Quadripartite Advisory Publication

(QAP)

Number 229 Edition 1

COMBAT IDENTIFICATION SYSTEMS – EVALUATION METHODOLOGIES AND MEASURES OF EFFECTIVENESS

DECLARATION OF ACCORD

1. Introduction

The Quadripartite Working Group on Army Operations Research (QWG AOR) established a Special Working Party on Combat Identification (SWP CID) under Terms of Reference dated 5 Dec 95. The authorized task of SWP CID is to "Establish measures of the benefits of standardization in the area of combat identification." The third sub-task was to produce a "Summary of appropriate CID methodologies and MOEs (measures of effectiveness) for assessing benefits of standardization of Combat Identification systems and procedures.." Contained herein are the national inputs for each of the QWG member nations.

2. Scope

The SWP CID determined that the scope of this QAP should be restricted to methodologies and MOE's used to evaluate Army systems affecting both dismounted and mounted troops. Excluded are methodologies and MOE's specifically used to evaluate air-to-air and air-to-ground CID systems. However, the methodologies presented are, in general, applicable to any CID systems.

3. Background Continuity and Related Documents.

Two related QAP's have been produced by the SWP CID. They are QAP 227, providing information on the baseline combat identification systems and operational procedures used by each country (including estimates of performance), and QAP 228, detailing technologies and systems that are currently under consideration or that have been considered and rejected for Combat Identification purposes. In addition, a detailed study plan for evaluating the benefits of ABCA standardization in the area of combat identification is being prepared.

4. Amendment.

The contents of this QAP should be revised as appropriate by contributing Armies, to reflect developments in national practices, and to maintain its currency.

5. Use

The procedures/information contained in this QAP should, whenever possible, be used by Armies to improve the level of standardization on Combat Identification.

May 1999

K. MACMILLAN
COLONEL
DIRECTOR
PRIMARY STANDARDIZATION OFFICE

CONTENTS

ANNEX A

The United States of America

Annex A: United States of America

1. Basic Analysis Tools.

The primary tool used for the analysis of force-on-force operations is the Combined Arms and Support Task Force Evaluation Model (CASTFOREM). Appendix A-1 contains an Executive Summary of CASTFOREM. This document was prepared by the U.S. Army Training and Doctrine Command (TRADOC) Analysis Center (TRAC) - White Sands Missile Range (WSMR), which maintains operational and configuration control of the model. Embedded in CASTFOREM is the ACQUIRE model, described in Appendix A-2. Developed and maintained by the Night Vision and Electronic Sensors Directorate (NVESD) of the U.S. Army Communications and Electronics Command (CECOM), ACQUIRE is used to determine if targets are acquired, and to what level, by specific sensors. Once the target is correctly identified, it is disengaged if it is a friend, and engaged if it is an enemy. If a correct identification cannot be made, the applicable rules of engagement (ROE) are used. With "weapons tight" ROE, unknown targets are not engaged. With "weapons free" ROE, unknown targets are engaged. Figure 1 shows the target acquisition process.

