AFIT/EN-TR-01-02
TECHNICAL REPORT
November 2001

MODELS, WEB-BASED SIMULATIONS, AND INTEGRATED ANALYSIS TECHNIQUES FOR IMPROVED LOGISTICAL PERFORMANCE

Raymond R. Hill Jr., Air Force Institute of Technology
S. Narayanan, Wright State University
Edward F. Mykytka, University of Dayton

GRADUATE SCHOOL OF ENGINEERING AND MANAGEMENT
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
14 Dec 01	Final	June 1999 - Sept 2001

Title and Subtitle Models, Web-Based Simulations, and Integrated Analysis Techniques for Improved Logistical Performance	**Contract Number**
	Grant Number
	Program Element Number
Author(s) Hill, Raymond R., S. Narayanan, and Edward F. Mykyta	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Air Force Institute of Technology Department of Operational Sciences (AFIT/ENS) 2950 P Street, Bldg 640 WPAFB, OH 45433-7765	**Performing Organization Report Number** AFIT/EN-TR-01-02
Sponsoring/Monitoring Agency Name(s) and Address(es) Dayton Area Graduate Studies Institute Attn: Dr. Frank Moore 3155 Research Blvd., Suite 205 Kettering, OH 45420	**Sponsor/Monitor's Acronym(s)** DAGSI
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes The original document contains color images.	

Abstract	

Abstract
In February 1999, a team of researchers from the Air Force Institute of Technology, the Wright State University and the University of Dayton teamed with researchers within the Air Force Research Laboratory, Logistics Research Division, Logistics Readiness Branch to propose a research agenda entitled, "Models, Web-based Simulations, and Integrated Analysis Techniques for Improved Logistical Performance." This proposal was submitted in response to the initial Dayton Area Graduate studies Institute request for proposals under the Joint Air Force Research Laboratory/DAGSI Basic Research Program. The particular project supported as HE15 within the Human Effectiveness Directorate and entitled Logistics Readiness. The proosal successfully competed and was selected for contract award. Between June 1999 and July 2001, the researchers from the collaborating institutes pursued a collective research agenda, one that was closely aligned with the missions of the AFRL Logistics Readiness Branch as well as other organizations within the United States Air Force. This final technical report summarizes the research efforts under the contract, AFIT-HE-99-10. This report includes descriptions of the accomplishments of the research as well as listings of the numerous papers produced, presentations made, and masters thesis completed diretly supporting, and supported by this research effort.

Subject Terms
Logistics, simulation, web-based simulation, JAVA, human factors, prognostics, ontology

Report Classification	**Classification of this page**
unclassified	unclassified
Classification of Abstract	**Limitation of Abstract**
unclassified	UU
Number of Pages	
54	

The views expressed in this technical report are those of the authors and do not reflect the official policy of the United States Air Force, Department of Defense, or the US Government.

Preface

In February 1999, a team of researchers from the Air Force Institute of Technology, the Wright State University and the University of Dayton teamed with researchers within the Air Force Research Laboratory, Logistics Research Division, Logistics Readiness Branch to propose a research agenda entitled, "Models, Web-based Simulations, and Integrated Analysis Techniques for Improved Logistical Performance." This proposal was submitted in response to the initial Dayton Area Graduate Studies Institute request for proposals under the Joint Air Force Research Laboratory/ DAGSI Basic Research Program. The particular project supported as HE15 within the Human Effectiveness Directorate and entitled Logistics Readiness. The proposal successfully competed and was selected for contract award. Between June 1999 and July 2001, the researchers from the collaborating institutes pursued a collective research agenda, one that was closely aligned with the mission of the AFRL Logistics Readiness Branch as well as other organizations within the United States Air Force. This final technical report summarizes the research efforts under the contract, AFIT-HE-99-10. This report includes descriptions of the accomplishments of the research as well as listings of the numerous papers produced, presentations made, and masters thesis completed directly supporting, and supported by this research effort.

Table of Contents

Preface ii
List of Tables v
Executive Summary vii
1. Introduction 1
 1.1 Project Objective 1
 1.2 Project Management 2
2. Background and Motivation 4
3. Task Summaries 7
 3.1 Air Force Institute of Technology Tasks 11
  3.1.1 The Modular Aircraft Support System (MASS) 12
  3.1.2 Pallet Optimization 12
  3.1.3 Autonomic Logistics 13
 3.2 Wright State University Tasks 13
  3.2.1 Organization of AF logistics knowledge and processes (OLK) 13
  3.2.2 Development of modeling infrastructure (DIMI) 14
  3.2.3 Development of decision support systems for logistics applications (DLA) 14
 3.3 University of Dayton Tasks 15
4. Task Accomplishments 16
 4.1 Air Force Institute of Technology 16
 4.2 Wright State University 21
 4.3 University of Dayton 31
5. Follow-on Work 33
 5.1 Air Force Institute of Technology 33
 5.2 Wright State University 33
6. Conclusions and Summary 34
Bibliography 35
Appendix A: List of Key Participants 36
Appendix B: List of Technical Papers Produced 39
Appendix C: Presentations Made 41
Appendix D: Masters Theses Produced 43

List of Tables

		Page
1	Board of Directors	3

List of Figures

1	Conceptual Approach for Research Effort	9
2	ALSim Object Interactions	17
3	Robust Optimization Architecture	18
4	Phase Inspection screen #1	23
5	Components for Integrating Genetic Algorithms with Simulation Analysis	28
6	Example Joint Density Function	32

Executive Summary

As the Air Force (AF) moves towards becoming an Expeditionary Aerospace Force (EAF) composed of Air Expeditionary Forces (AEFs), logistical issues, for both deploying and sustaining these forces, will drive the EAF vision. Models of logistics processes and integrated information technologies to support distributed logistics personnel are critical in supporting the EAF concept. Current logistics models cannot address the myriad of foreseen and unforeseen issues that the EAF concept presents. This research program develops a web-based, portable, and reusable environment for simulation modeling and analysis to provide the timeliness and relevance required to conduct the necessary analyses facing Air Force logisticians, planners and strategists. The Dayton Area Graduate Studies Institute Aerospace Basic Research Program provided the opportunity for researchers at the Air Force Institute of Technology (AFIT), the Wright State University (WSU), and the University of Dayton (UD) to team together to realize a research agenda focused on the logistical challenges facing the modern United States Air Force. The overall goal was to develop model-based information technology systems that support predictive analysis using web-based simulations and tailored user interfaces to logistics personnel at different levels of abstraction. The proposed effort sought to: (1) develop theories and methodologies for integrating simulations with information support, (2) design, implement, and evaluate proof-of-concept analysis tools, (3) interface with ongoing efforts in the related programs in AFRL such as LOCIS that focuses on integrated technologies for information access and integration, and (4) support operational and staff logistics development and planning organizations.

The primary focus of AFIT research was to apply the results of the research to problems of particular interest to the Air Force. Four areas were investigated: support equipment utilization analysis, three-dimensional pallet optimization, the autonomic logistics process, and methodologies for robust optimization. The WSU focus was to extend a Java-based architecture for modeling airbase logistics systems and integrating optimization techniques with simulations for systems analysis to perform analysis of critical wing-level logistics command and control functions. The fundamental objective was to integrate modular simulations with dynamic data updates from real-time systems and enable proactive decision making by logisticians during execution monitoring through what-if analysis and alternative plan generation. Associated phases of research include identification of the shared corpus of operational and contingency logistics knowledge, development of object-based representation, design of multiple tailored user interfaces to the same underlying world model, and seamless integration of information from distributed heterogeneous data sources. The UD effort focused on critical information support and evaluation issues, particularly those that relate to an analyst's ability to determine the data requirements necessary to portray the myriad sources of variability and uncertainty encountered in a logistics and EAF environment.

MODELS, WEB-BASED SIMULATIONS, AND INTEGRATED ANALYSIS TECHNIQUES FOR IMPROVED LOGISTICAL PERFORMANCE

1. Introduction

The Joint AFRL/DAGSI Aerospace Basic Research Program was created to encourage and develop greater and more effective collaboration between the Air Force Research Laboratory and Ohio's graduate science and engineering schools. The Program is managed by the Dayton Area Graduate Studies Institute, a collaborative organization involving The Ohio State University, the University of Cincinnati, the Air Force Institute of Technology, the University of Dayton, and Wright State University.

In February 1999, faculty members from the Air Force Institute of Technology (AFIT), Wright State University (WSU) and the University of Dayton (UD) collaborated on a research proposal, "Models, Web-based Simulations, and Integrated Analysis Techniques for Improved Logistical Performance," in response to a Dayton Area Graduate Studies Institute (DAGSI) request for proposals. This proposal was in response to a Human Effectiveness Director (AFRL/HE) research topic in the area of Logistics Readiness (topic HE-15). That proposal led to the award of a two-year contract between DAGSI and the research team from AFIT, WSU, and UD. This technical report summarizes the results from that two year effort.

1.1 Project Objective

As the Air Force (AF) began moving towards becoming an Expeditionary Aerospace Force (EAF) composed of Air Expeditionary Forces (AEFs), logistical issues, for both deploying and sustaining these forces, were viewed as drivers to the EAF vision. Models of logistics processes and integrated information technologies to support distributed logistics personnel are critical in supporting the EAF concept. The belief was that current logistics models could not address the myriad of foreseen and unforeseen issues that the EAF concept presents. The proposed research program was to develop a web-based, portable, and reusable environment for simulation modeling and analysis to provide the timeliness and relevance required to conduct the necessary analyses facing Air Force logisticians, planners and strategists. Cross-spectrum research, basic to applied, was needed to meet the research demand. This effort covered that spectrum, from theory-development (e.g., pallet optimization models, web-based simulation, multi-abstraction models) to application prototyping (e.g., plan generation, footprint reduction, concept evaluations). AFIT's and WSU's past work with the AFRL LOGCAT and LOCIS programs provided an initial base of experience and web-based Java experiences helped promote rapid technology transition. Supporting operational customers (e.g., Air Staff, Battlelabs, AMC) made the applied aspects immediately relevant and pertinent.

