MASTER OF SCIENCE
IN
OPERATIONS RESEARCH

PERFORMANCE METRICS FOR CORRELATION AND TRACKING ALGORITHMS

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Military commanders require situational awareness to support real-time decision-making. To obtain information on possibly hostile entities in an area of interest, surveillance systems, which receive information from sensors such as radars, intelligence, and other sources, are often used. One of the objectives of surveillance systems that track aircraft is the formation of a Single Integrated Air Picture (SIAP), that represents a coherent resolution of information. Correlation is the process by which sensor measurements and other information are combined to keep the SIAP up-to-date in real time. A correlator, which is the software implementation of a correlation methodology, must resolve ambiguities and conflicting information to provide an operationally useful synthesis of surveillance data. Possible ambiguities include missed tracks, extra tracks, or position and velocity errors. The metrics developed in this thesis are designed for use in evaluating the performance of air surveillance systems, of which correlators are an integral part. Maneuvering or closely spaced aircraft pose difficult issues for air surveillance systems. These are addressed by the performance metrics. Using scripted test scenarios in a modeling and simulation environment, comparisons of correlators can be made using nonparametric statistical methods. An experiment constructed in this manner can be used to support acquisition decision-making.

DoD KEY TECHNOLOGY AREAS: Command, Control and Communications, Modeling and Simulation, Sensors

KEYWORDS: Correlator, Correlator Performance Metrics, Surveillance Systems, Single Integrated Air Picture (SIAP)

EXPLORING THE VALIDATION OF LANCHESTER EQUATIONS FOR THE BATTLE OF KURSK

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This thesis explores the validation of Lanchester equations as models of the attrition process for the Battle of Kursk in World War II. The methodology and results of this study extend previous validation efforts undertaken since the development of the Ardennes Campaign Simulation Data Base (ACSDB) in 1989 and the Kursk Data Base (KDB) in 1996. The KDB is a computerized database developed by the Dupuy Institute and the Center for Army Analysis from military archives in Germany and Russia. The data are two-sided, time-phased (daily), highly detailed, and encompass 15 days of the campaign. The primary areas of analysis are the effect of using purely engaged forces in parameter estimation and the effect of

force weighting in forming homogeneous force strengths. Based on the numbers of personnel, tanks, armored personnel carriers, and artillery, three different data sets were constructed: all combat forces in the campaign, combat forces within contact that are both engaged and not engaged, and combat forces within contact that are engaged. In addition, a weight optimization program using a steepest ascent algorithm was developed and utilized. Findings indicate that Lanchester-based models provide a considerably better fit for data sets composed only of forces that are actively engaged. Also, Lanchester's linear model appears to provide the best fit to the Battle of Kursk data. Finally, optimization of force weights does not significantly improve the fit of Lanchester models.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Lanchester Equations, Battle of Kursk, Combat Models, Attrition, Model Validation

RE-ENGINEERING THE ENROLLMENT MANAGEMENT SYSTEM AT THE MONTEREY PENINSULA UNIFIED SCHOOL DISTRICT (MPUSD)

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This thesis establishes a Forecasting Enrollment Management (FEM) System within the Monterey Peninsula Unified School District (MPUSD). In particular, it examines the effect the forecasting of student enrollment since the untimely departure of the Deputy Superintendent (DepSup) who had performed the function as Chief Enrollment Official for over two decades. The closure of the Fort Ord Army Facility had a significant impact on the accuracy of enrollment projections and inadvertently affected the funding for special program allocations and staffing. The MPUSD has within its control twenty-three schools that service over 12,000 students each year using public funds. Four schools are located within military housing communities and typically service the school-age military dependents residing nearby. Each year's funding is determined by an estimate projected from the previous year's enrollment. The District is required to provide a budget request by April 15th of each school operating year. The school district currently has no computational model adequate for projecting student enrollment; MPUSD uses a working group process to achieve its objective. A model that can more precisely project the number of students in each future year is developed; it can provide a more efficient enrollment management process and provide the necessary checks and balances for the current method. The thesis considers independent community related variables and historical data, and shows that prior-year enrollment figures can forecast future-year enrollment projections with smaller variance than the current working group method.