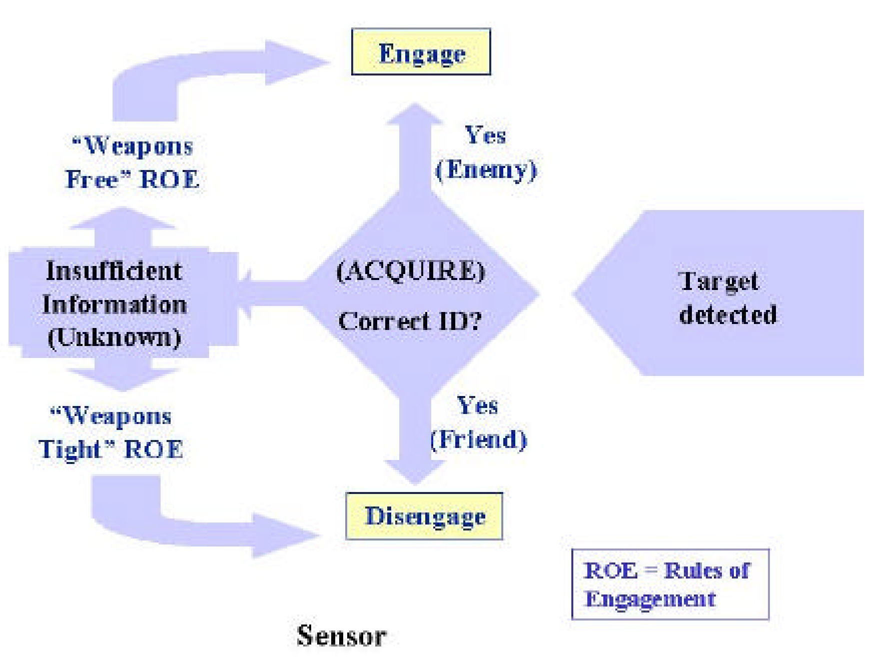

Figure 1. Original CASTFOREM Play of Target Acquisition

2. Combat Identification Analysis Tools.

In order to better represent fratricide opportunities, and to properly evaluate combat identification (CID) technologies, as depicted in Figure 2, changes were made to the play of target acquisition in CASTFOREM for use in the Battlefield ID Analysis of Alternatives (BI AOA).

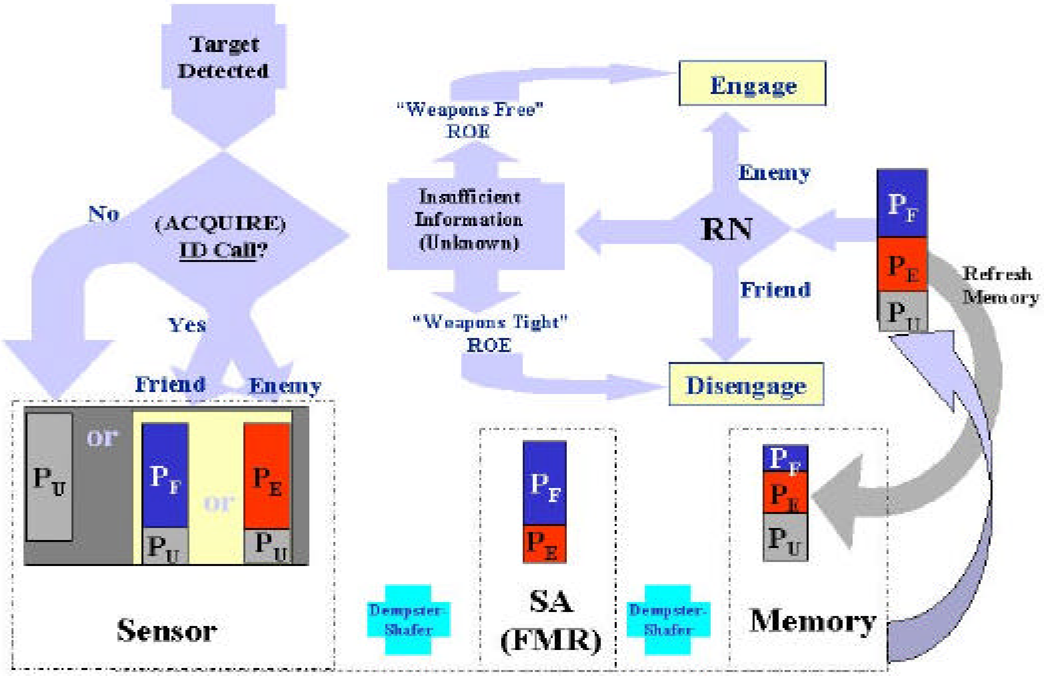

Figure 2. Revised Target Acquisition Process in CASTFOREM

a. Misidentification. Implementation of a set of misidentification (mis-ID) algorithms developed by the U.S. Army Materiel Systems Analysis Activity (AMSAA) enables modeling of crew errors in identification of vehicles. In earlier versions of CASTFOREM, target identification using the sensor would result either in correct ID or unknown target, i.e., a target was never identified incorrectly. With the revised process, if there is enough information for the crew to make an identification call, a simple algorithm is used to determine if that call is correct. If the ID call is not correct, another simple algorithm is used to determine if the force allegiance is correct. AMSAA Technical Report No. 609, provided in Appendix A-3, contains details of the mis-ID study.

