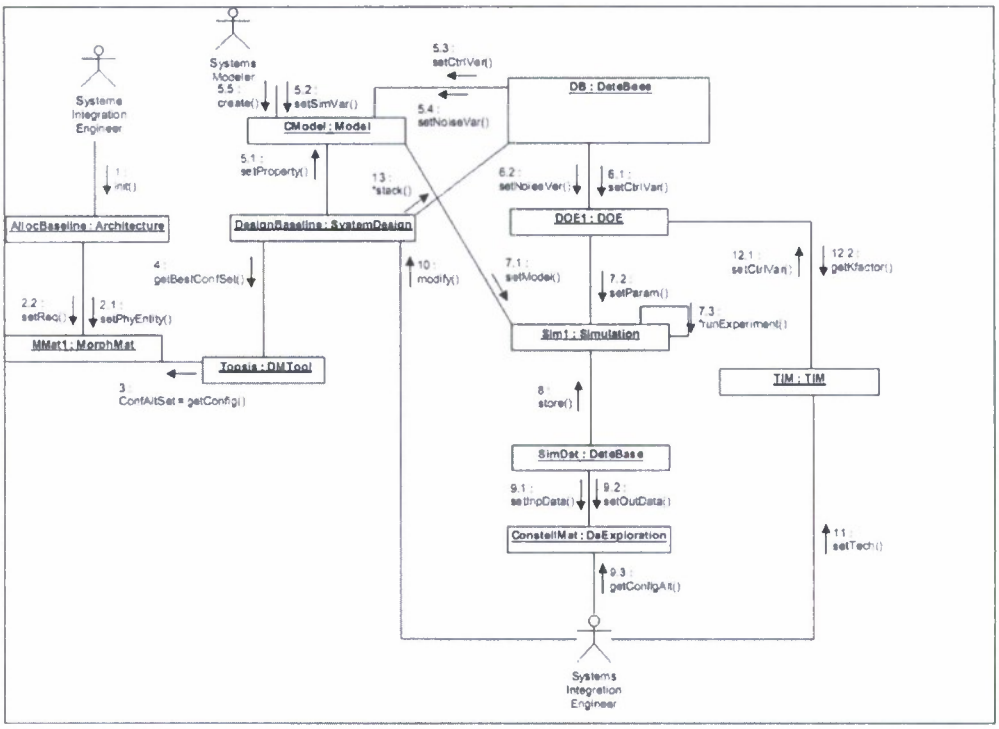

Figure 4: Communication Diagram for "Generate Baseline"

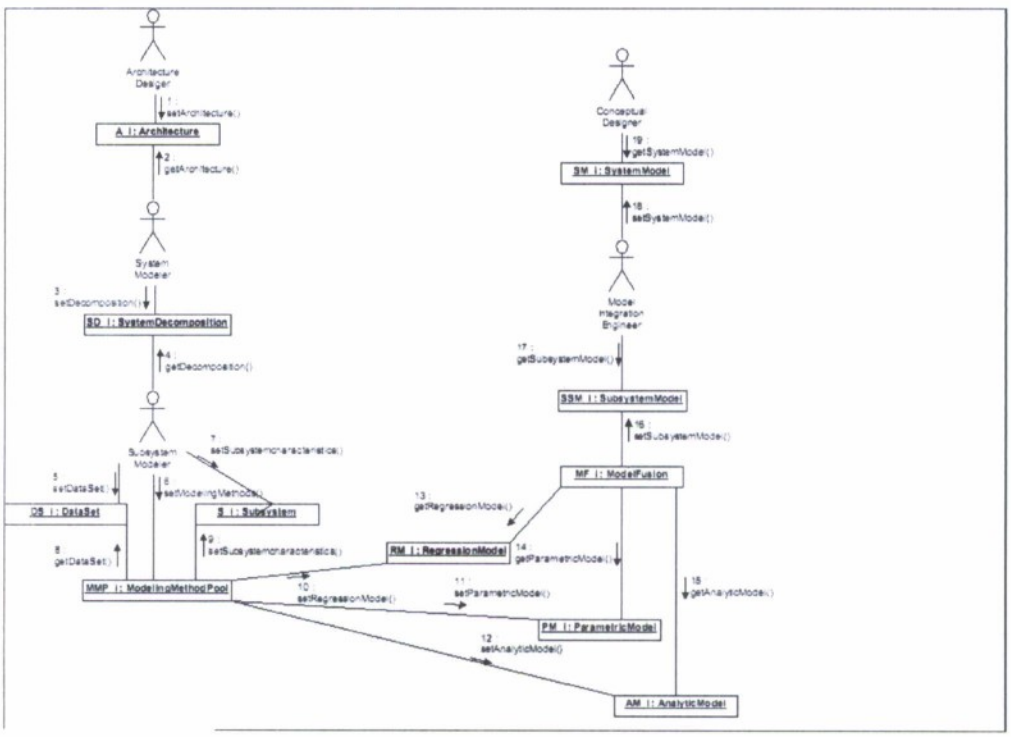

Figure 5: Communication Diagram for "Build System Model"

Future Work

With the initially created diagrams, future work regarding this task will be to iterate upon these diagrams until a refined version of the method is manifested. In addition, class diagram will be studied and created if it is necessary to help the designer recognize how to implement the process. Finally, all the diagrams will be integrated together to formulate the design process. The design process will address what design activities need to be accomplished, who will be involved in each activity, what information/resource is required, what tool/method will be utilized. With the design process, designers/decision makers should know how to design their own intelligent complex system which is capable of providing "assess-predict-plan-assess" functions.

Subtask 1.1.2: Notional Ship Development

Introduction

As it has been discussed in the original FY 2009 proposal, for the purpose of developing and testing the proposed design process, a sizing and visualization environment is required. This environment would allow for a ship product model (PM) development, starting from a notional baseline and furthermore developed, according to the instructions applied by the IRIS method. Complete ship configurations would be identified and sized using an object-based approach. Eventually, this notional ship would be key enabler for a set of studies that will constitute the proof of the IRIS concept.

Progress

The initial scope of this subtask was to generate a computer geometry model of a notional ship (baseline configuration), using Rhinoceros 3D® as the primary CAD tool. Moreover, a dynamic simulation environment of the ship engineering systems is envisioned to be built around it for analysis of operations.

Meanwhile, a new ship sizing and design tool has been acquired by ASDL. This tool is Paramarine, developed and made available by the Graphics Research Corporation (GRC). More information about Paramarine and its capabilities can be found at http://www.qinetiq.com/home_grc/products.html. Given the superiority and the offered analysis possibilities of this design environment, a decision has been made to implement a ship baseline in this new environment. While Rhinoceros 3D is an excellent graphical software package, it appears that one of its main limitations is that it is just a CAD environment, without any embedded modules for sizing and analysis of the PM architecture. On the other hand, a PM implemented in Paramarine would be easily exported to solid model file format that could be utilized by Rhinoceros 3D and further edited as a CAD model for any other purpose.

Returning on the objective of this task, the original proposed idea was to create a baseline notional ship that would be heavily based on a YP-679 configuration. Given that available engineering system models are sized for a YP sized configuration and the Navy's interest on this architecture, the choice of this baseline was very straightforward.

However, basic information around the geometry and the dimensions of the YP-679 was sparse; therefore all information that could be found from publicly available resources (web search for reports, schematics and fact sheets) has been imported to the Paramarine PM as reference information. Notional information has been added where required information cannot be available.

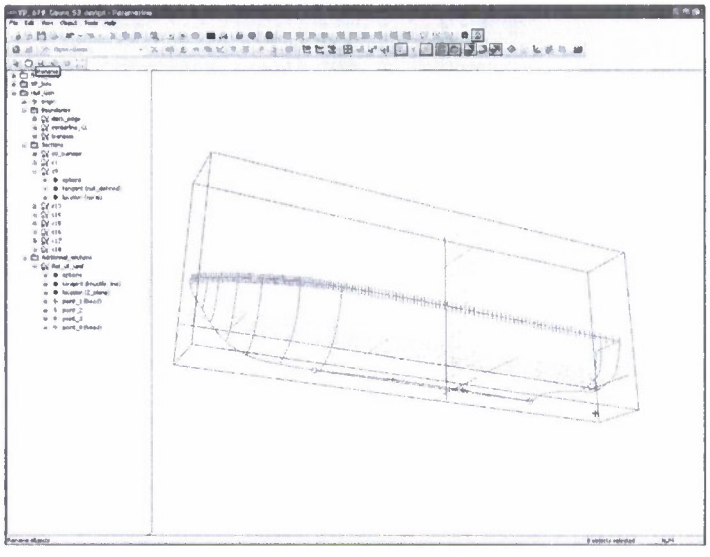

Figure 6: Early Stages of a Yard Patrol YP-679 Hull Generation in Paramarine

Future Work

Development of the YP -679 Paramarine model has been initiated early September 2009 (Figure 6), shortly after the acquisition of the software tool and the new user training course that occurred in August 2009. This task is planned to be complete by early October 2009, mainly including the generation of the hull, internal compartmentation and subdivision, as well as engineering systems representation (power generation and distribution, cooling, propulsion, etc.).