1.2 Project Management

This project featured a three-tier approach to overall project management. These tiers consisted of a Board of Directors (BOD), research project management team (PMT), and Integrated Process Team (IPT) leaders for each task. This approach provided oversight functions, direction to the entire research process, seamless integration of the research efforts and products, and responsive reporting and technology demonstration efforts.

The function of the BOD was to provide project oversight, ensure the relevance of the project, and provide a vehicle to promote outside agency understanding and appreciation of the research. The members of the BOD were representatives from various agencies to include the principal investigators from each of the collaborative institutions within this research as outlined in the table below:

Member Agency	Representative
Air Force Institute of Technology (AFIT)	Lt Col Hill, Principal Investigator, AFIT
Wright State University (WSU)	Dr Narayanan, Principal Investigator, WSU
University of Dayton (UD)	Dr Mykytka, Principal Investigator, UD
Air Force Research Laboratory	Dr Thomas, Logistics Readiness Chief Scientist
Air Force Research Laboratory	Ms Masquelier, Logistics Readiness Branch
Defense Advanced Research Projects Agency	Dr Carrico, Program Manager, Advanced Logistics Program
HQ AFMC	Mr Shawn Lyman

Table 1: Board of Directors

The PMT was responsible for the overall management and direction of the research projects. The PMT consisted of the principal investigator from each of the participant institutions in this research effort with AFIT as chair and primary member responsible for the compilation of required quarterly progress reports and final project technical reports. The PMT ensured timely and accurate reporting of technical progress by AFIT, WSU, and UD and maintained the Master Milestone Schedule submitted with each quarterly progress report. IPT leaders reported directly to the appropriate member of the PMT.

IPT leads were designated for each particular task accomplished within the scope of this research effort. The IPT lead was responsible for the management oversight, technical accuracy, and overall quality of their task. They were responsible for final technical products and technical demonstrations of the activity. WSU tasks included the architectural design based on object modeling of the logistics domain, modeling infrastructure development, and implementation and evaluation of prototype decision support systems instantiated from hybrid modeling techniques. AFIT tasks included development of decision support systems for several applications including pallet optimization, autonomic logistics, and aerospace ground equipment analysis. UD tasks included development of input modeling and statistical analysis techniques realized in objects transitioned to the modeling architecture.

2. Background and Motivation

The demands placed on the modern American military have changed dramatically over the recent years. These changes are not only due to resource reductions, but also due to increasing operational requirements and strategic uncertainty. Most of these changes place new challenges on agile combat support, and specifically logistics command and control. Logistics command and control focuses on making the right resources and information available to logisticians at the right place at the right time. Logistics readiness in the military impacts weapon system supportability and affordability, risk for operational logistics information systems, logistics users' decision-making capability, and, therefore combat support capability and mission effectiveness.

To meet the changing needs, the Air Force is quickly evolving to a force more expeditionary in structure and function. Aerospace Expeditionary Forces (AEF) represents a complete warfighting package comprised of disparate yet completely inter-functioning components from across the AF infrastructure. An AEF provides the warfighting commanders with on-demand combat capability, tailored to the situation at hand, and immediately available to meet any worldwide crisis warranting their deployment.

The Expeditionary Air Force (EAF) concept poses critical challenges within the AF core competencies of lean logistics and rapid global mobility. The only viable way for AEFs to function is to initially deploy just the warfighting necessities and upon deployment have the capability to efficiently and effectively bring in additional assets on an on-demand basis. The challenge is to determine what is "necessary" and exactly how to implement the "on-demand" re-supply system. Rapid global mobility implicitly assumes sufficient airlift assets to bring an AEF into the fight.

Logistics challenges have risen to the forefront of the EAF implementation strategy. These challenges will not be solved immediately and in fact represent a significant amount of work for years to come. Logistics planners and implementers, from wing and squadron level and all the way to Air Staff and Joint Staff levels, will be hard pressed to implement, maintain, and evolve the EAF/AEF concept to meet current and future demands.

The complexities of these challenges effectively prohibit exclusive use of "expert opinion" and legacy information systems. Models of logistics processes and integrated information technologies to support distributed logistics personnel are critical in supporting the EAF concept. A new generation of analytical tools, employing tailored views of pertinent logistics information, visualization techniques for rapid comprehension, and simulation and operational research tools for informed decision-making are needed. This research helped to advance the state-of-the-art in logistical analysis techniques while putting modeling tools in the hands of decision-makers requiring insight and information for EAF/AEF implementation issues. A Java-based environment developed in this effort, consisting of verified, validated, and reusable components that reflect the complexities in the logistics domain, has the potential to provide the capabilities to answer the complex questions facing modern logistics planners.

Logistics planners at different levels from the WPAFB Headquarters level down to the various wing and squadron levels require information systems tailored to their current needs providing insight into future logistics challenges posed by the AEF concept. Web-based technologies with tailored user interfaces and hybrid modeling techniques with capabilities of rapid assembly and deployment are needed to provide the required capabilities. AFRL's LOCIS program, complemented by the products of this research effort, will help to eventually realize such technologies.

Advanced concepts and proposed process improvement initiatives are a driving factor in current EAF/AEF implementation planning. Budget and time limitations prohibit the prototyping and field testing of each and every proposed system or improvement. Virtual prototyping and testing is the modern way to address such proposals and limit the actual building and testing to viable alternatives. Using customer contacts within the AF Battlelabs, the Logistics Management Agency, and the AFRL, we prototyped applications in this research to describe and analyze prospective logistics systems and processes. These models became a part of the modeling infrastructure and were extremely well received by the participating logistics agencies.

The need for this research was clear. The highly inter-connected, instant communications world of today can no longer be accommodated by the legacy approach to model building. The technical tasks undertaken in this effort included development of an ontology of logistics processes to support hybrid modeling methods, web-based simulations, optimization models for specific operational problems in the Air Force, and tailored user interfaces for proactive decision making tools make numerous theoretical contributions and are practically beneficial. Our research helped to support logistics planners. The modeling environment provided applications and proof of concept tools to address immediate logistical issues, and the web-based, interactive simulations are at the forefront in future modeling and simulation initiatives within the DoD, the AF, and the commercial industry.

3. Task Summaries

The overall goal of this program was to develop and apply model-based information technology systems to support predictive analysis of logistics systems using web-based simulations and tailored user interfaces for logistics personnel at different levels of abstraction. The simulations and associated interfaces support what-if analysis, look-ahead, and integration with real-time information from distributed sources. The effort sought to: (1) develop theories and methodologies for integrating simulations with information support, (2) design, implement, and evaluate proof-of-concept analysis tools, (3) interface with ongoing efforts in the related programs in AFRL such as LOCIS that focuses on integrated technologies for information access and integration, and (4) support operational and staff logistics development and planning organizations. The overall approach was based on a computational architecture implemented in the Java programming language.

The proposed program leveraged on significant research and development expertise of the investigating team in the areas of object-oriented programming, interactive simulation, optimization, visualization, distributed computing, human computer interaction, logistics systems analysis and operational modeling for manufacturing and defense applications. An interdisciplinary team of faculty members and graduate students from systems engineering, human factors engineering, and operational sciences worked together in the proposed research and technology development effort.

Figure 1 illustrates the overall framework for this research. The three major components of this framework are the Organization of Logistics Knowledge (OLK), Development of an Integrated Modeling Infrastructure (DIMI), and Development of Logistics Applications (DLA). The underlying tenets of the research and an overview of each component with its constituent pieces follow.

AF logistics is a large and complex domain involving logistics processes at different levels of abstraction. Models of logistics are useful in solving AF logistics sub-problems including aircraft acquisition planning, maintenance personnel allocation, and theater-level supply redistribution. Many models including simulation and optimization based methods have been developed for several sub problems characterizing and analyzing different aspects of the logistics operation. Most real world problems in AF logistics are highly complex and monolithic approaches to problem solving are inadequate. Hybrid modeling techniques that also explicitly accommodate human decision making through relevant information to support proactive decision making are critically needed. Integrating multiple modeling methods with information technology systems is made difficult by lack of common terminology and a common set of abstractions of the logistic processes. The research directly targeted this issue.