DoD KEY TECHNOLOGY AREA: Manpower, Personnel, and Training

KEYWORDS: Enrollment, Enrollment Management, Forecasting, Data Analysis, Data Collection, Process Engineering, Quality Assurance, Continuous Process Improvement

JAVAMIX: A TACTICAL DECISION AID TO EVALUATE MINEFIELD CLEARANCE PLANS

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A Tactical Decision Aid (TDA) for mixed minefield clearance, JAVAMIX, was designed, developed and tested. The TDA uses a Monte Carlo Simulation and it is based on the Monte Carlo option of the TDA MIXER (Washburn, 1995). The JAVAMIX Graphical User Interface (GUI) allows the user to introduce

different plans based on the sweep and resource types available and mine types expected. To clear the minefield the user is asked to choose a parameter file and to introduce a plan. Output tables are presented in a DOS window and permit the user to easily visualize if the chosen plan is tactically executable. The design of the system permits future developments such as the implementation of MIXER's other options and the introduction of new parameters.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Tactical Decision Aid for Mine Warfare, Java, Graphical User Interface

STATISTICAL ANALYSIS OF NAVAL AVIATION DEPOT REPAIR CYCLE TIME REDUCTION FOR THE F/A-18 C/D AIRCRAFT

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Reducing U.S. Navy inventory control problems associated with the F/A-18 C/D aircraft is critical to maintaining squadron readiness while minimizing procurement and repair costs. The Navy's Inventory Control Point has designed its Carcass Express program to ensure that critically short depot level repairables are serviced more quickly. The program was initiated on the S-3 Viking aircraft in 1999. Subsequently, the number of constrained carcasses was reduced by 40 percent, and the average depot repair cycle time was reduced by 12 days. This thesis attempts to quantify the savings that can be realized by instituting the Carcass Express program for the F/A-18 C/D. Data for F/A-18 C/D repairable items that were identified as having insufficient carcasses for repair to meet current demand levels are analyzed. These repairable items have high dollar values and significant backorders severely impacting squadron readiness.

It is shown that the Carcass Express program would provide an additional accrual of inventory over a four-year period for the items studied. The required funding needed to support the deficit between items available from the depot repair cycle and forecast quarterly demands would decrease. The Carcass Express initiative would improve the predictability of the Depot Repair Cycle by reducing repair cycle variability. This ultimately would lead to better inventory management.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Materials, Process, and Structures, Modeling and Simulation

KEYWORDS: Forecasting, Statistics, Repairable, Inventory, Operations

A MULTI-ATTRIBUTE DECISION SUPPORT MODEL FOR 'BEST VALUE' SOURCE SELECTION

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For decades, the federal government has grappled with the issue of how to determine the "best value" offer for services from among competing contractors vice awarding contracts based on lowest bid only. This thesis develops a risk-adjusted cost evaluation decision support model for use in government best value source selection. The thesis presents the Best Value Evaluation Methodology (BVEM), which assists the source selection team throughout the source selection process. BVEM encompasses the fundamentals of "best value" analysis including risk assessments of cost, schedule, technical feasibility, and contractor past performance. BVEM generates a multi-attribute utility measurement (MAUM) score for each proposal

based upon the assessed risk. The MAUM score is used to define Triangular and Beta probability distributions for use in Monte Carlo simulations to determine risk-adjusted cost estimates. BVEM also emphasizes the use of upper confidence levels as a better comparison tool for best value than singular point estimates. Additionally, the thesis develops a software implementation of BVEM, called the Cost-Risk Enhanced Source Selection Evaluation Tool (CRESSET). Based on Microsoft Excel and Palisade @RISK software, CRESSET may be used to generate appropriate risk distributions, weighting criteria, quantitative results and visual displays of relative risk for each proposal for use in best value analysis. CRESSET is also useful for preparing more realistic budget estimates.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation, Other (Contracting)

KEYWORDS: Acquisitions, Contracting, Best Value, Proposal Evaluation, Cost-Risk Analysis, Simulation

ANALYSIS OF MAINTENANCE RECORDS TO SUPPORT PREDICTION OF MAINTENANCE REQUIREMENTS IN THE GERMAN ARMY

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Today the German Armed Forces are faced with a broad, varied and graduated range of tasks including missions outside Germany. A major challenge in planning the force structure for missions like the one in Kosovo is to predict the required maintenance capacities. This thesis conducts an exploratory data analysis of maintenance records of the German Army, using the wheeled reconnaissance tank "Luchs" as an example. The question under investigation is whether or not data from the maintenance records can be used to support a future "maintenance prediction tool." It is shown that repairtime distributions extracted from the data can be used to model the repair process in a simulation. The Weibull distribution family, which is commonly used in reliability applications, proved flexible enough to simulate repairtimes and workorder supply times. Implementing these results in a simulation of the repair process will improve the accuracy and quality of the simulation output. In addition, this thesis discusses data quality issues and makes design suggestions for a new maintenance organization software. Data problems can be minimized if the problems identified in this study are aggressively attacked during the design and implementation phases of the new software.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation, Other (Logistics)