Subtask 1.2: Integration of heterogeneous dynamic systems

Introduction

In the final report for 2008, the initial steps for the time-discrete integration and co-simulation of different confidential third-party dynamic models have been presented. Conditions regarding constraints between the models were discussed. It was observed that the simulation of dynamic systems on a digital computer can only be executed at discrete time steps. Variable/adaptive time step algorithms have been presented which enable the simulation to run in a shorter time and at greater accuracy. Models were developed to investigate and demonstrate the feasibility and viability of the selected approaches. The results showed that the approach of using variable time steps is promising. Accuracies and run times were greatly improved. The application of a simple algorithm is comparatively easy. No optimizations have been made yet.

Progress

One problem of eo-simulation with proprietary sub-models is the evaluation of the rcsulting eombined model. The behavior of the eombined model is by dcfinition not known. Hence, assumptions and approximations must bc made in order to determine whether the observed model behavior is within the expeeted. Speeifieally, an error must be estimated. Ideally, the error should not only be estimated, but error bounds should also be givcn. This would enable the algorithm to determine whether the simulation still behavcs as expeeted. In order to evaluate the error and its bounds, a mathematieal approaeh is suggested that eombines eoneepts of numerical integration and polynomial interpolation to find a simulation path that eomes elosest to the estimated system behavior. The suggested approaeh eonsists of an interpolation of previous points, the estimation of a local slope that translates best to the system behavior in the next point in time, and a Taylor theorem approach to thc estimation of the funetion and the error.

Figure 7 shows the cause of error in the evaluation of a differential equation. The approach is the Euler method, the simplest way to numerieally integrate such a function

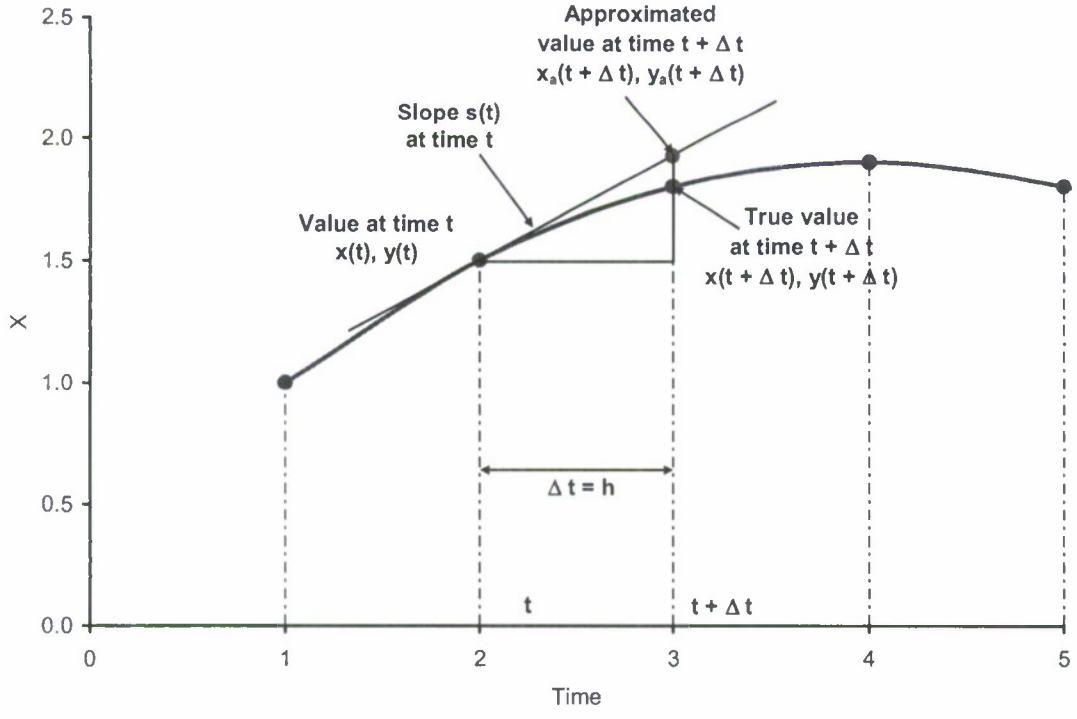

Figure 7: Cause of Error in Numerical Integration

It is clear that as long as the seeond derivative of the underlying function is not ehanging, the error will continue to inerease. It is also elear that redueing the time step will deerease the error. However, ideally the time step should be large in order to reduee the amount of ealeulations. Henee, a new approach ean be evaluated that tries to improve and somewhat forecast a better slope at the eurrent position, in order to be able to get a better approximation of the underlying funetion. Figure 8 shows an approaeh that uses future

simulation outputs to determine a better, more accurate slope. This approach is the Heun's method, or Runge-Kutta 2.

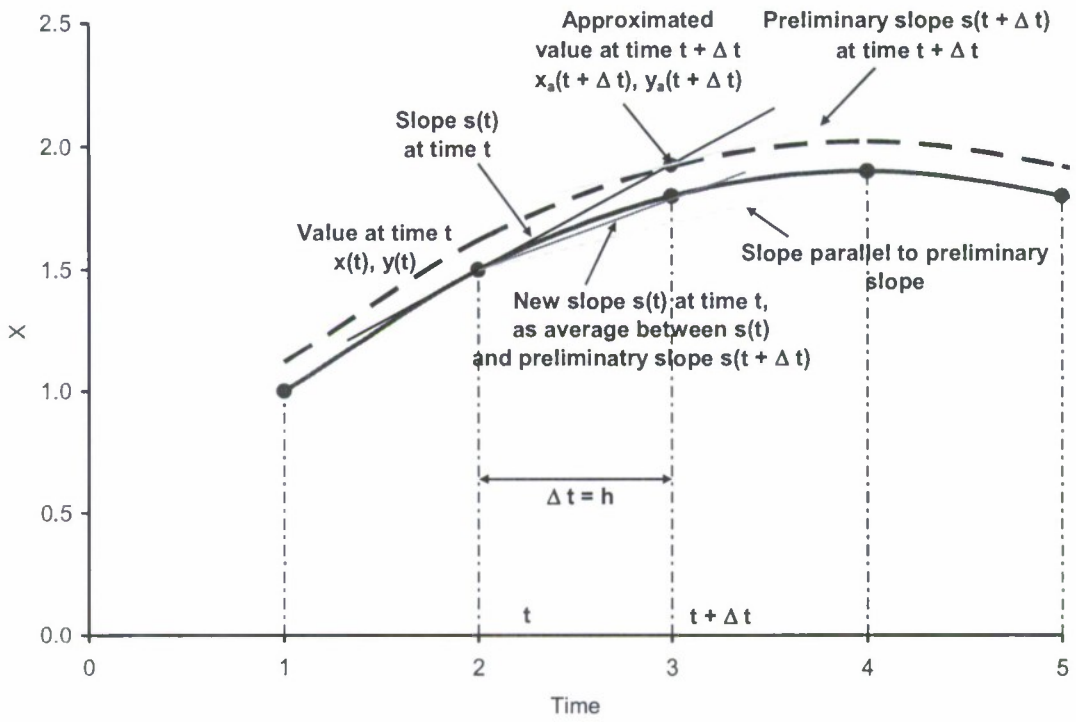

Figure 8: Better Approximation of Underlying Function by Adjusted Slope

This approach can be extended to more points evaluated for slope approximation, resulting in higher-order methods. However, this alone does not yet give an error or an error bound. However, the approach in Figure 8 and other higher-order methods of similar approach are based on the approximation of a function using a Taylor series and Taylor's theorem. This theorem is mathematically well defined, and allows for both error estimation and error bounding. The approach uses similar techniques that are used in numerical integration. It derives the approach using first principles of numerical integration, and extends those principles to the co-simulation of several dynamic systems. It unites the integration techniques with the Taylor theorem to not only estimate the closest point as the next step in the simulation, but to also give an error estimate, based on which it will be possible to optimize the simulation execution time and error, and to react upon shock impacts that may come from within the system or from external factors. Previous points will need to be regressed or otherwise approximated, adding an additional error that will need to be specified and bounded. Like the simple variable time step in previous discussions, this approach will be tested with a simple model at first, and then extended to a system that consists of several sub-systems with different system frequencies, making the overall system a stiff system. This approach is currently under development, and will be a Ph.D. thesis for one of the members of the IRIS team (Matt Hoepfer).