b. Information Fusion. The revised target acquisition representation changes the play of sensors and incorporates two additional factors in the decision process. The Appliqué display provides the basis for inclusion of a quantification of the crew's Situational Awareness. The crew's memory of prior decisions regarding each target is the third factor. Each of these factors is represented by a 3-tuple of fractions. Each fraction is in the range (0,1), and each 3-tuple sums to unity. The components of the 3-tuple consist of Probability of Friend, Probability of Enemy and Probability of Friend or Enemy. The third component is actually the probability mass that cannot be assigned to either Friend or Enemy. To simplify the notation, this component will be referred to as the Probability of Unknown. Mathematically, the 3-tuples are combined using the Dempster-Shafer[1] technique.

c. Sensor input. The ACQUIRE model is still used to determine the level to which a target can be acquired; however, the probabilities fed into the Dempster-Shafer calculation are not output values from ACQUIRE. Instead, they are intended to represent the high level of confidence that the crew would have in their identification of the vehicle. Whether the ID call is correct or not, if an identification call can be made, the result is a high probability of Friend (0.95 - with the remaining 0.05 assigned to Unknown), or Enemy (probability assignments of 0.95 to Enemy and 0.05 to Unknown). The revised model results in Unknown with probability of 1.0 if there is not enough information for the crew to make an ID call.

d. Situational Awareness. Quantification of the crew's situational awareness consists of separating the field of regard (FOR) for the platform into as many as four zones. Zone boundaries are defined by an arc through the nearest Enemy target, and radial lines from that arc through the left-most and right-most enemy targets in the FOR. The three FMR fractions consist of (number of Friendly targets/Total targets), (number of Enemy targets/Total targets), and (number of Unknown targets/ Total targets). It must be noted that only targets that appear on the Appliqué display are considered in the calculation of the force-mix ratio (FMR). As depicted in Figure 3, Zones 1, 2, and 4 consist exclusively of friendly targets. Therefore, the described calculations would yield P(Unknown)=0 for these three zones.

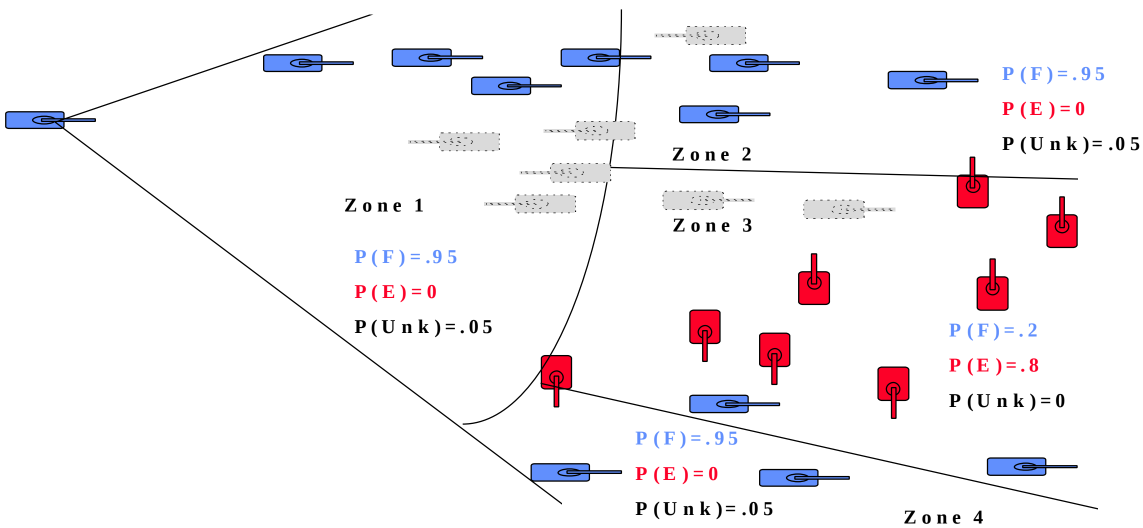

Figure 3. Calculation of Force-Mix Ratio (FMR)