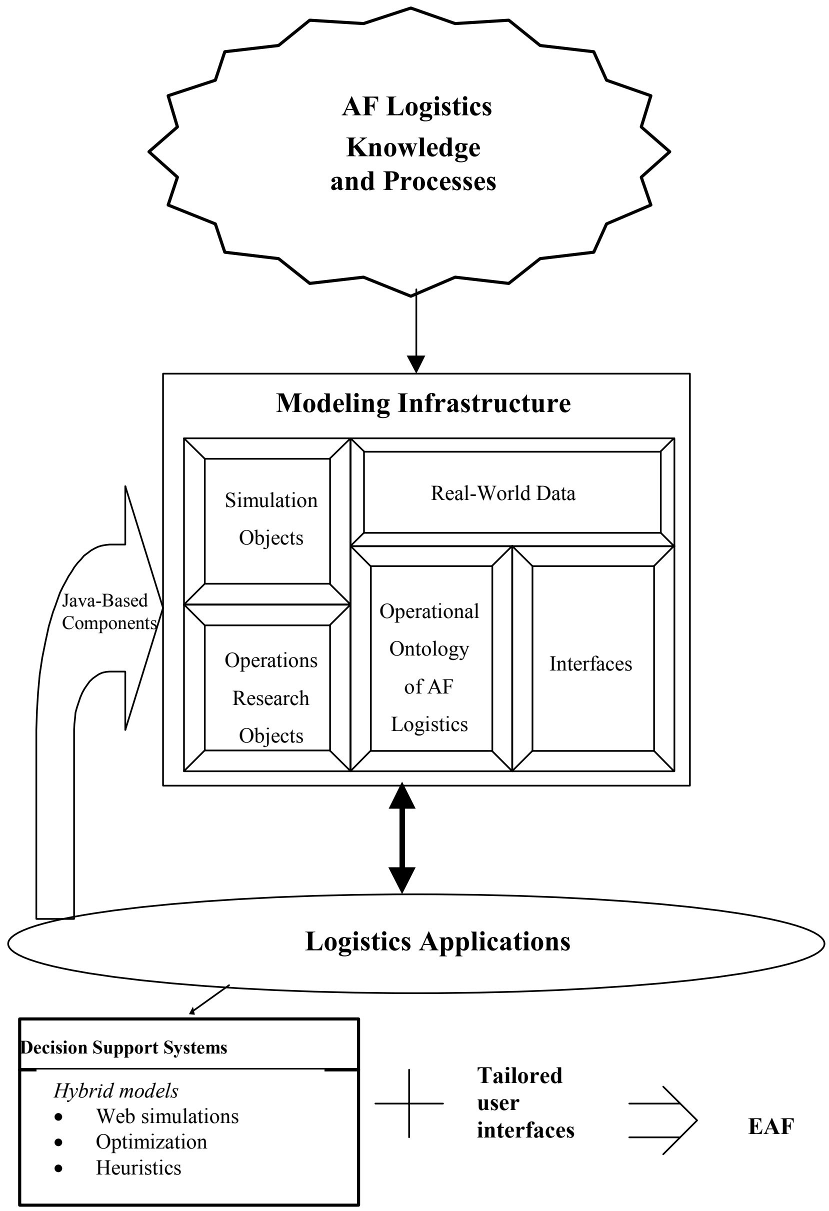

Figure 1: Conceptual Approach for Research Effort

Using an interdisciplinary approach with a wealth of logistics domain experience by the DAGSI/AFRL participants, we developed a comprehensive reference model for problems in AF logistics. A reference model is a standardized description for purposes of modeling, design, and analysis (Biemens & Vissers, 1989; Arango & Prieto-Diaz, 1991). A related concept is that of an ontology, which is a specification of knowledge about a domain of application (Guarino, 1995). The domain analysis essentially captured the logistics knowledge and processes needed by the modeling methods and information technology systems shown in the research framework. A key issue is that the ontology developed during this process was derived specifically for purposes of integrating simulations, optimization methods, and information technology systems for logistic systems analysis.

For AF logistics analysis, we adopted predominantly an object modeling approach (Rumbaugh et al., 1991). This approach was chosen because it facilitates a one-to-one mapping between real-world objects and their software abstractions, and because it enables explicit representation of system operation and control (Narayanan et al., 1998). The object model will specify the objects and associated data important in analysis (e.g., aircraft, resources, sorties, courses of action, etc.), relationships between objects (including constraints used in optimization models), and behavior of objects due to logistic processes. In research on modeling logistics control situations in manufacturing and airbase systems, we previously effectively represented domain knowledge in terms of physical objects, decision-making or control objects, and information objects. The decision-making objects were organized along a hierarchy to model controllers at different levels of abstraction using the same underlying representation (Narayanan, et al., 1994; Narayanan et al., 1998). We leveraged the organization of the shared knowledge associated with real-time logistics control along this proven methodology. The object model was instantiated in the modeling infrastructure shown in the research framework and integrated for application of hybrid modeling methods for operational AF logistic problems. The modeling infrastructure was implemented using the Java programming language because of its support for object-based modeling, multi-threaded capability, distributed computing, tailored user interface capability on the Internet, and ease of use (Narayanan et al., 1997).

Another major component of this research was to apply the modeling infrastructure to a variety of problems representing real-world AF problems. Initially, a set of problems involving modeling methods such as simulations and optimization were undertaken and then later expanded. During these efforts, the library of objects in the modeling infrastructure grew. Each of these applications had a basis in actual problems or areas of interest to the logistics community.

Our goal in this research effort is to define an architecture from which component models and information technology systems for logistical applications could be rapidly assembled, validated, and employed to address important, relevant issues in logistics and related application areas. The resulting research efforts led to novel theoretical hybrid modeling methods, unified reference models for integrating descriptive models such as simulations with prescriptive techniques in optimization and resulted in much needed human-integrated problem solving techniques for supporting the EAF concepts. The modeling infrastructure along with the applications to operational AF logistics led to viable solutions to complex problems facing the Air Force and their move into an EAF environment.

Feedback obtained through the application of the modeling infrastructure to logistics applications were used in further refining the infrastructure thus leading to robust, flexible, and powerful integrated tools for improved logistical performance. An overview of the subtasks involved in OLK, DIMI, and DLA, and an overview of real-world applications where we demonstrated our concepts are outlined in the following section.

3.1 Air Force Institute of Technology Tasks

AFIT's major technical activities involved applying the knowledge from the logistics domain analysis efforts to problems of particular importance to the Air Force.

3.1.1 The Modular Aircraft Support System (MASS)

The Modular Aircraft Support System (MASS) will design, build, and demonstrate proof-of-concept aerospace ground equipment (AGE), multi-functional in design, in modular, multi-function carts. Utilization of MASS components promise to increase AGE affordability and reduce airlift requirements for a deploying AEF. Numerous operational and conceptual issues surround MASS development and MASS utilization by an operational unit. This activity will expand the Modeling Infrastructure by developing modeling tools to examine and provide developers and operators insight into MASS utility.

3.1.2 Pallet Optimization

The Logistics Contingency Assessment Tool (LOGCAT) will improve wing-level deployment planning and re-planning. The Unit Type Code Development, Tailoring and Optimization (UTC-DTO) includes packing 463L cargo pallets. Efficient pallet optimization can reduce total pallet requirements, enhance load-master efforts, improve resource allocation planning, and improve AF responsiveness. Current optimization approaches are two-dimensionally focused while a pallet employs a three-dimensional (3-D) space (length, width, and height). Estimation approaches use layers of two-dimensional bins, using bin-packing optimization approaches for each layer, to build to the entire pallet. This approach requires strong assumptions about the items within each layer. Modern computing techniques can accommodate a direct, 3-D approach provided appropriate mathematical formulations of the problem and problem solution techniques are defined and implemented. This activity sought to address the theoretical and computational issues in the 3-D packing problem.

3.1.3 Autonomic Logistics

Autonomic Logistics (AL) is the innovative concept of Strike Warfare Support for the 21st century. AL moves logistics functions from a reactive to a proactive mode utilizing advanced diagnostics and support processes. As a key enabler for the Joint Strike Fighter, AL must be fully examined and understood before the JSF is operational. This task addressed the AL process and sought to first define the AL domain developing abstractions of its key processes and applying these to key AL concepts. This was followed by efforts to extend the work, expanding the operational utility of the AL software models and demonstrating the capabilities of JSF to examine and resolve key AL issues.

3.2 Wright State University Tasks

WSU's major technical activities of the research included: (1) Organization of AF logistics knowledge and processes (OLK), (2) development of modeling infrastructure (DIMI), and (3) development of decision support systems for logistics applications (DLA), which also includes implementation and evaluation of tailored user interfaces for integration with human decision makers in the logistics domain. Each of these activities is described in more detail below.

3.2.1 Organization of AF logistics knowledge and processes (OLK)

The Organization of AF logistics knowledge and processes (OLK) task includes (a) domain analysis, (b) object modeling, (c) optimization/web-based simulation components identification, and (d) decision support system specification. In this context, domain analysis is the process of identifying and organizing knowledge about a class of problems in AF logistics to support the description and solution to those problems. This analysis was conducted through results from the published literature (Popken, 1992; Narayanan et al., 1997), field studies at operational sites, and interviews with AFRL researchers. Through object-oriented analysis and design, we organized the entities, their behavior and interrelationships. Components needed for web-based simulations including clock, statistical distributions, random variables, inter-process communication, user interfaces, & objects ~~of~~ representing logistical entities, as well as optimization components such as operators used in genetic algorithms or hooks to math programming packages were identified.

3.2.2 Development of modeling infrastructure (DIMI)

The Development of modeling infrastructure (DIMI) task included (a) specification of design goals, (b) architectural design and implementation, and (c) evaluation. Design goals of the modeling infrastructure (MI) included support for hybrid analysis techniques, interactive systems support, modular and reusable software abstractions, and tailored user interface connectivity. Design specifications were developed using unified modeling language (UML) and implementation was done using Java on a variety of systems ranging from SGI workstations to personal digital assistants (e.g., Palm pilot). Palm pilot type devices facilitate the ability of on-site logisticians to input real-time data from operational environments. Generic interface classes were developed and specialized for the different applications. The MI was evaluated in terms of how well it represented prototypical scenarios for the suite of AF logistic applications addressed in this effort.

3.2.3 Development of decision support systems for logistics applications (DLA)

The development of decision support systems for logistics applications (DLA) task included (a) identification of a suite of representative applications from AF logistics, (b) development of models, (c) generation/refinement of generic software abstractions in the modeling infrastructure, (d) model application, (e) design, implementation, and evaluation of tailored user interfaces in decision support systems, and (f) generating recommendations for hybrid modeling methods improvement and for informed decision support in real-world problems. In addition to the applications involving aerospace ground equipment analysis, wing-level deployment re-planning, and specifically pallet optimization previously identified as falling within AFIT tasks, other applications for which AFRL's LOCIS program is useful were considered during the research. Appropriate models such as simulations or optimization techniques were developed when deemed necessary. The software abstractions in the MI were used for analysis using these simulation/optimization methods. User interfaces were developed for the applications and tailored for different users. These were evaluated empirically using operational participants. Evaluative measures include the extent to which the interfaces are usable and are effective in integrating solutions from different modeling techniques.

3.3 University of Dayton Tasks

UD’s efforts directly supported the applied research of WSU and particularly AFIT. Their task extended the theoretical input modeling constructs of the architecture and addressed critical information support and evaluation issues relating to modeling and simulating the myriad sources of variability and uncertainty encountered in the logistics and EAF environment. Accurate data models are needed to assess the validity of simulation and decision-support models and utilize these tools effectively for planning and analyses. Current models generally have enormous data demands, typically requiring complete specification of the joint distribution of complex multivariate inputs, or imply structures unlikely to be encountered in the real-world logistics and EAF environment. This task focused on the development of multivariate data models that require only the limited information about inputs expected to be available for predictive logistics analysis, namely data that portrays the marginal distributions of the inputs and a measure of the correlation between them.

4. Task Accomplishments

The previous section of this report laid out the agendas for each of the research tasks. In this section we summarize the accomplishments under each of the research tasks for this research effort.