Future Work

Within the next three months, the mathematical prineiples of the suggested approach will be eolleeted, refined, and synthesized to an overall approaeh for eo-simulation. A simple model to test the approaeh already exists, and will be modified to include the new mathematical methods. Further down the road, a more complieated and realistic model will bc developed, whieh will represent a ship system and which will serve to evaluate the approaeh and make sure that it is applieable beyond a "lab" environment. Further investigations will inelude issues with time steps and data exehange sehedules in stiff systems, as these issues may eause further problems in a real world simulation. Also, the upper and lower bounds for time steps, and the algorithms for time step settings will be evaluated and tested.

Task 2: Intelligent Autonomous System

Subtask 2.1: High Level Control

Introduction

Since the IRIS designed systems are complex in nature, the system often eonsists of multiple subsystems which provide neeessary funetionalities to the system. As a result, various subsystems work together to aehieve the overall operational goal of the system, therefore, a tradeoff analysis should be conducted across the multiple objectives to optimize the objective of the system. As a result, proper decisions need to be made from a systems point of view to keep the system working funetionally and effectively.

The high level eontrol of the M&S environment is responsible for prioritizing the subsystems on resource allocation using dynamic decision making and control approaehes. In the implementation, the high level controller will assign priorities to thc serviccs loads and determine the appropriate actions needs to be takcn in order to effectively distribute multiplc resources.

Progress

A rule-based high lcvel controllcr is employed to set priorities for serviee loads requiring eooling resourees. It ean decide what is important at whieh point in time, and how important in comparison to others on obtaining required resources. This prioritization is based on the evaluation of operating environment, ship status and mission being performed. In addition, an approaeh that uses an optimization funetion that takes into aeeount relevant system parameters and mission status was also investigated. It was found that the rule based eontroller is effeetive in making autonomous deeision and easy to be implemented when allocating a single resouree to serviee loads.

The rule-based high lcvel eontroller possesses a eertain degree of intelligenee when deeiding on the load prioritization. It makes deeisions guiding the resouree alloeation based on the mission that the ship is performing and thc resource status a service load has. It determines the priority in which a serviee load get resouree by evaluating how a serviee load is important to best perform the eurrent mission based on the situation at hand. It also depends on if a serviee load requires resouree urgently. For instanee, if a

load has high priority beeause it is critical to the operation of other subsystems and based on the mission status, but this load has a large margin before it reaehes a eritieal stage (e.g. not extremely hot but running at a regular operating temperature), then it makes sense to save some of the resources and not provide this load with further resource. This will be achieved by providing two outputs from the high level eontrol module: a priority, and a eontrol aetion rccommendation (i.e., percentage of the maximum rcsource requirement of the serviee load). This eontrol action increases as the load approaehes a eritieal operating condition within a safety margin. This deeision making strategy implemented in the high level eontroller is effeetive and results show it ean inerease the efficieney of resouree usage.

Future Work

Further work will foeus on investigating and utilizing more advaneed deeision making and control methods to deal with the resouree alloeation problem. The method needs to bc effectively to manage multiple resources and aecount for the interaetions between rcsources.

Subtask 2.2: Multi-Agent Based Mid-level Control with Dynamic Inference Engine

Introduction

The objective of this research is to develop a comprehensive, generalized framework for the eontrol system design of a general large-seale complex system under significant uneertainties, with the foeus on distributed control architecture design and distributed inference engine design.

Progress

Hybrid Multi-Agent Based Control (HyMABC) arehiteeture is proposed via eombining hierarehieal eontrol arehiteeture and modulc control arehiteeture with logieal replieation rings. A Multiple Seetioned Dynamie Bayesian Network (MSDBN) as a distributed dynamie probabilistie inferenee engine ean be embedded into the control architecture to handle uneertainties of general large-scale complex systems. MSDBN deeomposes a largc knowledge-based system into many agents. Each agent holds its partial perspeetive of a largc problem domain by representing its knowledge as a Dynamie Bayesian Network (DBN). By using different frequcncies for local DBN agent belief updating and global system belief updating, communication cost and inference global consisteney can bc effectively balaneed. In this research, fully faetorized Boyen-Koller (BK) approximation algorithm is used for loeal DBN agent belief updating, and statie Junetion Forest Linkage Tree (JFLT) algorithm is used for global system belief updating.

MSDBN assumes statie strueture and stable eommunieation network for the entire system. However, for a real system, sub Bayesian network as a node eould be lost, and eommunieation network eould be shut down due to partial damages in the system. Therefore, on-line and automatic MSDBN structure formulation is necessary for making robust state estimations and inereasing survivability of the whole system. Distributed Spanning Tree Optimization (DSTO) algorithm, Distributcd D-Sep Set Satisfaction

(DDSSS) algorithm, and Distributed Running Intersection Satisfaction (DRIS) algorithm are proposed in this research. Combination of those three distributed algorithms and Distributed Belief Propagation (DBP) algorithm in MSDBN makes state estimations robust to partial damages in the whole system.

Combining the distributed control architecture design and distributed inference engine design together leads to a formal procedure of control system design for a general large-scale complex system as shown in Figure 9.

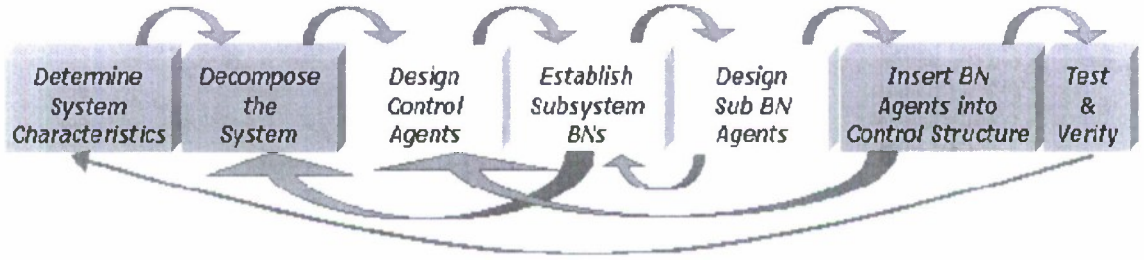

Figure 9: Process of Control System Design for Large-Scale Complex Systems

In order to check the effectiveness and validity of the proposed methodology and process and show how to implement the process step by step, the control system design of a simplified ship-wide Chilled Water System (CWS) is used as a proof of concept. Currently, the sketch of the implementation has already been formed and most part of the coding is finished.

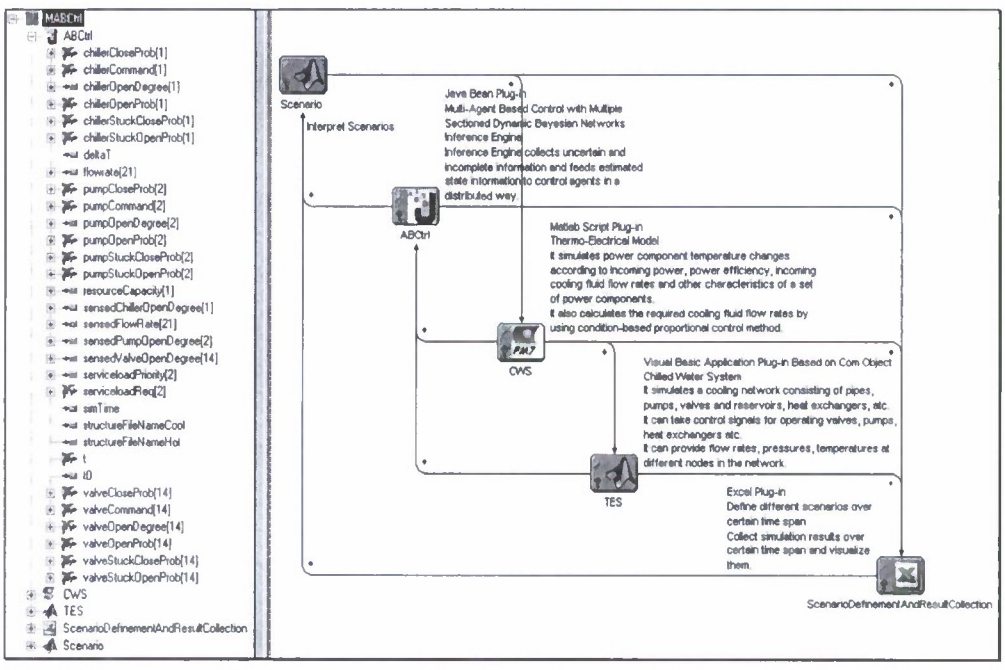

Figure 10: The Entire Test Model in ModelCenter Analysis View

The integrated model shown in Figure 10 will be briefly discussed in this report and detailed discussion of every module will be in the final report. The integrated model includes five modules: Scenario, ABCtrl, CWS, TES and ScenarioDefinementAndResultCollection. Scenario module transforms the scenarios defined in ScenarioDefinementAndResultCollection module into the format which is compatible with CWS module created in Flowmaster. ABCtrl includes HyMABC and MSDBN, which consist of dozens of control agents and three Bayesian network agents. The internal structure of each Bayesian network agent and the relationships among them are shown in Figure 11. All of the agents are established in JADE which is completely implemented in Java language, while CWS simulates fluid network which balances energy, pressure and mass flow rate of fluid. TES is a thermoelectric model and it also includes low level feed back controllers. ScenarioDefinementAndResultCollection is implemented in Excel worksheet. It defines the scenarios, collects the simulated results and visualizes the results.

