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THE JUDY THEATER SURVEILLANCE AND STRIKE SIMULATION MODEL

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ABSTRACT

JUDY is a stand-alone constructive architecture-level simulation designed specifically to investigate the potential contribution of current and emerging systems, concepts, and technologies to the prosecution of theater targets, including ground, air, and ballistic. The simulation includes all phases of end-to-end target prosecution: surveillance, cueing, exploitation, command & control, sensor & weapon tasking, fire control, strike, and engagement. JUDY can address various theater mission areas, including:

- wide area ground surveillance/reconnaissance
- surveillance & strike of time critical targets
- theater missile defense (TMD)
- boost phase intercept (BPI)
- ground strike surveillance & planning (ATO support)
- imagery exploitation, target classification & ID
- real-time retargeting of strike packages
- air-breather surveillance & intercept (ADI, CMD)

A key feature of JUDY is the ability to model an integrated multi-mission architecture including the simultaneous operation of TMD, BPI, CMD, and Air Strikes. The JUDY model was designed to support architecture-level trade studies, examine parametric sensitivities, and provide first order insights into issues of system performance and concepts of operations (CONOPS). JUDY is a faster than real-time Monte Carlo discrete event simulation that explicitly models surveillance platforms, strike assets, C4I processes, point-to-point communications, and upwards of 100,000 individual threat vehicles. The individual threat entities operate in a geographic environment that includes: terrain elevation (DTED), road networks, cultural data such as foliage, and a simplified atmosphere. Multi-replication batch run times may range from 5-30 minutes on a Sun Sparc 20.

1 BACKGROUND

Soon after the conclusion of Desert Storm, the Defense Advanced Research Projects Agency (DARPA) established the WarBreaker facility to explore the potential contribution of current and emerging surveillance technologies, command and control concepts, and weapon systems to the prosecution of theater Time Critical Targets (TCTs) using Distributed Interactive Simulation (DIS) and Man-In-The-Loop (MITL) experiments. However, it quickly became clear there was an immediate need for a more traditional constructive simulation tool to support architecture analyses and performance-level trade-offs of WarBreaker technologies and concepts. Such a tool could be used for the conduct of quantitative studies and analyses while also serving the DIS component by helping to filter and define the scenarios and cases of interest for MITL experiments. This need spurred SAIC to design, develop, and employ the JUDY theater surveillance and strike architecture-level simulation model. Since its origin, JUDY has expanded and evolved to become a unique tool within the analysis community, capable of addressing a variety of mission areas.

2 MODEL OVERVIEW

The JUDY model is a Monte Carlo, discrete-event system simulation model of approximately medium fidelity. JUDY's primary focus is on the evaluation of architecture-level performance and CONOPS metrics among the Blue Forces with a mission against the Red forces. The JUDY model is designed as an entity based simulation to assess the performance of small numbers (dozens) of Blue Force surveillance and strike entities against large numbers (thousands) of Red Force threat entities. The Blue surveillance, C4I, and weapon elements are all explicitly modeled as well as the Red threat elements and targets. Functionality within JUDY is modeled at the necessary "performance level" required to evaluate the system and architecture impacts. For output, JUDY collects a wide variety of statistical metrics for evaluating defense performance and effectiveness including sensor utilization, platform utilization, sensor and weapon tasking, weapon expenditures, communications loading, and threat leakage. JUDY is written in FORTRAN 90 and consists of approximately 50,000 lines of code with 400 subroutines. User and technical documentation for JUDY is available (Brouse, Cann, and Kalbaugh 1996).

From the outset, JUDY was designed to be plug and play since alternative architecture and system design was the intended analysis regime. The highest level Blue entity is an element. An element is typed as an aircraft, ground site, aircraft, or satellite. All elements may have sensors, weapons, functions, and communications associated with them. At the extremes, a Blue architecture may consist of a single, centralized, multiple function element or many, distributed, single function elements.

The Red threats are designed to be a single entity but can represent some level of aggregation. The threats move across the terrain in deterministic or random motions. The movement can be on-road or off-road. Fixed ground targets such as bridges, C2 nodes, and IADS sites may also be specified. In addition, Red threats may be defined as aircraft, cruise missiles, or ballistic missiles.