4.1 Air Force Institute of Technology

The MASS modeling and analysis effort looked at such issues as flight-line travel time, just-in-time delivery of support equipment, and examined the sensitivity of MASS reliability to measures of operational capability of the deployed force. Model results suggest that the MASS system will effectively replace legacy ground equipment as there will be little to no impact on mission accomplishment. Further, due to the reduced volume requirements to transport the MASS, as compared to the larger, single function legacy units, MASS offers significant reductions in logistics footprint requirements. Although still a research and development project, sensitivity studies on engineered MASS reliability data show little sensitivity in terms of fielded unit requirements due to less than expected reliability levels.

The pallet packing work developed a true 3-dimensional packing formulation. The 3-dimensional packing problem is an extremely difficult combinatorial optimization problem that has vexed optimization researchers for a long time. The best past formulation efforts used stacks of 2-dimensional packs yielding a quasi-3-dimensional packing formulation. This initial effort seems to have at least cracked the initial code and is even getting answers using a non-linear code applied to the exact formulation for small problems. Due to the combinatorial explosion for even modest sized problems, a genetic algorithm solution technique was tested for larger problems, again applied to the exact formulation.

The Autonomic Logistics modeling effort focused on building the modeling infrastructure component required for the modeling, with less emphasis provided to the conduct of analysis. The resulting initial model was named the ALSim (for Autonomic Logistics Simulation). The end result was a modeling infrastructure built in Java containing the fundamental classes and objects with which to conduct effectiveness analyses for autonomic logistics questions. The high-level design in terms of the model object interactions is depicted in Figure 2 below.

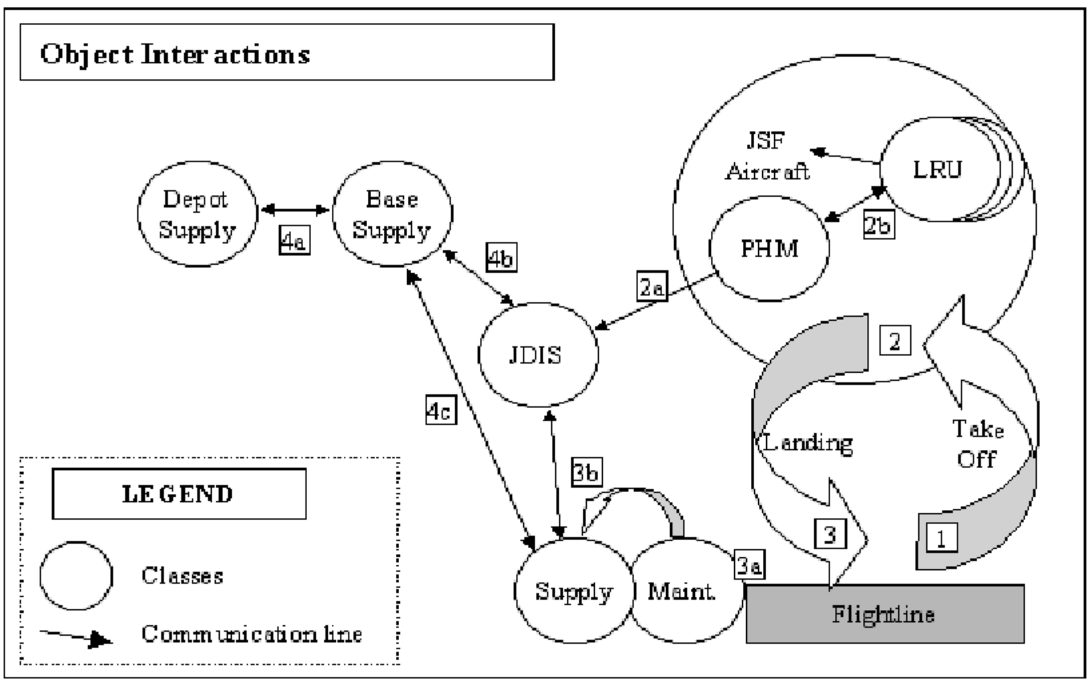

Figure 2: ALSim Object Interactions

An additional task, supplemental to the basic three previously described, was dubbed the robust optimization effort. A particularly perplexing challenge for planners involves considering multiple competing scenarios for which a single overall solution is required. We would like to evaluate the trade-offs among these many disparate scenarios in a systematic fashion, but instead, we have mostly settled for group-based reconciliation. We thus define a **robust force solution** as that solution "providing the best overall outcome as evaluated with respect to some set of scenarios each of which has an associated likelihood of occurrence." We treat this multi-scenario space as a composite of the component scenario spaces where each component space contributes relative to its likelihood of occurring or relative to its importance weight. We then employ a meta-heuristic, such as a genetic algorithm, to search the composite multi-scenario space for a "maximizing" solution. Such a solution is robust across the component scenarios (with respect to the particular component scenario weights employed). The evaluation of any solution in the multi-scenario space is itself a composite function of the individual scenario evaluations of that solution. The following Figure 3 outlines the overall architecture of our robust optimization.

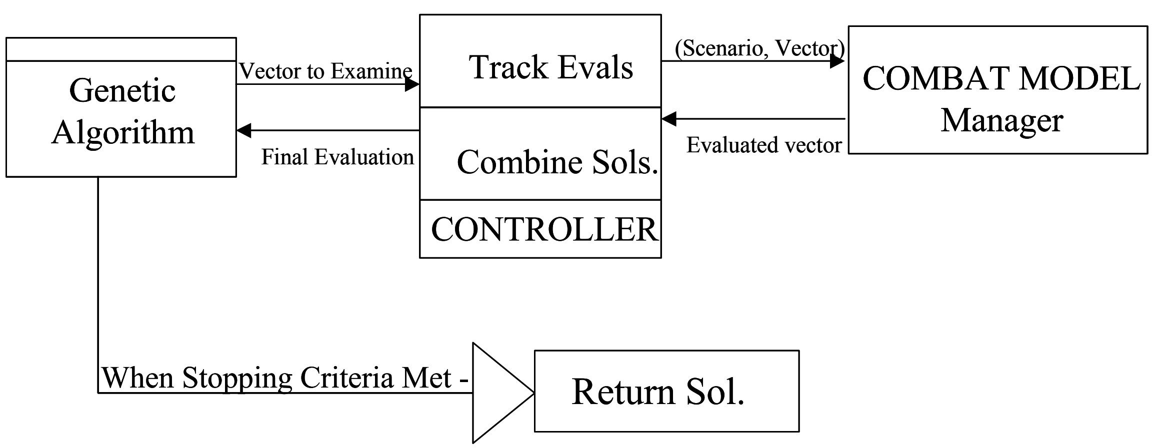

Figure 3: Robust Optimization Architecture

This effort culminated with using a genetic algorithm to search for a robust solution for three force planning scenarios where each candidate solution is evaluated using the Combat

Forces Analysis Model, a large scale linear programming model used by the Air Force for weapons allocation and force structure planning.

Initial work on the MASS task led to a request from the Air Force's Air Mobility Command to develop and prototype a comparative methodology for sizing a support equipment force. In particular, AMC personnel were struggling with how best to determine how many of the new Self-Generating Nitrogen Servicing Carts (SGNSC) to deploy. Current beliefs within the Air Force maintenance community are that there is an over-abundance of support equipment, all of which must be maintained. Intrigued by the utilization study results emanating from the MASS task, AMC asked AFIT to apply a similar methodology to determining how to size a SGNSC force. This study was undertaken, completed, and briefed (via the thesis defense by MacKenna) to the study sponsors. Significant findings in this study included the potential to reduce the fielded force by approximately 25% and the insight (previously overlooked) that equipment utilization studies must specifically address maintenance personnel utilization as well as the purely equipment utilization information normally collected.

The pallet optimization work was extended into a search for and design of a new heuristic for solving the 3-dimensional pallet-packing problem. This new heuristic was designed to mimic human intelligence as applied to a 3-dimensional packing situation. Human packing behavior was observed and a set of rules was developed based on these observations. These rules were then implemented within a solution algorithm, and the algorithm was run against a myriad of test problems. These problems were both benchmark problems from the academic literature and randomly generated problems of varying difficulty. Overall results were comparable to the best know solutions but were obtained at a fraction of the processing costs associated with other solution approaches.

The initial Autonomic Logistics effort focused on building an initial, high-level simulation model of the ALSim. The next step was to develop a methodology for adding modeling detail to the prognostics health maintenance (PHM) component of the ALSim. The initial effort simply calculates the instance the PHM detects degraded performance of a JSF line replaceable unit as a constant percentage of the items actual failure time. Increasing model fidelity requires adding a probability of detection curve, variable detection time, allowing for false positives, and learning curve effects. While the ideal approach to adding these features involves analyses and models based on actual data, that data is simply not available. To overcome these deficiencies, a simulation was developed to generate a PHM component sensor signal suitable for analysis. The Signal Generator is a very generic simulation that builds a sensor signal. Once the signal is generated it needs to be analyzed to determine if and when component failure can be predicted. The basic premise is to be able to predict impending failure. Discriminant analysis or building an artificial neural network seem best suited to analyzing the signal data. The basic approach of both analysis methods is distinguishing between various populations. In PHM, we differentiate between a component in a healthy state and a component in a failure state. Neural networks tend to have higher accuracy rates than discriminant analysis because neural networks use nonlinear functions. However, predicting healthy versus failing components is currently a one-dimensional problem (sensor signal). With this in mind, the neural network analysis and discriminant analysis should lead to similar classification accuracies. The goal is to use the resulting neural network to build two separate distributions (or possibly two sets of distributions at different realized failure times) to incorporate directly into ALSim, rather than using a constant percentage of failure time to model prediction of failure or degradation. One distribution would be used in modeling the uncertainties in the actual time a failure or degradation is predicted. The other distribution introduces the reality of false positives (predicting a failure or degradation for a healthy component) into the model and allows for modeling the uncertainties in time for these events.

The robust optimization efforts continued again using CFAM and three notional force planning scenarios. However, the current effects focused on comparing meta-heuristics applicable to robust optimization. In particular, we compared the performance of a genetic algorithm (past year efforts) with the performance of the OptQuest meta-heuristic solver. OptQuest is based on a heuristic called scatter search and employs a neural network evaluator as a means for reducing the number of solution evaluations performed. Research results indicated the OptQuest heuristic outperformed the genetic algorithm heuristic.