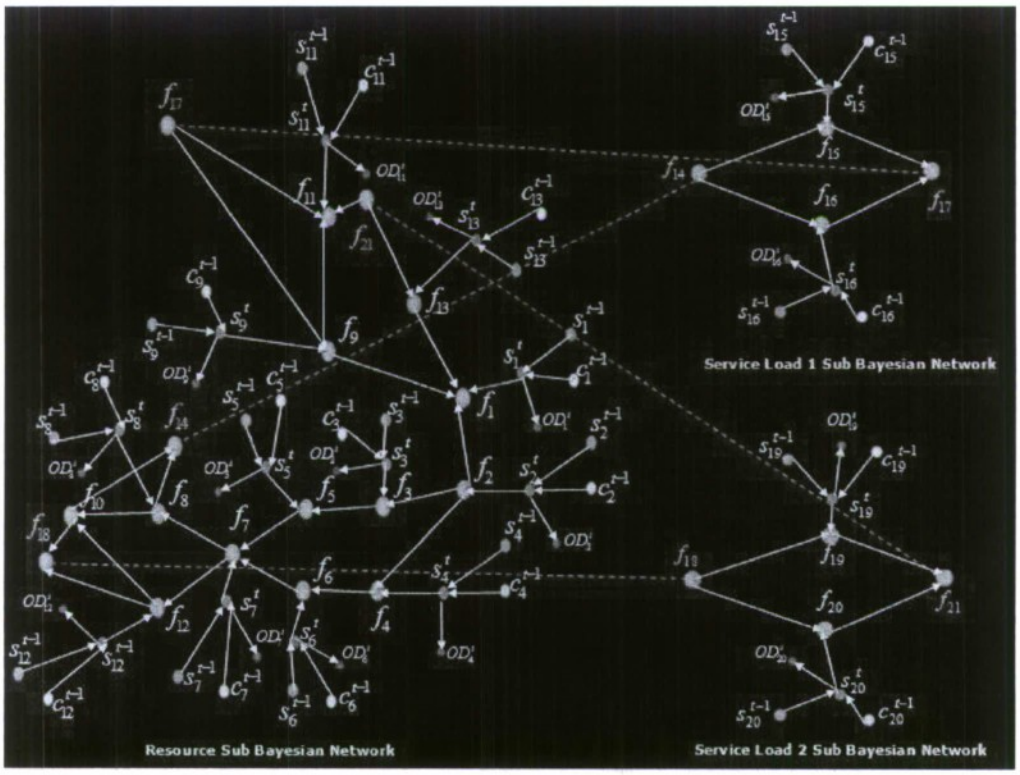

Figure 11: MSDBN of the Simplified Chilled Water System

Future Work

As mentioned before, the sketch of the implementation has already been formed and most part of the coding is finished. Further debugging and coding will be continued in the following 3 months. Data collection and data analysis will be carried out in the near future.

Task 3: Graph-Based Component Surrogate Modeling

Background

The task goal is to develop a M&S method of a chilled-water network that is capable of taking the connection-topological configuration among the components of the network as a "design variable." Then integrated the design-space exploration or the design optimization process, this proposed M&S environment may enable a simulation-based design for resiliency and survivability. The method consists of three key ideas – a graph-based topological modeling, object-oriented component model definition, and surrogate modeling for representing components' behaviors. Though the development of the method is based on the application for fluid systems modeling, the development approach has also considered more extended uses including the application to an electric power network which is another most common type of physics networks in engineering systems, just with minimal modifications of the method.

Progress

The blue print of the M&S method was developed previously so the task during the last 3 months has been on the implementation of the method with the chilled-water system of the notional YP as the modeling example.

As the development environment of M&S, Python script language was chosen. The early proof-of-concept model was implemented with Matlab, but as the task progressed, Matlab was found to be inadequate as the development environment of the graph-based component surrogate modeling method since Matlab is inherently not designed to perform object-oriented coding (although its late versions have object-oriented coding features) and as a result is less capable of creating a model with dynamic topological changes. Compared to Matlab, Python is object oriented but is also a script language like Matlab, which makes it easier to learn and maintain than other lower level object-oriented programming languages such as C++ or Java. Python also features a Matlab-like interactive shell and matrix data structures with a proper configuration becoming a great Matlab alternative.

The progress of the task on the Python-based M&S implementation can be divided into five phases:

Phase 1: Development and test of the basic classes for a simulation environment like a solver and a data manager and the classes of the graph elements such as nodes, edges, sources, sinks, and damages.

Phase 2: Development of the damage scenario generator class and test of the damage simulation of the M&S environment

Phase 3: Development and test of a "prefect" damage controller.

Phase 4: Development and test of the experimental design class for the network topological space.

Phase 5: Building the model of the chilled-water system of the notional YP and demonstration of damage analyses and topological design space exploration.

Currently, the progress of Phase 1 is over 90%, Phase 2 about 70% and Phase 4 about 40% completed (the percentage numbers are subjectively estimated). A simple model used for the proof of concept in the previous works was recreated in this M&S environment, and the simulation for both a normal operation condition (i.e. no damage) and a damaged condition was run with success.

Figure 12 is a UML class diagram of the M&S environment built with Python for the fluid system. This diagram is not yet completed so it is subject to change as the task moves forward. Future changes will include additional classes for the controllers and the further development of the classes in *post_proc* module.

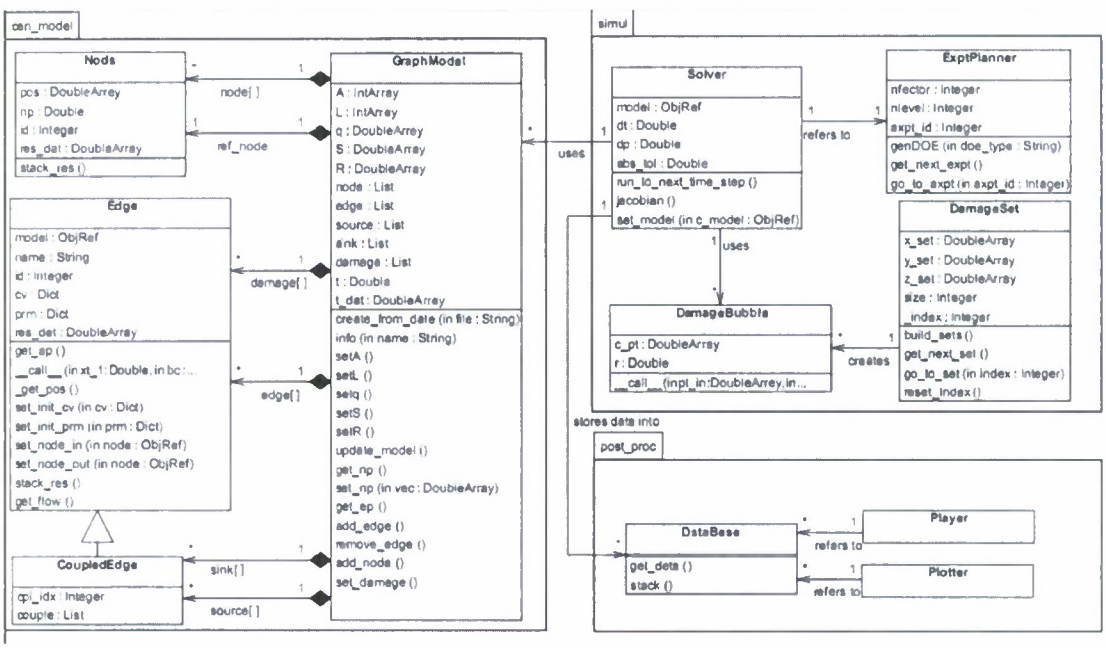

Figure 12: Class Diagram of M&S Environment

Although the result of the eode is only marginally valid for debugging proeess, Figure 14 and Figure 15 are only presented for the demonstration purpose. Figure 13 shows the location of a single damage applied in the simulation. The modcl is under a normal operation condition with a pump running at about 3000 rpm, and then the damage oceurs at 2 sec. of the simulation time. The model in the simulation has shown quite reasonable responses in generally but there are several points that need to be debugged. In Figure 14, the flow rates at the servicc loads 1 and 3 drops signifieantly with the drop of the inlct pressurc when the damage happens. At the same time, the water is being lost through thc ruptured ends of the damaged pipelines with a lot higher flow rates than the ones of the pipelines maintained in undamaged condition.