KEYWORDS: Maintenance, Repairtime Distribution, Data Quality, German Army

ORGANIZATIONAL CLIMATE AND ITS RELATIONSHIP WITH AVIATION MAINTENANCE SAFETY

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Naval Aviation is continually looking for ways to reduce its mishap rate. Recognizing a growing concern for issues related to aging aircraft, focus has expanded to include maintenance operations. It is accepted that human error is a causal factor in at least eighty percent of all mishaps, with maintainer, line, or facility-related factors accounting for one out of five major mishaps. One of several actions taken to reduce the

mishap rate is the Maintenance Climate Assessment Survey (MCAS). Created to give Naval Aviation unit commanding officers a sense of the maintenance climate of their unit, the MCAS reveals the maintainer's perception of safety climate. Beginning in July 2000, the MCAS administration became available via the Internet. This thesis analyzes the results of the first 2,180 responses recorded via the Internet version of MCAS. Findings include: a) administration of the Internet-based MCAS yields results similar to the paper-and-pencil version; b) differences were detected among the participating units and the Model of Organization Safety Effectiveness components; c) the relationship between MCAS score and Incident Rate, although slightly negative, is indistinguishable from random variation; and d) there was no evidence that demographics bias the results. These findings could be accounted for by the fact that a unit's safety climate typically improves after a mishap. Requiring all units to complete the survey annually would allow tracking over time to uncover trends. One area for further research is investigating the feasibility of adapting the MCAS to afloat and ashore units.

DoD KEY TECHNOLOGY AREA: Other (Naval Aviation)

KEYWORDS: Safety Climate, Human Error, Maintenance

STATISTICAL VALIDATION OF TRACK QUALITY NUMBERS FOR JOINT INTEROPERABILITY TESTING OF THEATER AIR AND MISSILE DEFENSE FAMILIES OF SYSTEMS

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Joint interoperability is fundamental to the effectiveness of a Theater Air and Missile Defense (TAMD) Family of Systems. Under the Joint Data Network concept, systems compete for reporting responsibility of a possible missile track by issuing track quality numbers related to the covariance matrix of the estimated position and velocity. The system that reports the highest track quality number is assigned reporting responsibility for the track. Verifying that reported track quality numbers are accurate is an integral part of an interoperability test and evaluation program for a TAMD family of systems. In this thesis a framework for measuring the accuracy of track quality numbers, based on reported position and velocity, is described. The framework is applicable to family of system tests consisting of either live missile tracking or modeling and simulation data. Issues that arise in assigning truth objects to tracks are discussed. Measures of performance are proposed based on statistical tests to describe the accuracy of track quality numbers for each system under evaluation in family of systems interoperability testing. Applying the metrics to missile data reveals instances when the reported track quality numbers by TAMD systems are too high.

DoD KEY TECHNOLOGY AREAS: Sensors, Modeling and Simulation, Command, Control and Communications

KEYWORDS: Tracking, Trajectory Estimation, Track Quality, Interoperability, Test and Evaluation, Theater Air and Missile Defense

AN ARMY RESERVE MANPOWER PLANNING MODEL

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Because of the expected shortages in its Active Guard and Reserve (AGR) program, the Army Reserve is considering two manpower policy changes. One is the use of Position Vacancy Promotions (PVP) and the

other is to allow more officers to serve beyond 20 years of Active Federal Service (AFS). To evaluate the impact of these policy changes, either individually or in combination, on alleviating the shortages, this thesis develops the Army Reserve Manpower Planning model (ARMP). ARMP is an optimization model that determines the annual numbers of accessions, promotions, and separations that best meet the authorized inventory targets. Results from ARMP suggests that a combination of extension of the AFS requirement and allowing PVP can nearly eliminate the shortage in the near future if implemented immediately. ARMP is also useful for managing the AGR officer force.