4.2 Wright State University

WSU tasks focused on the infrastructure needed to develop model-based information technology systems that support predictive analysis using web-based simulations and tailored user interfaces to logistics personnel at different layers of abstraction. These include: (1) Organization of AF logistics knowledge and processes (OLK), (2) development of modeling infrastructure (DIMI), (3) development of decision support systems for logistics applications (DLA), which also includes implementation and evaluation of tailored user interfaces for integration with human decision makers in the logistics domain.

Through field studies and interviews with logisticians at two air bases, and decision making activity analysis using observation and semi-structured interviews with production superintendents of operational F-16 maintenance units at Hill AFB, UT, we developed a better understanding of command and control decisions made by squadron commanders in logistics planning. These studies along with review of material associated with the LOCIS program at WPAFB, led us to organize logistics knowledge and processes of relevance to planning.

This domain knowledge became the basis of the development of the modeling infrastructure, which is essentially a set of classes and a hierarchy of objects implemented using an object-oriented programming language, Java. Objects from the infrastructure can be instantiated to model squadron-level maintenance planning. The instantiated model supports decision support at three different levels: (1) information presentation only, (2) minimum level of support for interactive analysis, and (3) highly interactive system. The decision support system takes as input data from simulation runs for prototypical AEF scenarios and provides tailored user interfaces depending on levels of support. Both the simulation components and user interfaces were programmed using the Java language.

Two modes of decision support were instantiated for the task of aircraft selection under the AEF scenario. One mode simply presented information, while the other provided more interactive decision support based on a methodology developed by a WSU student, Todd Kustra, for his master's thesis. These systems were evaluated using maintenance personnel from the 445th Air Force Reserve Squadron and Air Force Materiel Command familiar with the elements of aircraft selection. Results showed that the interactive decision support system significantly decreased the time to complete the task, but did not conclusively demonstrate performance accuracy improvement or increased confidence in the generated solution. Figure 4 shows a phase-inspection screen developed for this system.

Kustra's thesis made practical contributions to information systems research by outlining a methodology for creating decision support systems in complex logistics planning. Contributions include uncovering decision support needs for the organizational strata of front line supervisors, applying current naturalistic decision theory to the logistics arena, and defining a level of interaction between the decision maker and the decision support system that accommodates sub-goal variation while maintaining the structure of the knowledge-based framework.

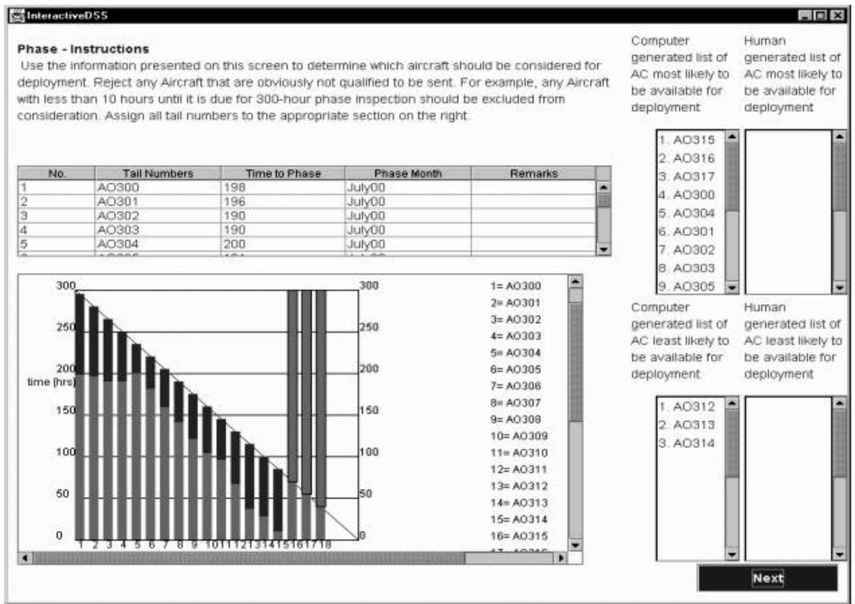

Figure 4: Phase Inspection screen #1.

Use of Image theory to identify decision activity greatly increased the level of detail and understanding of the decision process of Production Superintendents. Standard methods for identifying decision subtasks do not necessarily direct the method in which those tasks will be incorporated into the decision support system. Uncovering the image states of the subject matter experts led to the acquisition of two types of decision strategies. These decision strategies, once identified, not only changed the order of presentation, but highlighted significant structural changes to the algorithms used in providing computer-aided suggestions to the user.

Decision support needs for line supervisors in logistics have been largely deferred in favor of high visibility management where the informational needs are more globally oriented, integrating vast amounts of data combined with uncertainty and a heterogeneous perspective. Lower levels of management have different needs for decision support than upper level managers, but remain just as dependent on informational computer support. Large problem spaces, even at the squadron level complicate the thorough examination of data and hinder the process of shortfall identification, repeat or recurring problem analysis, and determination of system patterns on which quality decision making depends. Impactful decision support incorporating satisficing heuristics may enable a more direct and immediate application of supervision on the production of aircraft sortie generation and on overall squadron production.

Application of current naturalistic decision theory to the logistics arena provides a human-centered perspective that takes advantage of the organic teleological processes inherent in human mental schemas. Providing information constrained to fit these processes allow decision makers more direct application of pertinent information to affect the generated solution within the context of the knowledge-based framework. Formalization of the decision makers natural choice strategies to evaluate decisions based on compatibility and profitability, adoption or progression, abbreviates the decision process reducing internal complexity and confusion, thereby reducing decision time.

The third contribution of the research is the further clarification of the role of humans in the human-machine system. By defining a level of interaction between the user and the decision support system, image states and goal directed behavior inherent to logistics organizations can be applied to the decision process while taking advantage of computer processing speed to identify patterns, process heuristics, and make computations. Sub-goals can be evaluated visually, using the computer to display graphical representations of information patterns while leaving the option to examine the data individually. Progress towards a realistic, useful generated solution can be monitored, assessed, and altered, allowing the decision maker to review the solution's compatibility with projected needs.

In the experiment, the Interactive Decision Support System (IDSS) suggested that greater speed can be realized in the decision process. Kustra's thesis anticipated an increase in performance, confidence, and trust in the generated solution, which did not materialize in the study. Due to the low number of participants, only general conclusions can be drawn from the research to include a suggested increase in solution generation time using the decision support system.

We integrated visualization interfaces developed for simulation with the decision support system. We also explored approaches towards integrating human reasoning with soft computing and simulation for logistics systems performance analysis. Specifically, we developed an approach that integrates genetic algorithms with discrete-event airbase simulations for exploring the solution space in the context of aircraft repair time analysis.

Simulation is a powerful tool often used to test the viability of resource combinations to successfully achieve a given mission. Popken (1992) notes with logistics that the high levels of complexity and entity-interactions as well as uncertainty make strictly analytical solutions intractable. However, simulation does not require the simplifying assumptions needed by analytical models, and can handle system complexity and interactions, and account for uncertainty as well. Hence, simulation is a powerful instrument for studying the consequences of different choices for "what-if" analysis in fields such as airbase logistics. It can be applied to determine the reactions of an airbase under differing conditions with various types and amounts of available resources.

Although simulation plays a crucial role in understanding systems in AF logistics, it is "not a design tool" (Mollaghasemi and Evans, 1994). While simulations provide the benefit of aiding decision-makers, developing realistic simulations of military systems is a complex and formidable undertaking. Evolutionary learning is necessary to increase the flexibility of simulation and optimization to deal with parameters which may be complex or discontinuous, and to manage multiple, conflicting system objectives (Lu et al, 1991).

Statistical methods, such as designed experiments and the resulting response surface methodologies have been successfully applied to integrate optimization with simulation. However, when solution spaces are rugged, as found with most complex dynamic systems, then systematic techniques such as response surface methodology may not provide the type of results desired. Evolutionary computation methods such as genetic algorithms, because they operate on the “characteristic space” of a problem, and can potentially learn what types, levels, and combinations of parameters are found in the stronger solutions and are thus insensitive to solution topologies.

Figure 5 illustrates the framework for integrating genetic algorithms with simulations for the exploration of the solution space. The solution explorer consists of five major modules: the Input Specifier, the Simulator, the Encoder/Decoder, the Genetic Algorithm Iterator, and the Final Solution Set Generator.

Genetic algorithms fit into the framework by creating new designs based on the results of initial designs and the analyst's goals for the system. The analyst provides these as input into the Input Specifier. This input includes data files of the set of initial designs, a quantitative fitness function that embodies the performance objectives of the system, and the parameters for the GA such as number of iterations and rates of mutation and crossover. The initial design population may be manually generated "best guesses" by logisticians, or automatically generated using a range of values for different system parameters, and may include the number of times to simulate each design to boost statistical confidence.

The Input Specifier is tightly coupled with the Simulator so that the data files are understood and the system parameters needed to evaluate the fitness function are tracked. The Simulator executes the system model for the given designs and evaluates the performances based on the fitness functions. If designs are evaluated more than once, an average fitness is calculated. This data is then passed to the Encoder/Decoder. The Encoder/Decoder receives the designs and their corresponding fitness values from the Simulator. It orders the design parameters under study. If desired, the parameters can be translated from decimal to binary, octal, or other number-bases. These parameters are then fashioned into strings of GA chromosomes. Each string begins with a key that marks the size of individual genomes on the chromosome. For example, in the chromosome"2132704", the first character, "2," is the key that says all genomes are two characters long. The parameters encoded in this chromosome are 13, 27 and 4. In the context of the repair time analysis problem, “13” could represent the encoded number of aircraft, “27” the encoded number of mechanics of a particular type, and “04” the encoded number of equipment of a specified type. Decoding works in the opposite direction of encoding, breaking the chromosome into genomes, translating between number-bases, and structuring the new parameter values so that they can be read by the Simulator.