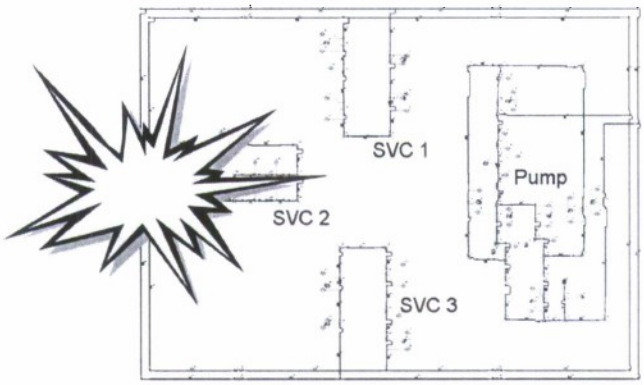

Figure 13: Damage Given in Simulation

The qualitative behaviors of the model seem correct but the numerical result still has large errors. This is mainly because the surrogate models are not accurate enough. Just for the sake of spending minimal efforts in the debugging process, the surrogate models used in the simulation were not generated with rigorous fine-tuning and validation processes result in large numerical errors in the simulation. This problem will be however corrected as more accurate surrogate models will be created in the final demonstration. In Figure 15, there is a strange overshot of the water flow rates at the ruptured ends of the low-pressure pipelines (i.e., pipe_lp_nw and pipe_lp_sw), which should be corrected by further debugging efforts.

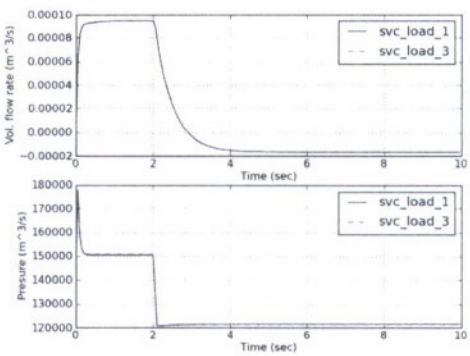

Figure 14: Flow rate and Inlet Pressure to Service-Load Pipelines 1 and 3

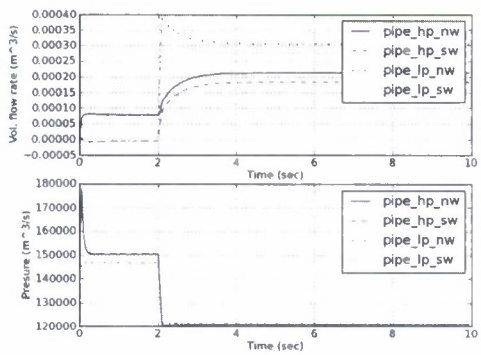

Figure 15: Flow rate and Pressure at the Pipes near Rupture

Future Work

As briefly mentioned, the future work will mainly focus on Phase 3, Phase 4 and Phase 5, coding for M&S implementation. Phase 5 is all about the test and demonstration of the final version of the M&S environment which will therefore be the deliverable results. One or two submissions for publication are planned, and at least one will be submitted by the end of this year.

Task 4: Human in the Loop Control

Introduction

The HMI was originally written in pure JavaScript as a first step to understanding how an AJAX style web application might enable human-in-the-loop control. The application included many features to facilitate its use within the design cycle. Some of these features included a simple and easy to understand user interface and accessible configuration files stored on an application server. Although the first version was very successful, the expansion of the original proved to be difficult. Maintenance issues raised as it was learned how dependent JavaScript was from browser to browser, or even differing versions of the same browser. In response to these impediments it was proposed to port the code base from JavaScript to a Flex-framework implementation. This shift would provide many advantages including the opportunity to compile the code permitting a more stable maintenance condition.

Progress

Progress for this task can be broken into four categories. The first category is the development of the basic libraries that will serve as the foundation for the whole application. The second category is concerned with the recovery of the initial capability of the original version of the HMI. The third category is involves the expansion upon the original capabilities. The finial and most essential category is that of documentation.

The basic libraries are under current development and being documented in parallel. The complete list of classes under the HMI library presently:

- dashML (handles communications with the server during runtime)
- dateToEnglish (translates dates and times into terms of years, months, weeks, days, hours, minutes, seconds)
- E4XParser (XML Parser)
- simComponent (graphical widgets for simulations)
- simComponentCanvas (canvases for graphical widgets)
- simDataManager (handles static and dynamic datasets for simulations)
- svgCompilerAgent (handles server side compiler events during runtime)
- winManager (handles windowing system and multi-tasking)
- xml2xml (translates between multiple xml schemas)

These libraries handle all the fundamental operations and functionalities of the HMI client. At this point these support the full capabilities of the original HMI, but they remain under development for future capabilities.

The newer Flex based implementation is required to reproduce all the capabilities of the original version. The most recent advancements meet this standard with room to grow. These capabilities being:

- Centralized code base
- Serve multiple clients simultaneously
- Hybrid server side and client side web-applications
- Object-Oriented Programming
- Scalable Vector Graphics
- ModelCenter™ Simulation Plug-in
- Real time user interface
- Ready to use out of the box (distributed as a virtual machine)

Despite these accomplishments both the original and the new version lack adequate error handling and logging. The new version does in fact comprise the ability to catch errors without crashing (most of the time), but it lacks a logging system altogether. Thus every error is immediately brought to the user's attention even if the error is not critical. During other instances the errors are not detailed enough to provide any real meaning.

The expansion effort to increase the current capabilities has been approached from three fronts. The first major extension is the integration of the HMI with a SQL database. The database will provide the infrastructure for the storage and retrieval of complex data structures. This means more complex configurations, management, and data handling. These plans will enable some of the more advanced feature such as multi-concurrent-user handling, TiVo like functions for time domain simulations, and the archiving of simulation data and user interaction data for post analysis.

The databases basic interfaces are in place, with a few more advanced interfaces for more specialized tasks. The database schema is still in its first iteration with only basic functions in service. MySQL is currently being used, but the schema design is compatible with other database systems with very minor changes required.

Future Work

Task 4 is running on time following closely to the proposed plan described in the 2009 statement of work. However two issues have arrived that require further attention. The most pressing is a more advanced error handling and logging mechanizes. It would be desirable to categorize the errors in order to maximize their usefulness to the users. It would also be useful to create a hybrid logging system that is keep by both the client application and the server. This arrangement could help troubleshoot communication errors of the network.

The second issue relates to the scalable vector graphics (SVG) render. The original version of the HMI used the web browsers ability to render SVG. This is no longer

available in the Flex framework. Some sueeess had been made using another open-souree SVG render, however the projeet did not fully support all the eapabilities of SVG and the projeet reeently has ehange direetions and goals. Unfortunately, the new direetion is not eompatible with the HMI. Currently we are looking at a more advaneed render, however this render most be exeeuted on the server. This solution seems viable sinee these renderings only need to be eompiled during eonfiguration time. Onee the renderings are eompiled the elient ean manipulate the images loeally without burdening the server.

Task 5: A Methodology for Improving System Effectiveness in Resilient Systems Design

Subtask 5.1: Theoretical background and framework development

Introduction

Aeeording to literature, there have been several survivability evaluation frameworks that have been used for assessing survivability. Sueh frameworks typieally inelude input metries, parameters, response metries and relationships. In order to propose and establish the theoretieal framework, the basis of its realization should rely on the fact that there is a minimum set of engineering subsystems that are required for supporting basie system operations and funetions. Sueh funetions eould be to provide electrie power, mobility, eooling and eontrol. To generalize this elaim, two "funetionally similar" systems ean be formulated to generate, distribute and deliver a value (electrieal or meehanieal power or information) to a reeipient. Given that system effeetiveness is direetly dependant to how systems ean maintain their ability to perform sueh funetions under any environmental eonditions, similar faetors and metries will be responsible for system survivability. A subset of this environment should be a set of deseription variables and parameters for representing the effeet of system threats, hazards and faults. With this subtask, a survey and a tabulated elassifieation of possible threats that a system ean eneounter will be eonstrueted. A pattern will be investigated for seenario preseribed system attaek or impaet similarities. Based on observations, threat taxonomy ean be ereated, based on the response that they induee to a system.