DoD KEY TECHNOLOGY AREAS: Manpower, Personnel, and Training, Modeling and Simulation

KEYWORDS: Manpower Planning, Personnel, Optimization, Army Reserve, Active Guard and Reserve

STOCHASTIC SIMULATION OF A COMMANDER'S DECISION CYCLE (SSIM CODE)

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This thesis develops a stochastic representation of a tactical commander's decision cycle and applies the model within the high-resolution combat simulation: Combined Arms Analysis Tool for the 21st Century (Combat XXI). Combat XXI is a Joint Army-Marine Corps effort to replace the Combined Arms and Support Evaluation Model (CASTFOREM)—a legacy combat simulation. Combat XXI is a non-interactive, high-resolution, analytical combat simulation focused on tactical combat. Combat XXI is being developed by the U.S. Army TRADOC Analysis Center-White Sands Missile Range (TRAC-WSMR) and the Marine Corps Combat Development Command (MCCDC). Combat XXI models land and amphibious warfare for applications in the research, development and acquisition, and the advanced concepts requirements domains. Stochastic decision-making enhances Command and Control (C2) decision processes in Combat XXI. The stochastic simulation of a commander's decision cycle (SSIM CODE) addresses variability in decision-making due to uncertainty, chance and the commander's attributes. A Bayesian Network representation of a conditional probability model for a commander's decision cycle is implemented in SSIM CODE. This thesis develops, applies and evaluates the effectiveness of SSIM CODE.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Computing and Software, Command, Control and Communications, Battlespace Environments

KEYWORDS: Combat Models, Simulation, Decision-Making, Decision Cycle

CASE STUDY IN MODELING AND SIMULATION VALIDATION METHODOLOGY

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The military develops and uses simulations to analyze nearly every aspect of defense. How accurate are these simulations and to what extent do they produce dependable results? This thesis explores practical validation techniques from the bottom-up in the form of a case study. The platform used is the theater ballistic missile defense aspects of the new simulation Wargame 2000. This research will be particularly useful when combined with further case studies to provide a global perspective to validating large-scale military models and simulations. Wargame 2000 is compared to a baseline existing model, EADSIM.

The focus here is not to validate or invalidate Wargame 2000 but to develop real, usable tools to compare a simulation's results against baseline results. This work focuses on measures of effectiveness characteristic of missile defense. Data collection includes defense battery search, engagement and intercept times for a variety of threats but does not include tracking information. Results from each model are compared using both graphical methods and inferential statistics. Insight is provided into developmental and data production issues which can make the validation process more effective and meaningful.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Validation, Simulation Validation, VV&A, Model-Test-Model, Wargame 2000, EADSIM, Theater Ballistic Missile Defense

EFFECTIVENESS OF NAVAL SURFACE FIRE SUPPORT TO THE ARMY BRIGADE COMMANDER IN A LITTORAL CAMPAIGN

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Since the end of the Cold War, the Army has been engaged in an unprecedented number of joint contingency operations that run the gamut from humanitarian efforts in Cuba and Haiti to peace-enforcing and peace-keeping in Bosnia to full scale war in Southwest Asia. These operations, the result of an increasingly complex international security environment, hint at future missions involving American forces aimed at protecting U.S. interests worldwide.

To engage and defeat future threats to our national security, the Army must transform itself into a more strategically responsive, lethal force. The Army is faced with the challenge of lightening the force while simultaneously increasing its survivability and lethality. Reach-back technologies from sea, air, and space can provide Army units with added lethality without encumbering them further.

This thesis analyzes the ability of the Army to effectively utilize Naval Surface Fire Support (NSFS) to provide indirect fire in support of brigade-sized units. The Fire Support Simulation Tool (FSST) takes the capabilities and limitations of weapon systems being studied and simulates their employment in the context of a well-defined scenario for analysis. The output from the simulation provides the input for the analysis of NSFS.

By comparing the utility of several well-constructed courses of action, the FSST can help decision-makers determine the effectiveness of NSFS within the context of the scenario being considered. The results of this analysis determined that although a myriad of issues such as training, mistrust, and synchronization must be addressed to make reach-back fires successful, there is strong *quantitative* and *analytical* evidence to support the effectiveness of NSFS to an Army Brigade commander engaged in a littoral campaign.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Command, Control, and Communications, Computing and Software, Conventional Weapons, Modeling and Simulation

KEYWORDS: NSFS, simulation, Java, FCS, IBCT, Artillery, DD21, DD-21, Paladin, Crusader