The environment consists of a table top playing surface that can be overlaid with masks to represent cultural data, line-of-sight (LOS) data, road data and weather data. Two modes for LOS can be used: direct DTED computation or a LOS distribution derived from DTED. Road data is provided by Digital Chart of the World (DCW).

These three model segments (elements, threats, environment) comprise the basis of JUDY's modeling features and are described in more detail as follows.

3 BLUE ELEMENT DEFINITION

The element is the basic building block of a surveillance and strike architecture. The element is defined by its component definitions which are the platform type, the procedure (or function) definition, the sensor definition, the weapon definition and the communications definition.

As a platform, an element may be an aircraft, a ground site, or a satellite. Each platform is set to be either active or inactive at the onset of a simulation. In addition, each platform is given a tasking mode. The tasking modes control whether the platform will accept internal or external tasking and whether the platform will change its waypoints to accommodate the tasking and targeting.

The aircraft requires that a home base, takeoff time, flight waypoints and aircraft type be defined. All aircraft will start at the home base, takeoff at a given time, then traverse the waypoints as the simulation progresses. An aircraft's characteristics include speed, rate of turn, endurance, rate of climb, and turn around time. The takeoff time can be randomized to ensure different starting conditions for each replication. When the aircraft has reached the limit of its endurance it will return to base, unless it is currently tasked to perform a strike in which case it will return to base when the strike is complete. The aircraft will also return to base when it has used the last of its weapons.

A fixed ground element will be situated at its location throughout the entire simulation. The satellite element does not move and is geo-stationary over the scenario geography at all times.

The functionality of an element is defined by the procedures it has onboard. Each procedure allows the element to accept certain communications inputs, perform certain functions, and output communications messages to specified destinations. The functions which may be assigned to elements include:

- sense
- process
- detect
- recognition
- correlation
- data fusion
- sensor management
- weapon allocation
- ground target strike
- air target strike
- boost phase intercept strike
- data relay
- fire control radar

All necessary functions to complete an architecture and mission must be mapped to the elements. When using more than one element, the functional flow is defined by prescribing a destination element for each function's outgoing communications messages. An example functional flow for a theater missile defense mission is shown in Figure 1.

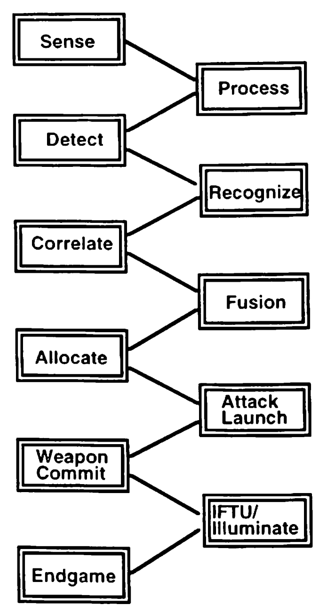

Figure 1: Example TMD Functional Flow

Each function has an inherent time, number of processors, and list of destinations. A function on an element can name its own element as its destination if the next function is onboard the same element.

Each sensor package used onboard an element is described by its sensor characteristics. Each sensor package can have multiple components and each component requires resources to operate. In addition, each sensor package is given a limited number of resources available at any one time. This allows control over the simultaneous operation of multiple sensor components. Sensor characteristics which define sensor operation include field of view constraints (azimuth, elevation, range), resolution, frequency, scan time, beamwidth, minimum detectable velocity, Pd, target location error, and other detailed radar parameters. Sensors which can be modeled in JUDY include MTI, Spot SAR, Strip SAR, ISAR, EO/IR imagery, space-based IR, airborne IR, and air defense surveillance and fire control radars.

Weapons in JUDY can be delivered from ground systems (i.e. SAMs and ATACMS) or air vehicles (i.e. AAMRAM and ground munitions). Weapons delivery is modeled using interceptor flyout fans or a constant velocity. Aircraft delivery systems may be enabled by on-board target acquisition sensor such a forward looking infrared (FLIR). If an aircraft does not immediately acquire the target, the aircraft may perform a search.