Progress

It has been identified that the basie information around a eomplex system that this framework is ealled to be able to deseribe, should eontain the following:

- System Geometry and Speeifieations (Drawings, CADs, pietures, produet models)
- Engineering Subsystems
    - Types (electrieal, meehanieal, hydraulie)
    - Geometry (spees, topologies, engineering sketehes)
    - Performanee ratings
    - Cost
    - Connectivity
    - System states

- Mission profiles
  - Goals and objectives
  - Figures of merit
  - Time frames
- Threats and hazards
  - Types
  - Impact data and models
  - Failure rates and modes
  - Response and recovery times

Under construction is a list for possible threat identification. This is essentially a tabulation of intelligent/non-intelligent threats vs. the three main types of change, context, expectation and form of the physical system. The next step (also currently under development) is a Microsoft Excel template to host a compatibility matrix of threats to system and subsystem types.

Future Work

The scope of this task is to deliver a framework of metrics, parameters and relationships that would support system survivability evaluations, including subsystem degrees of freedom, response metrics and relationships/bonds that can capture causality and subsystem interaction at a minimum. The framework will be defined in an object oriented modeling environment, such as *UML and SysML*, comprised of class definition, activity and communication diagrams.

Subtask 5.2: Formulation of analysis tools and integration into a M&S environment

Introduction

Individual models of engineering subsystems are combined to produce integrated models for dynamic simulation. Part of this particular effort will be a routine that models and investigates damage propagation on a naval system. The damage model engine will analyze (damage prediction) and visualize (on the Paramarine ship PM) the damage propagation throughout the particular architecture. In this task, a total ship systems operations M&S environment is the desired outcome, including an investigation of damage generation and propagation.

Progress

For the purpose of understanding model how damage on a system occurs and propagates, several theoretical models have been considered and processed. The most common mechanism for damage propagation is when systems are directly connected and immediately affected. With a given initial point of damage (e.g. faulty node) in a systems network, there can be a direct prediction of what other nodes will be affected. A common approach for this prediction is the usage of *deactivation diagrams*.

However, there is another mechanism that can reveal more consequences on system performance, due to the occurrence of a damaged subsystem. Emerging behaviors can

trigger further complication in normal system operation and propagate the effects of initial damage to system network neighborhood that is either physically far from the initial damaged point or not necessarily physically connected to the faulty component. A dynamic simulation of systems operation is expected to reveal the final set of affected subsystems and compartments, in order to identify the ship's overall performance capability at the point that damage has propagated to great extent.

The above scheme is briefly described in the following schematic (Figure 16). Ultimately, the results of the dynamic simulation will be processed in order to identify any possible directions of improvement.

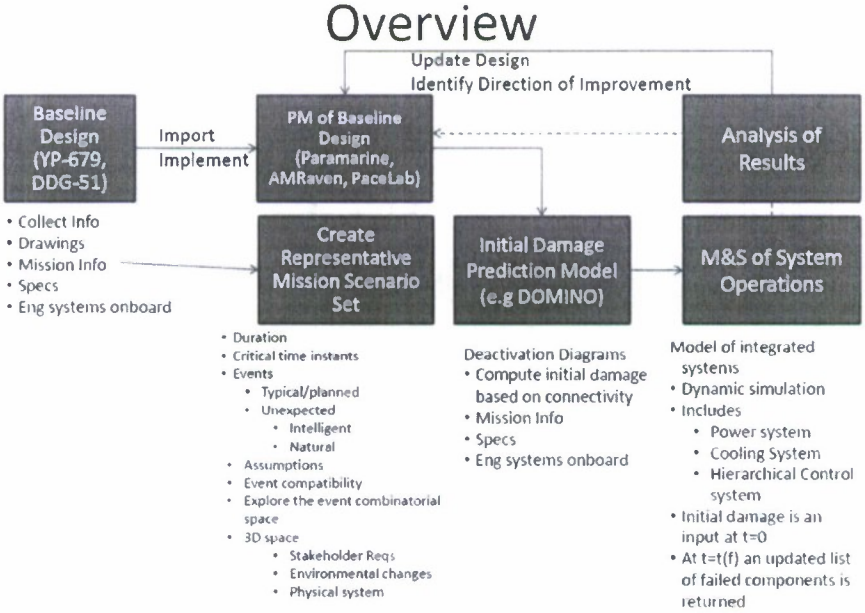

Figure 16: Modeling &Simulation Environment for Survivability Analysis

The current status of the effort is that the above environment is about 30% complete. Baseline information and a product model available. The initial damage prediction module is expected to be provided by the Navy (DOMINO) and more work will be required for further understanding of how this enabler can be integrated in the process.

Future Work

Except for the integration of DOMINO in the M&S environment, further efforts are required for the systems modeling and integration. While power system and cooling system models are available, the IRIS team is currently working to validate the integrated environment that has been constructed. Furthermore, an infrastructure concerning the processing of simulation responses needs to be finalized. This will allow for various tasks to be performed, such as design space exploration, decision making on design enhancements, etc.

Subtask 5.3: Development and evaluation of a complete method

Introduction

With the emergence of the previous capabilities, a complete method will be developed and tested on a small scale YP-679 naval system. With task 3, the theoretical framework, combined with the analysis environment will become the main elements of the survivability based design methodology. The final solution should be the one that satisfies top level performance constraints subject to the scenarios considered. Last step of the method development would be the application of scientific techniques for testing and evaluation of the method itself

Progress

The ship baseline for the method development will be the YP-679. Thus, no concept exploration will be part of this method, rather than the exploration of the design space for ensuring flexibility in the case that system requirements might be altered. For the purpose of demonstrating how this method can yield a more resilient design, a specific approach has been accepted as a means of method verification. Three designs will be produced originating from the same baseline, yet they will be optimized for different objectives. One will just be a performance oriented design. The second will encompass survivability enhancement features but not necessarily any enabling capabilities for a more resilient design (e.g. like an IRIS system). The third approach will be a more resilient design, which would be capable of reconfiguring and demonstrating intelligent responses to the same set of test scenarios. Ultimately, the three designs will be compared in terms of their performance in safety and survivability along with any increase in system complexity and design cost.

Future Work

While strategies for method development and verification have been iterated upon and finalized, the bulk of the work for actually producing the three designs and evaluating them against each other, is still part of the future work for the remainder of this agreement.