The GA Iterator receives the design chromosomes and fitness values from the Encoder/Decoder. Using the stochastic binary tournament method, two chromosomes are selected randomly from the population, the fittest is reproduced for the next generation, and mutation and crossover with the other chromosome produce necessary variation. These next-generation chromosomes are fed into the Encoder/Decoder and then into the Simulator. This process of Simulator-Encoder-GA Iterator-Decoder continues until the Solution Explorer reaches a terminating condition or generation, or the GA Iterator converges on a design, at which point the Final Solution Set Generator presents the final generation of designs to the analyst for further study.

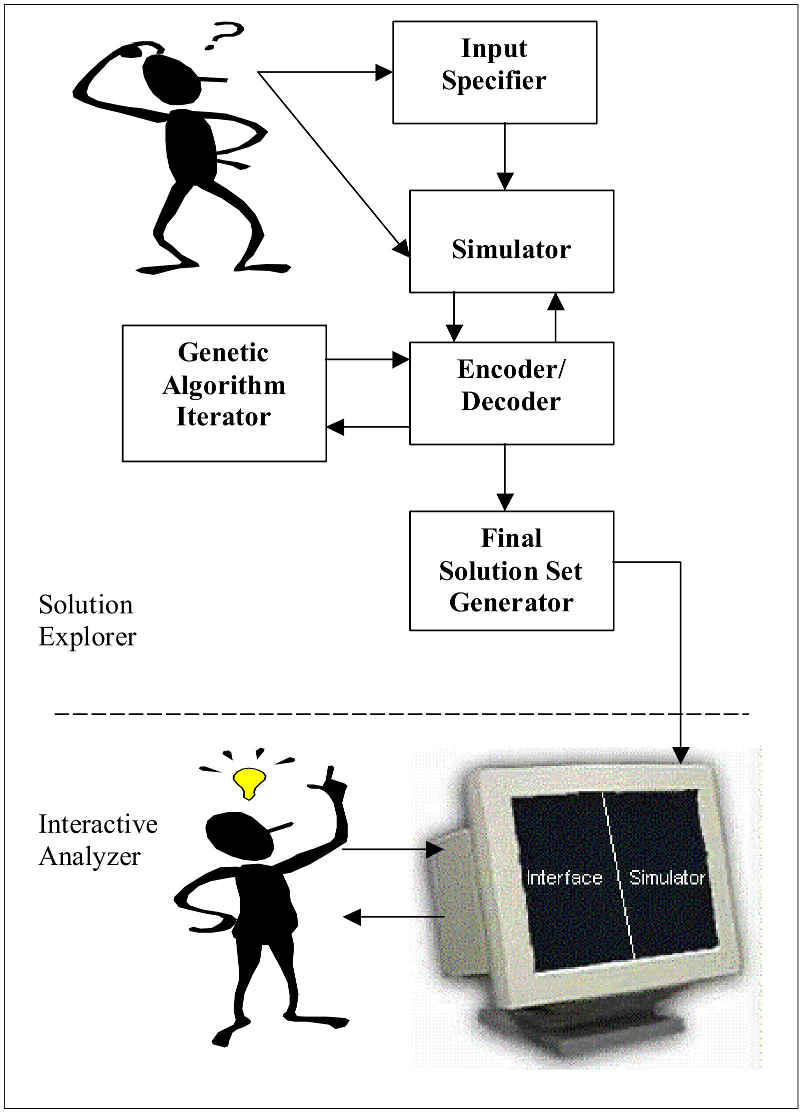

Figure 5. Components For Integrating Genetic Algorithms With Simulation Analysis.

All the modules for the solution explorer were implemented using the Java programming language. The architecture contains classes that provide the infrastructure for any simulations (e.g., random number generators, simulation clock, event calendar, etc.), classes to model an airbase (e.g., aircraft, scheduler, failure generator, maintenance resources, subsystems, information, etc.), and classes useful for the GA implementation.

To evaluate the effectiveness of the components of the system, a realistic repair time analysis problem was considered, applied to JADIS, and analyzed. The case study was conducted on a FX-99 scenario, a prototypical problem in repair time analysis. Statistical analysis was performed on the recorded fitness values to determine if significant improvement had occurred. Improvement was determined as significant increase in the average fitness value of one generation over that of a preceding generation.

From the Mann-Whitney test ($p = 0.002$), one could see that the solution explorer leads to significant improvement over the initial designs with just one iteration of the GA. Beyond that, however, the GA does not cause meaningful improvement from one generation to the next. These findings are supported by the Tukey test which also shows that additional improvement after the first generation may require more iterations. This suggests that, the GA becomes less effective over time as it approaches a potentially near optimal solution set. The GA produces a significant improvement over the original design population in just one generation but the magnitude of improvement decreases rapidly after that point. Details of the study can be found in Schneider, et al., In Press.

Overall the solution explorer explores the design space, saving the analyst from this tedium, and presents a final solution set that outperforms the original. The analyst would thus have had an opportunity to conduct a detailed analysis on each solution to determine which best met the combination of quantitative and qualitative goals. In JADIS, simulation is coupled with a front-end optimization routine that uses GA, which saves time by pruning the search space for the analyst. As it uses the genetic algorithm, it does not operate on design parameters directly but improves the entire population of alternatives under consideration without concern for mathematical functions that may not be continuous or even available. The final results from the optimization process showed improvements of the initial designs.

4.3 University of Dayton

The University of Dayton tasks focused on the modeling and generation of multivariate random variables within simulations of logistics systems. The major objective was to evaluate, develop, and implement valid models to characterize the dependence between variables whose relationships are only known partially, that is, characterized only by their marginal distributions and a measure of the correlation between them.

An exhaustive review of the literature uncovered only a small amount of research in this field and confirmed the initial conjecture that existing methods for generating correlated random variables assume or imply a specific joint distribution for the random variables generated. Careful examination of the resulting joint distributions also showed these to very often be very somewhat irregular in nature and inconsistent with common modeling intuition. (For example, the following figure depicts the joint probability density function implied by applying a common method for generating random vectors of this type when applied to two random variables that each have standard normal marginal distributions and a Spearman's rank correlation of 0.8. The fact that certain combinations of the two variables cannot be obtained from this joint distribution, especially near their respective means, is surprising and highly counterintuitive.)

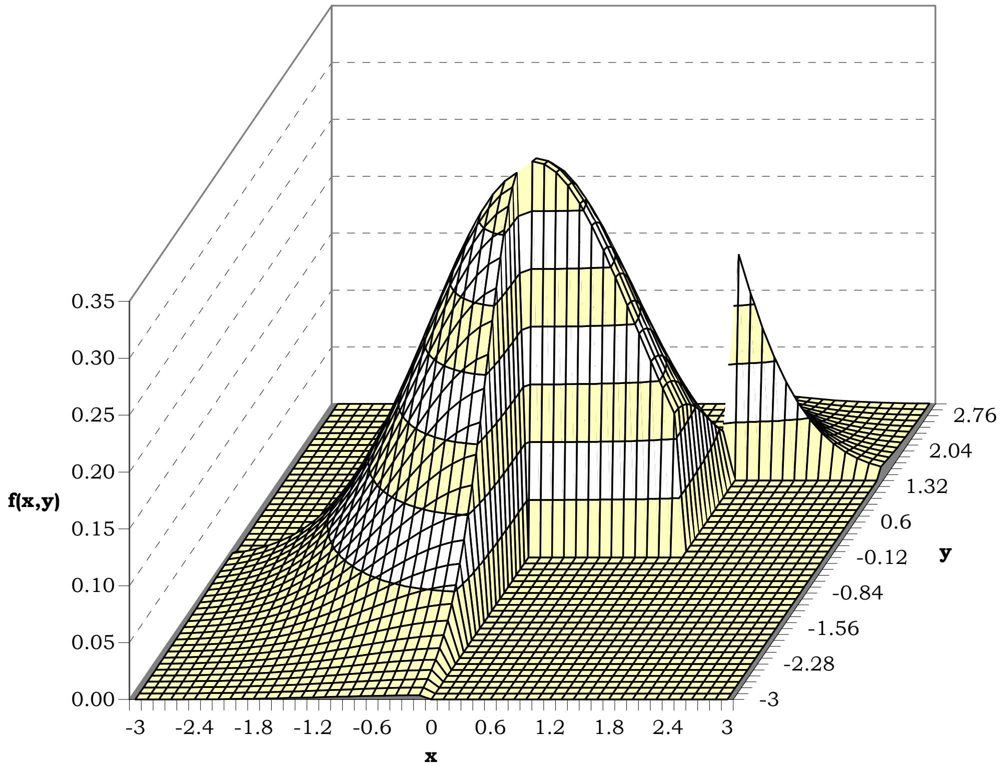

Figure 6: Example Joint Density Function

Since an unexpected joint distribution (or at least one inconsistent with the real-world phenomena being modeled) would obviously render a model invalid, the types of joint distributions commonly encountered in logistics simulations were next investigated, using data obtained from AFRL/HESR. The resulting analysis revealed, somewhat serendipitously, that no combinations of even any two variables in the data sets examined had the type of structure that was the primary subject of this research. That is, the variables examined either were independent, functionally related, or conditionally related. In each case, sufficient information existed so that appropriate joint distributions could be inferred from the known relations between the variables and, more importantly, so that they could be simulated validly using standard random variate generation methods. Thus, the potential problem envisioned by this portion of the research was a non-issue for the types of logistics systems being simulated and no special purpose methods for random variate generation or analysis are required to ensure model validity. Research in the broader area originally proposed continues independently, building on the foundation developed in this research project.

5. Follow-on Work

5.1 Air Force Institute of Technology

The research effort completed under the auspices of DAGSI has yielded follow-on research. AFIT has one student examining the fundamental algorithms that are required to realize PHM. A fundamental assumption of PHM is that advanced sensors will be able to detect, and more importantly predict, impending failures. This assumption is based on the belief that a component failure will be preceded by some indication that the failure is eminent. If advanced sensors can be trained to detect these tell-tale signs, then advanced mechanical and avionic systems can be produced that provide a level of "health" awareness. Unfortunately, little has been done in the area of algorithm research and development to achieve the promise of PHM. AFIT research is focused precisely on this problem.

In addition, work continues on extending the ALSim model. The goals for this model include eventually providing a model useful for those program offices involved in prognostics and autonomic logistics. Since such efforts are planned not only for existing aircraft, but also for future aircraft, there is a real potential for providing a useful tool for ALSim and PHM-related analyses.