Communications within JUDY are point-to-point between elements. The communications capability of an element is defined by its baud rate and the function message sizes. Each element has transmit and receive message queues with maximum message buffer and queue disciplines. Message queues can be either FIFO (First In, First Out) or LIFO (Last In, First Out). Once a transmit or receive buffer limit has been exceeded, messages are lost. . Communications within JUDY may be LOS-constrained or non-LOS constrained

4 RED THREAT DEFINITION

JUDY is capable of modeling a variety of threat target types (ground, air, ballistic). Each threat target type is defined by its motion style, value, LOS type, and terrain following nature. JUDY allows these target motion styles:

- fixed (no motion)
- random motion on roads
- random motion off roads
- TCTs on roads
- TCTs off roads
- deterministic motion off roads
- air breathers (waypoints)
- ballistic missiles (flyout curve)

Target value is used to rank targets during strike allocation. The LOS type specifies whether LOS calculations are done with actual DTED or a statistical interpretation of DTED. Additionally, a target may travel at an absolute altitude or at an altitude above local terrain.

Movement types associated with road networks require additional road input data defined in detail in separate input files. JUDY has been used to model as many as 200,000 individual ground targets moving along a road network.

5 ENVIRONMENT DESCRIPTION

JUDY operates in a geographic environment that includes: terrain elevation, road networks, cultural data such as foliage, and a simplified atmosphere. The terrain elevation can be defined using DTED data or using a cumulative density function (CDF) which is a pre-processed statistical interpretation of minimum grazing angles based on DTED. It is also possible to run JUDY with a bald earth. The road networks are defined by a series of nodes (intersections) and links (connections).

Cultural data consists of a type or code for each grid point in the scenario geographic region. Cultural data codes exist for water, open land, forest or vegetation, and urban areas. In addition to cultural specifications for each grid point, a delimitation flag for each grid point may also be specified to exclude certain region from consideration. The simplified atmosphere includes a fraction or percent of grids affected by weather and an update time for each weather calculation..

6 MODEL OUTPUT

The JUDY model is capable of generating a wide variety of outputs which describe the event history of the simulation. If desired, each key event or activity may be traced throughout the simulation. In addition, JUDY collects and reports a vast array of descriptive statistics which provide measures of effectiveness for architecture performance. The JUDY simulation model generates three primary output files. First, JUDY can record each key event during a replication in a history file. Next, JUDY collects and reports statistics for each Monte Carlo trial or iteration in the replication statistics file. Lastly, JUDY collects and reports statistics over all replications in the grand summary statistics file.

Pertinent output statistics are gathered in all key functional areas such as surveillance, communications, battle management, weapons systems use, and defense effectiveness. The statistics collected include sensor utilization, targets detected and tracked, tasking response time, target revisit rates, target location certainty, area coverage. In addition, the model outputs strike mission effectiveness, targets killed, sorties flown, weapons fired, and threat keepout distance.

7 INTERFACE TO OTHER MODELS

JUDY may be linked through input/output with other associated tools to form an analysis chain suitable for addressing particular theater surveillance and strike issues. RASPUTIN may be employed on the front-end to provide credible threat vehicle deployments and movements. CTEM, which generates optimal strike platform allocations across the target set, may provide a master attack plan for JUDY in order to assess surveillance support to the ATO. JUDY may also be used with a mission planning tool which generates specific pre-planned sensor tasking instructions for associated surveillance assets. In the near future, animation of JUDY model event dynamics will be available.

8 SUPPORTED ANALYSES

The JUDY model was heavily employed as a major analytic component of DARPA's WarBreaker program and it has supported a number of other DARPA surveillance and technology studies. SAIC has used JUDY to explore and evaluate a variety of concepts including off-board targeting, wide area surveillance, and persistent/precision track, boost phase intercept, and integrated theater defense operations. JUDY has also been used to investigate HAE UAV performance issues and candidate CONOPS. JUDY has also been employed, in conjunction with other models, to assess the contribution of HAE in the planning and execution of the ATO process. JUDY has been used to support the Navy Real-time Targeting Study, Joint Precision Strike studies, and various other ADI and CMD analyses. Examples of analyses supported with the JUDY simulation are found in Brouse, Cann, and Kalbaugh (1995).

REFERENCES

Brouse, D. R., W. A. Cann, S. Kalbaugh. May 1996. JUDY Simulation Model User's Reference. SAIC Technical Report, Arlington, Virginia.

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AUTHOR BIOGRAPHIES

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