Appendix

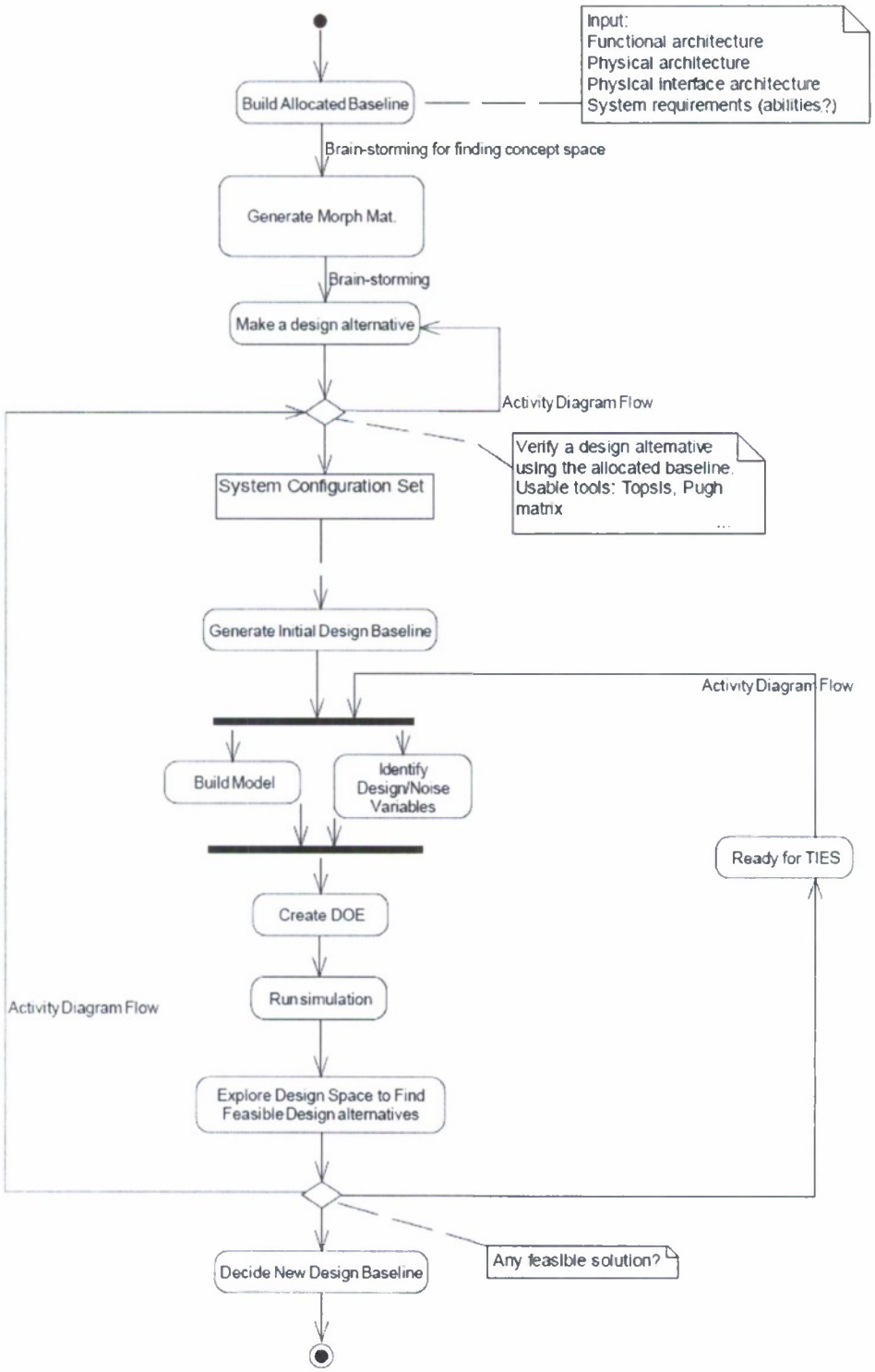

Figure 17: Activity Diagram for "Generate Baseline Concept"

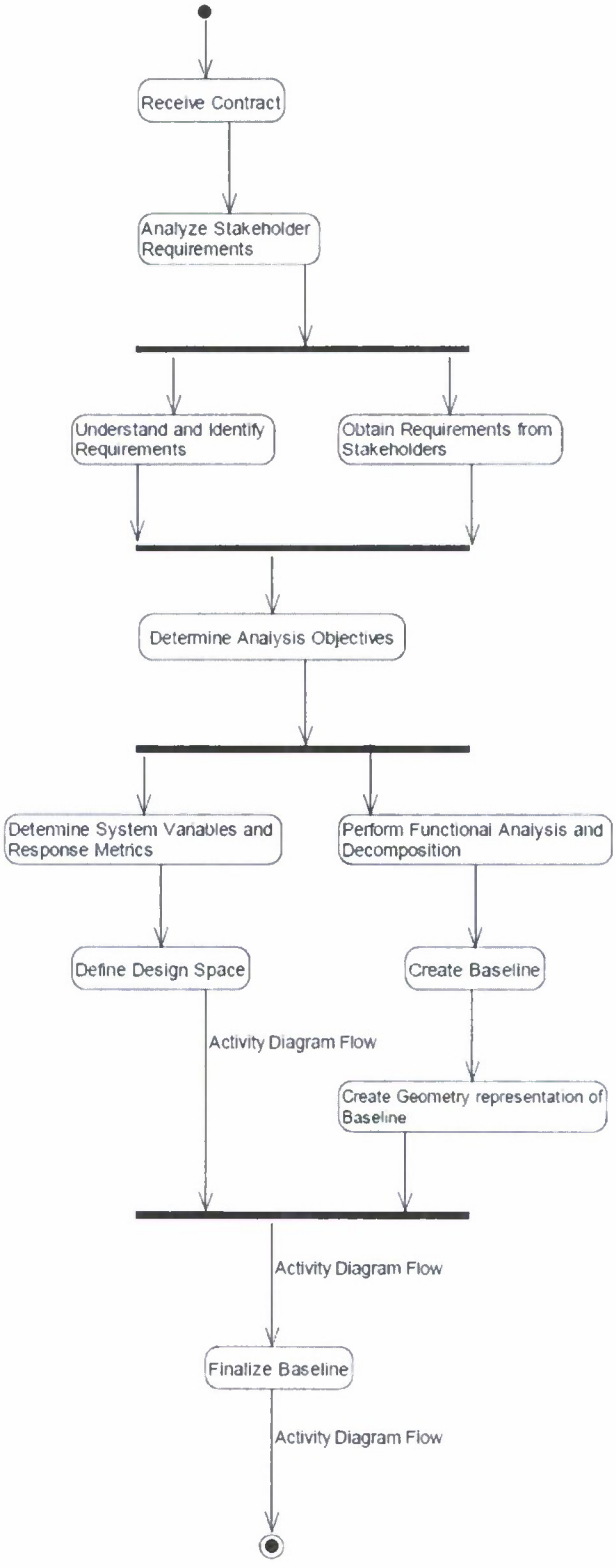

Figure 18: Activity Diagram for "Analyze System"

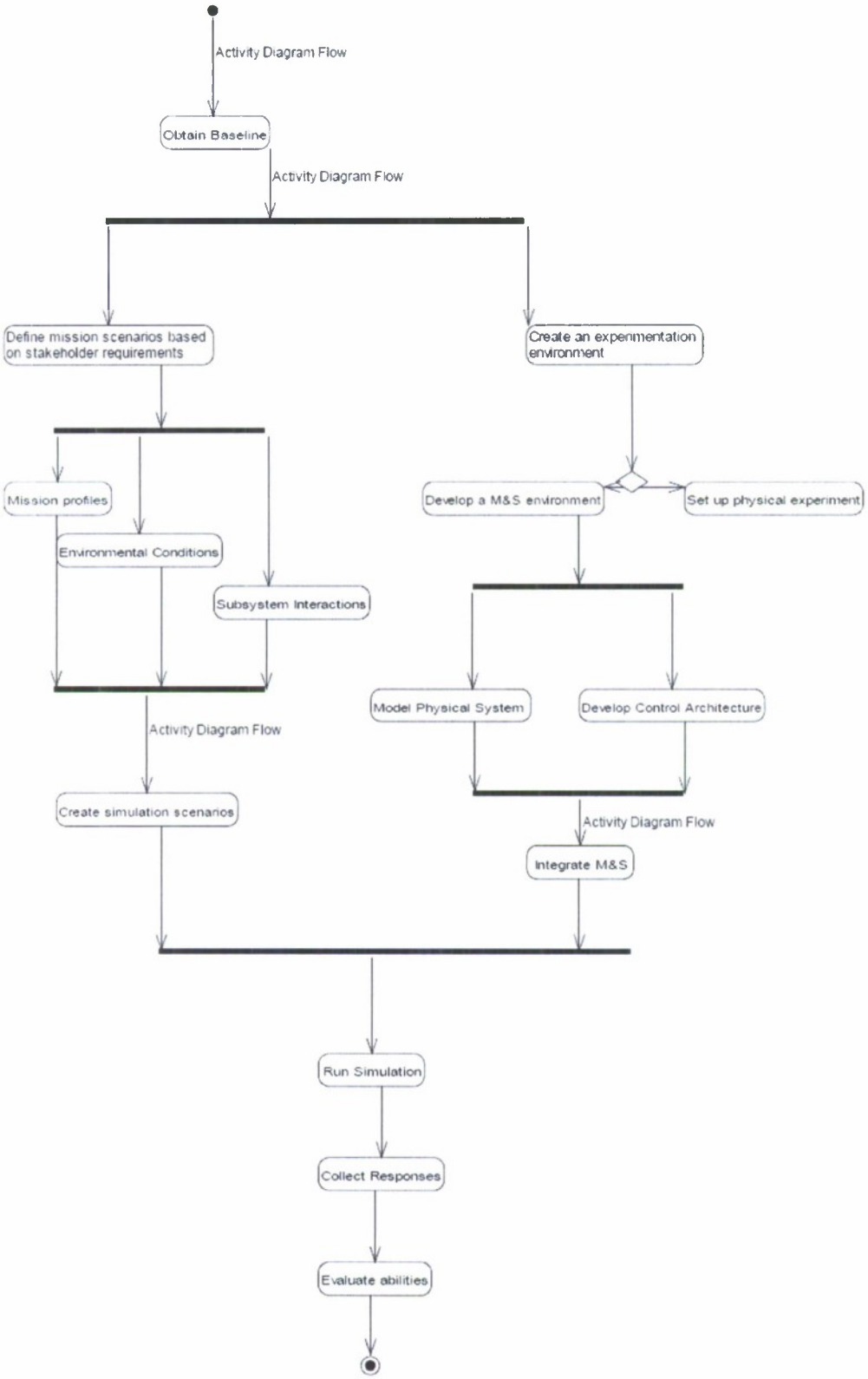

Figure 19: Activity Diagram for "Evaluate Abilities"