5.2 Wright State University

The Air Force Research Laboratory (AFRL) Human Effectiveness Directorate has funded a small-scale follow-on effort to WSU through KLSS (Kelley's Logistics Support Systems), a Miami Valley Industry as a contract vehicle. This effort is aimed at supporting research on real-time interactive scheduling in Air Force logistics. Work has continued on the modeling infrastructure under the DAGSI funded effort to incorporate additional features in supporting real-time interactive scheduling.

On a related research topic, Intel Corp. has funded an effort that enabled the use of the architecture to a supply chain problem involving modeling of logistic processes. Subhashini Ganapathy from WSU completed her master's thesis in this area in Summer 2001.

In addition, WSU teamed with AFIT, KLSS, and Boeing to submit a large proposal to the Navy on modeling Naval logistics. Although the proposal received positive reviews, it was not funded.

6. Conclusions and Summary

The DAGSI sponsored research effort, Models, Web-Based Simulations, and Integrated Analysis Techniques For Improved Logistical Performance, provided an incredibly beneficial research opportunity to the faculty and student members involved in the research. The combination of theoretical examinations coupled with applied research into actual Air Force problems provided an ideal synergy for the particular expertise each of us brought to the effort.

The overall research program was to be evaluated on the extent to which the research results are used in Air Force systems, the number of refereed papers, number of masters thesis and Ph.D. dissertations completed. The appendices to this report provide a gauge of how well we accomplished our goals. Appendix A lists the numerous participants in this effort. Appendix

B lists the 11 technical papers produced through the research accomplished. These papers represent archival journal entries and submissions as well as national and international conference proceedings. Appendix C lists the 23 presentations made to publicize this research. These presentations include technical interchanges as well as well-known national and international conferences. Finally, Appendix D lists the 10 Masters theses supported by and produced related to this research.

Bibliography

Lu, S. C-Y., Tcheng, D. K., and Yerramareddy, S. (1991). Integration of simulation, learning and optimization to support engineering design. Annals of the CIRP, 40(1), 143-146.

Mollaghasemi, M. and Evans G. W. (1994). Multicriteria design of manufacturing systems through simulation optimization. IEEE Transactions on Systems, Man, and Cybernetics. 24(9), 1407-1411.

Popken, D. A. (1992). An object-oriented simulation environment for airbase simulation. Simulation. 59(5), 328-338.

Schneider, N. L., S. Narayanan, C. Patel, T. Carrico, and R. Hill. (In Press). Integration of genetic algorithms with airbase simulations for repair time analysis. *International Journal of Industrial Engineering*.

Appendix A: List of Key Participants

A.1 Principal Investigators, Faculty Members.

HILL, RAYMOND R., Jr., Lt Col, USAF, Associate Professor of Operations Research, Dept of Operational Sciences (AFIT/ENS); B.S., Mathematics, Eastern Connecticut State University, 1983; M.S., Air Force Institute of Technology, 1988; Ph.D., The Ohio State University, 1996. Lt Col Hill's research interests include simulation and optimization with ongoing funded research performed for multiple AF Battlelabs, Air Staff agencies, the LMA and AFRL/HES. Tel. 937.255.6565 Ext. 4323 (DSN 785); FAX 937.656.4943 (DSN 986); e-mail: *ray.hill@afit.edu*

MILLER, J. O., Lt Col, USAF, Assistant Professor of Operations Research, Dept of Operational Sciences (AFIT/ENS); B.S., United States Air Force Academy, 1980; M.B.A., University of Missouri at Columbia, 1983; M.S., Air Force Institute of Technology, 1987; Ph.D., The Ohio State University, 1997. Lt Col Miller's areas of interest include simulation, operational modeling, and ranking and selection methods. Tel 937.255.6565 Ext. 4326 (DSN 785); FAX 937.656.4943 (DSN 986); e-mail: *john.miller@afit.edu*

MOORE, JAMES T., Ph.D., Associate Professor of Operations Research, Dept of Operational Sciences (AFIT/ENS); B.A., Mathematics, University of Colorado, 1974; M.B.A., The University of Wyoming, 1978; M.S., Operations Research, Air Force Institute of Technology, 1981; Ph.D., Mechanical Engineering (Operations Research), The University of Texas at Austin, 1988. Dr. Moore's research interests include optimization, mathematical programming, integer programming, scheduling, and heuristic search methods. He has done sponsored research for Air Force Studies and Analyses Agency, Air Mobility Command, Air Force Materiel Command, Air Force Space Command, United States Strategic Command, and US Army Recruiting Command. Tel 937.255.6565 Ext. 4337 (DSN 785); FAX 937.656.4943 (DSN 986); e-mail: *james.moore@afit.edu*

KOUBEK, RICHARD, J. Ph.D., Formerly Professor and Chair, Department of Biomedical, Industrial, and Human Factors Engineering at Wright State University; Ph.D., industrial engineering, Purdue, 1988. He recently became Department Head of Industrial and Manufacturing Engineering at Penn State. Dr. Koubek's research interests are in human computer interaction, usability, and cognitive ergonomics. He has published numerous refereed technical articles in these areas and has directed research projects funded by National Science Foundation, Office of Naval Research, and the US Postal service. He is Editor of the *International Journal of Cognitive Ergonomics* and is a member of the Editorial Board for the *International Journal of Human Factors in Manufacturing* and *the International Journal of Human-Computer Interaction*. He has recently co-edited two books—*Design of Computing Systems: Cognitive Considerations* and *Design of Computing Systems: Social and Ergonomic Considerations*. Tel 937.775.5045; Fax 937.775.7364; e-mail: rkoubek@cs.wright.edu.

NARAYANAN, S., Ph.D., P.E., Associate Professor and Interim Chair, Department of Biomedical, Industrial and Human Factors Engineering at Wright State University; Ph.D., Industrial and Systems Engineering, Georgia Institute of Technology, 1994. Dr Narayanan's research interests are in modeling and analysis of complex systems and understanding and aiding human decision making through computational tools. His domains of interest include logistic systems, remote vehicle command and control, discrete manufacturing, and navigation of large, multi-media information sources. He has published over 50 technical articles in these areas and obtained sponsored research of about $2 million as a principal investigator in the last five years from AFOSR, AFRL, State of Ohio, Intel Corp., and LEXIS-NEXIS. Tel 937.775.5046; Fax 937.775.7364; e-mail: snarayan@cs.wright.edu.

MYKYTKA, EDWARD F., Ph.D. Professor, Dept. of Engineering Management and Systems, University of Dayton; B.S., Mathematics, University of Dayton, 1976; M.S., Industrial Engineering, University of Iowa, 1978; Ph.D., Systems Engineering, University of Arizona, 1983. Dr. Mykytka's research interests include simulation modeling and analysis, quality and reliability improvement, and applied statistics. He has supported major modeling, analysis, and education efforts for the C-17 Systems Program Office, AMC, the Defense Modeling and Simulation Office, and other DoD agencies. Tel 937.229.2238; FAX 937.229.2698; e-mail: *emykytka@engr.udayton.edu*

A.3 Principal Investigators, Masters Students

AFIT (MS Thesis Completed)

Brian Ballew
Erhan Baltacioglu
Barry Bennett
Gokay Bulut
Reginald Festejo
James MacKenna
Michael Malley
Rene Rebulanan

WSU (MS Thesis Completed)

Todd Kustra
Subhashini Ganapathy

UD

Brian Rizzoli

A.4 Principal Investigators, Air Force Research Laboratory

CHRISTOPHER K. CURTIS, AFRL/HESR, (937) 255-6718, Chris.Curtis@he.wpafb.af.mil. Current position is Advance Logistics Project Air Expeditionary Force (ALP-AEF) Initiative Program Manager. Will also become the Deputy Program Manager for Logistics Control and Information Support (LOCIS). Received BSEE in 1985 from University of Cincinnati.

BARB MASQUELIER, AFRL/HESR, (937) 656-7005, Barb.Masquelier@he.wpafb.mil.
Barbara L Masquelier is a senior industrial engineer for the Logistics Readiness Branch, Air Force Research Laboratory. Her major research interests include enhancement of human performance in complex logistics systems, applications of wearable computer technology, and information requirements analysis. She has a M. S. in Logistics Management from the Air Force Institute of Technology and a B. S. in Human Factors Engineering from Wright State University.

MATTHEW TRACY, AFRL/HESS, (937) 255-8360, Matthew.Tracy@he.wpafb.mil
Matthew C. Tracy II is a senior mechanical engineer for the Sustainment Logistics Branch, Air Force Research Laboratory. His major research interests include enhanced support equipment, reliability measurement methodologies, and application of advanced program management techniques. Positions have ranged from aircraft maintenance to system program office support and laboratory program management. He has a M. S. in Management Science and a B. S. in Mechanical Engineering from the University of Dayton.

Appendix B: List of Technical Papers Produced

N. L. Schneider, S. Narayanan, C. Patel, T. Carrico, and R. Hill. 2001. Integration of genetic algorithms with airbase simulations for repair time analysis. Accepted by *International Journal of Industrial Engineering*.

T. Kustra & S. Narayanan. (Abstract Accepted, Full Chapter Under Review). A decision support system for logistics systems analysis using image theory and work domain analysis. For *Handbook of Cognitive Task Design*, E. Hollnagel (Ed.), Lawrence Erlbaum.

O' Fearna, F. C., R. R. Hill and J. O. Miller. 2001. A Methodology to Reduce Aerospace Ground Equipment Requirements for an Air Expeditionary Force. Accepted for publication by *International Journal of Logistics: Research and Applications*.

MacKenna, J., R. R. Hill, and W. Cunningham. 2001. *Using Simulation to Determine Support Equipment Inventory Levels*. Submitted to *Journal of Logistics*, November 2001.

Baltacioglu, E., J. T. Moore, and R. R. Hill. 2001. *The Distributor's Three Dimensional Pallet-Packing Problem: A Human Intelligence-Based Heuristic Approach*. Submitted to *European Journal of Operational Research.* April 2001.