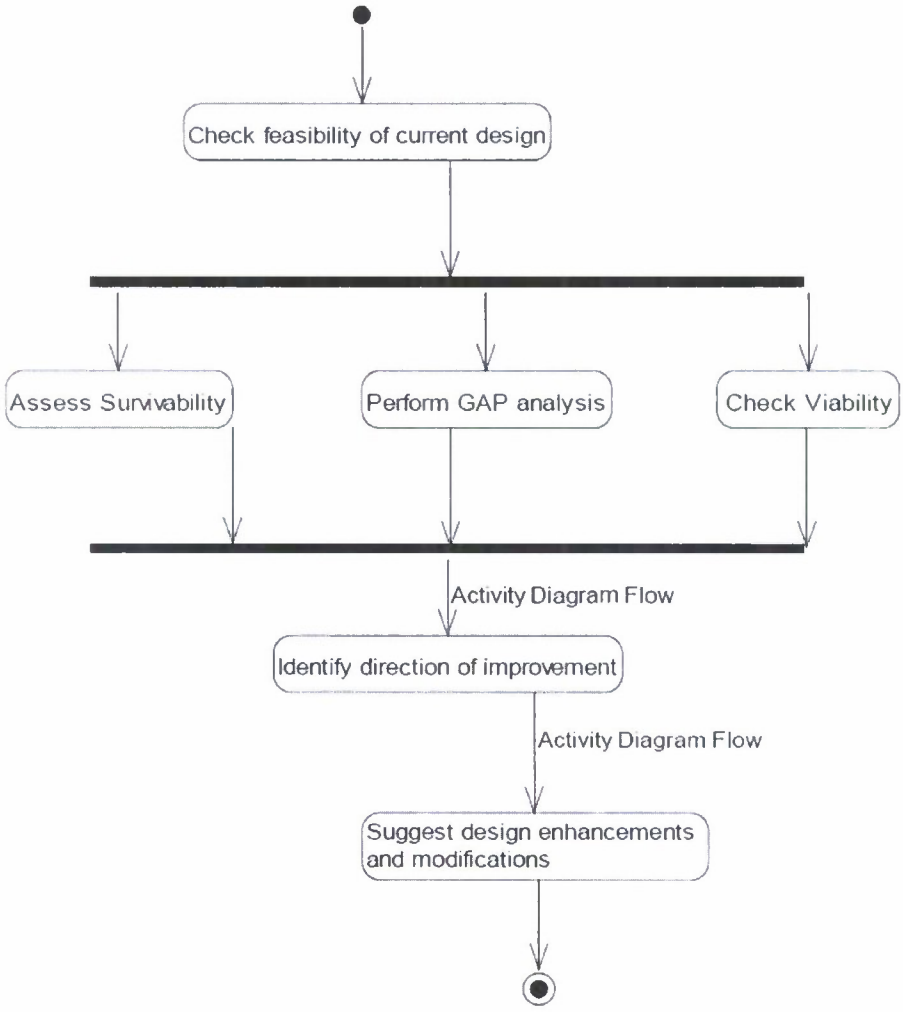

Figure 20: Activity Diagram for "Modify Design"

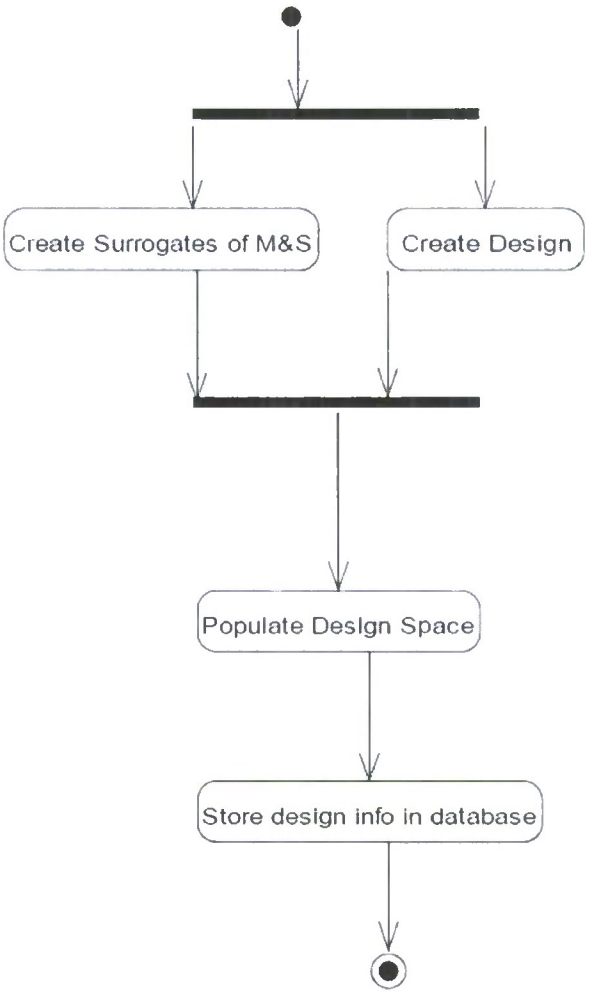

Figure 21: Activity Diagram for "Store Design"

Cost Expenditure Status Report

Figure 22 shows the projected expense (based on the total budget of $155,305) over the contract period and actual expense for the month of July, August and September. We are trying to keep our cost on the target. The difference between the projected and actual expenses is due to the fact that the completed travel cost has not been reflected in this summary and potential travel has not been scheduled.

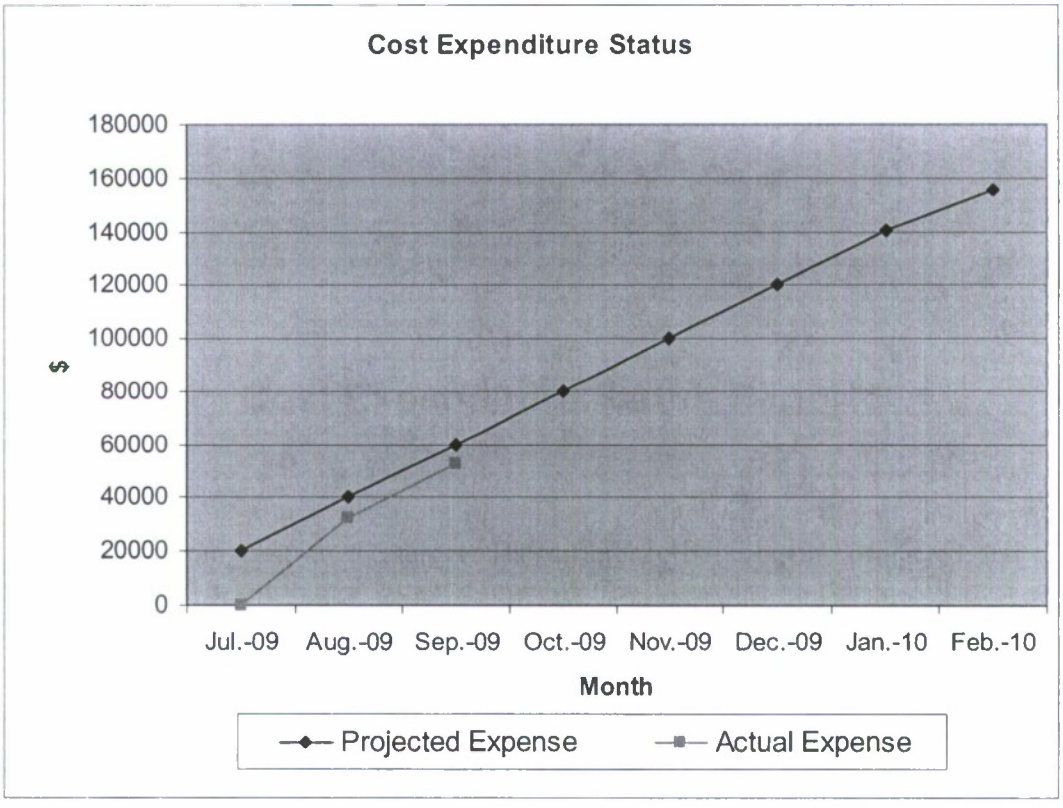

Figure 22: Cost Expenditure Status

Georgia Tech Research Corporation

Georgia Institute of Technology
Office of Sponsored Programs
Atlanta, Georgia 30332-0420 U.S.A.

October 2, 2009
In reply refer to: #112048

Director, Naval Research Lab
Attn: Code 5596
4555 Overlook avenue, SW
Washington, D.C. 20375-5320

Subject: Technical & Cost Expenditure Report
Project Director(s): Mavris, Dimitri
Telephone No.:
Contract No.: NOOO14-09-C-0394
Prime No: N/A
"INTEGRATED RECONFIGURABLE INTELLIGENT SYSTEMS (IRIS) FOR COMPLEX NAVAL)
Period Covered: 11/1/2008 – 11/30/2008

The subject report is forwarded in conformance with the contract/grant specifications.

Should you have any questions or comments regarding this report(s), please contact the Project Director.

Sincerely,

Kamie Cunningham
Date Entry Specialist

Addressee: 1 copy
DTIC 2 copies