Hill, R. R. and G. McIntyre. 2000. A Methodology for Robust, Multi-Scenario Optimization. *Phalanx*, Vol 33, No. 3, September 2000.

N. L. Schneider, S. Narayanan, C. Patel. (2000). Integrating genetic algorithms and interactive simulations for airbase logistics planning. *Soft Computing in Industrial Applications*, Suzuki, Roy, Ovaska, Furuhashi and Dote (Eds), Springer-Verlag, London, UK, 309 – 317

Miller, J. O., M. Malley, and R. R. Hill. 2001. *Modeling Prognostic Health Management for the Joint Strike Fighter*. Proceedings of the 10th Annual Industrial Engineering Research Conference, Dallas, TX, 20-22 May 2001.

Hill, R. R., G. McIntyre, and S. Narayanan. 2001. *Genetic Algorithms for Model Optimization*. Proceedings of Simulation Technology and Training Conference (SimTechT) 2001, Simulation Industry Association of Australia, Canberra, Australia, May 28-31 2001.

S. Narayanan, 2001. Presented an invited keynote tutorial on "web-based interactive simulations" at the IASTED's advanced simulation and modeling conference in Marbella, Spain, 2001.

Hill, R. R., J. O. Miller, and G. A. McIntyre. 2001. *Applications of Discrete Event Simulation Models to Military Problems.* Accepted for publication in *Proceedings of the 2001 Winter Simulation Conference,* B. A. Peters, J. S. Smith, D. J. Medeiros and M. W. Rohrer, eds., Institute of Electrical and Electronics Engineers, Washington DC.

S. Narayanan. 2000. *Web-based simulations*: *Introductory Tutorial,* Proceedings of the 2000 Winter Simulation Conference, Institute of Electrical and Electronics Engineers, Washington DC.

Appendix C: Presentations Made

"Incorporating Utilization Information to Size Aircraft Support Inventories" R. Hill, Institute for Operations Research and the Management Sciences (INFORMS) Conference, Miami, FL, 5-8 Nov, 2001.

"Applications of Discrete Event Simulation Modeling to Military Problems" R. Hill, G. McIntyre and J. O. Miller, 2001 Winter Simulation Conference, Washington, DC. December 2001.

"Genetic Algorithms for Model Optimization" R. Hill, G. McIntyre, and S. Narayanan, Simulation Technology and Training Conference (SimTechT) 2001, Canberra, Australia, May 28-31 2001.

"The Distributer's Three-Dimensional Pallet-Packing Problem: A Human Intelligence-Based Heuristic Approach", R. Hill, E. Baltacioglu, and J. T. Moore, Military Operations Research Society Symposium, Annapolis, MD, 12-14 Jun 01.

"Applications of Discrete Event Modeling to Military Problems" G. McIntyre, J. O. Miller, and R. Hill, 2000 Winter Simulation Conference, Orlando, Fl. December 2000.

"Modeling the Modular Aircraft Support System for Improved Air Force Logistics" R. Hill, R. Festejo, and J.O. Miller, Industrial Engineering Research Conference 2000, Cleveland OH, 23 May 2000.

"Modeling the Joint Strike Fighter's Autonomic Logistics System" J.O Miller, R. Rebulanan, and R. Hill, Industrial Engineering Research Conference 2000, Cleveland OH, 23 May 2000.

"A Methodology and Experiment Using Robust, Multi-Scenario Optimization Techniques" R. Hill, B. Bennett and G. McIntyre, 68th Military Operations Research Society Symposium, US Air Force Academy, June 2000.

"Modeling Prognostic Health Management for the Joint Strike Fighter" J.O. Miller, M. Malley, and R. R. Hill. Industrial Engineering Research Conference 2001, Dallas, TX, 20-22 May 2001.

"Web-based simulations" S. Narayanan. 2000 Winter Simulation Conference, Orlando, Fl. December 2000.

"Models, Web-Based Simulations, And Integrated Analysis Techniques For Improved Logistical Performance" Project Team, Technical Interchange with AFRL/HES, October 1999.

"Models, Web-Based Simulations, and Integrated Analysis Techniques For Improved Logistical Performance" Project Team, Technical Interchange with AFRL/HES, March 2001.

"Models, Web-Based Simulations, And Integrated Analysis Techniques For Improved Logistical Performance" R. Hill, Dayton Area Graduate Studies Institute Aerospace Basic Research Program Symposium, February 2000.

"Models, Web-Based Simulations, And Integrated Analysis Techniques For Improved Logistical Performance" R. Hill, Dayton Area Graduate Studies Institute Aerospace Basic Research Program Symposium, February 2001.

"Robust Multi-Scenario Optimization of an Air Expeditionary Force Structure Applying Genetic Algorithms to the Combat Forces Assessment Model" B. Bennett. Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio, Thesis Defense, March 2000.

"An Analytical Comparison of the Reduced Footprint of the Modular Aircraft Support System (MASS) vs. Current Aerospace Ground Equipment (AGE)" R. Festejo. Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio, Thesis Defense, March 2000.

"The Distributor's Three-Dimensional Pallet-Packing Problem: A Mathematical Formulation and Heuristic Solution Approach" B. Ballew. Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio, Thesis Defense, March 2000.

"A Simulation of ALS Using Java Programming Language" R. **Rebulanan**. Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio, Thesis Defense, March 2000.

"Requirements-Based Methodology For Determining Age Inventory Level" J. A. MacKenna. Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio, Thesis Defense, March 2001.

"Robust Multi-Scenario Optimization Of An Air Expeditionary Force Structure Applying Scatter Search To The Combat Forces Assessment Model" G. Bulut. Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio, Thesis Defense, March 2001.

"A Methodology For Simulating The Joint Strike Fighter's (JSF) Prognostics And Health Management System" M. Malley. Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio, Thesis Defense, March 2001.

"The Distributer's Three-Dimensional Pallet-Packing Problem: A Human Intelligence-Based Heuristic Approach" E. Baltacioglu. Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio, Thesis Defense, March 2001.

Appendix D: Masters Theses Produced

T. W. Kustra. 2000. *A methodology to develop interactive decision support systems for complex United States Air Force logistics planning*. Department of Biomedical, Industrial, & Human Factors Engineering, Wright State University, Dayton, Ohio.

S. Ganapathy. 2001. *Model-based decision support system for supply chain analysis*. Department of Biomedical, Industrial, & Human Factors Engineering, Wright State University, Dayton, Ohio.

Bennett, Barry. 2000. *Robust Multi-Scenario Optimization of an Air Expeditionary Force Force Structure Applying Genetic Algorithms to the Combat Forces Assessment Model*. Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio. AFIT/GOR/ENS/00M-02

Festejo, Reginald. 2000. *An Analytical Comparison of the Reduced Footprint of the Modular Aircraft Support System (MASS) vs. Current Aerospace Ground Equipment (AGE).* Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio. AFIT/GOR/ENS/00M-13

Ballew, Brian. 2000. *The Distributor's Three-Dimensional Pallet-Packing Problem: A Mathematical Formulation and Heuristic Solution Approach.* Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio. AFIT/GOR/ENS/00M-01

Rebulanan, Rene. 2000. *A Simulation of ALS Using Java Programming Language.* Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio. AFIT/GOR/ENS/00M-19

MacKenna, James A. 2001. *Requirements-Based Methodology For Determining Age Inventory Level.* Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio. AFIT/GLM/ENS/01M-15

Bulut, Gokay. 2001. *Robust Multi-Scenario Optimization Of An Air Expeditionary Force Force Structure Applying Scatter Search To The Combat Forces Assessment Model*. Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio. AFIT/GOR/ENS/01M-03

Malley, Michael. 2001. *A Methodology For Simulating The Joint Strike Fighter's (Jsf) Prognostics And Health Management System.* Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio. AFIT/GOR/ENS/01M-11

Baltacioglu, Erhan. 2001. *The Distributer's Three-Dimensional Pallet-Packing Problem: A Human Intelligence-Based Heuristic Approach.* Department of Operational Sciences, Air Force Institute of Technology, Wright Patterson AFB, Ohio. AFIT/GOR/ENS/01M-02

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to an penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
14-12-2001	**Technical Report**	Jun 1999 – Sep 2001

4. TITLE AND SUBTITLE	
Models, Web-Based Simulations, and Integrated Analysis Techniques for Improved Logistical Performance	**5a. CONTRACT NUMBER** AFIT-HE-99-10
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Hill, Raymond R., S. Narayanan, and Edward F. Mykytka	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Air Force Institute of Technology Department of Operational Sciences (AFIT/ENS) 2950 P Street, Building 640 WPAFB OH 45433-7765	AFIT/EN-TR-01-02
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Dayton Area Graduate Studies Institute Attn: Dr. Frank Moore 3155 Research Blvd., Suite 205 Kettering, Ohio 45420	**10. SPONSOR/MONITOR'S ACRONYM(S)** DAGSI **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
In February 1999, a team of researchers from the Air Force Institute of Technology, the Wright State University and the University of Dayton teamed with researchers within the Air Force Research Laboratory, Logistics Research Division, Logistics Readiness Branch to propose a research agenda entitled, "Models, Web-based Simulations, and Integrated Analysis Techniques for Improved Logistical Performance." This proposal was submitted in response to the initial Dayton Area Graduate Studies Institute request for proposals under the Joint Air Force Research Laboratory/ DAGSI Basic Research Program. The particular project supported as HE15 within the Human Effectiveness Directorate and entitled Logistics Readiness. The proposal successfully competed and was selected for contract award. Between June 1999 and July 2001, the researchers from the collaborating institutes pursued a collective research agenda, one that was closely aligned with the mission of the AFRL Logistics Readiness Branch as well as other organizations within the United States Air Force. This final technical report summarizes the research efforts under the contract, AFIT-HE-99-10. This report includes descriptions of the accomplishments of the research as well as listings of the numerous papers produced, presentations made, and masters thesis completed directly supporting, and supported by this research effort.

15. SUBJECT TERMS
Logistics, simulation, web-based simulation, JAVA, human factors, prognostics, ontology

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Raymond R. Hill Jr., Lt Col, USAF (ENS)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)* (937) 255-6565, ext 4323; e-mail: Ray.Hill@afit.edu
U	U	U	UU	54	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18