[1] Shafer, G., *A Mathematical Theory of Evidence*, Princeton University Press, Princeton, NJ, 1976

In order to avoid computational difficulties with the Dempster-Shafer algorithms, in these zones the probability of Friend is set to 0.95 (rather than 1.0), and the remaining 0.05 is assigned to P(Unknown). However, Zone 3 will always have P(Unknown)=0, but may have both P(Friend) and P(Enemy) non zero.

d. Memory. The final component of the engagement decision process is the crew's memory of the target. The probability of Friend and probability of Enemy decay exponentially through time, with the "lost" probability mass migrating to the probability of Unknown. Memory is updated with the 3-tuple derived from the fusion of the three input 3-tuples.

3. Limiting the number of Technology Combinations.

In QAP 228, a number of systems and technologies under consideration by the U.S. Army for use as combat ID devices are described. The number of possible combinations of systems at the various levels in the architecture makes it impossible to play all combinations exhaustively in a force-on-force simulation. To reduce the number of combinations to a manageable set, a mathematical programming approach is described in Appendix A-4.

4. Measures of Effectiveness (MOE's)

The following measures of combat effectiveness are derived from CASTFOREM modeling results:

- Loss Exchange Ratio
- Specific Exchange Ratio
- Percent of Total BLUE Losses Due to BLUE Fires (Fratricides)
- Combat Effectiveness Over Time

While MOE's provide a macro-view of the results, the Measures of Performance (MOP's) listed below address fratricide reduction and performance.

- Fratricide Engagements (Potential and Occurrences)
- Fratricide Avoidance
- Successful Target Identification of an Enemy Resulting in an Engagement
- Target Misidentifications Resulting in a Potential Fratricide Engagement
- Target Misidentifications Resulting in No Engagement

Appendix A-1

TRAC-WSMR-TD-94-005

CASTFOREM (Combined Arms and Support Task Force Evaluation Model) Update: Executive Summary

Appendix A-2

ACQUIRE Model Description

US Army CECOM Night Vision and Electronic Sensors Directorate
ACQUIRE Range Performance Model for Target Acquisition Systems

ACQUIRE is an analytical model developed by the Army's Night Vision and Electronic Sensors Directorate that predicts target discrimination and target spot detection range performance for systems that image in the visible, near infrared, and infrared spectral bands. Ranges and probabilities predicted by the model represent the expected performance of an ensemble of trained military observers with respect to an average target having a specified signature and size.

For a target imbedded in a nonuniform or cluttered background, discrimination of characteristics that separate the target from the background is required in order to perform detection. Similarly, discrimination of target characteristics and features is required in order to perform recognition and identification tasks among classes and types of targets. Target discrimination range predictions are made using a two-dimensional formulation of the Johnson cycle criteria methodology.

Target discrimination is usually divided into three levels: (1) detection - determination that a target of potential military interest is present within the sensor field-of-view; (2) recognition - discrimination between specific objects within a class of similar objects (truck, tank, APC, etc.); (3) identification - discrimination between specific targets (T72, M1, HMMWV, etc.). The probability of detecting, recognizing, and identifying a target is a function of the number of equivalent cycles resolved on the target by the sensor. For a target at a given range and apparent signature, the number of cycles resolved is determined by either Minimum Resolvable Temperature Difference (MRTD) or Minimum Resolvable Contrast (MRC)

For a target against a uniform background, detection may occur when the signal-to-noise ratio (SNR) on the display element that subtends the target exceeds the SNR of the background. The only requirement is that sufficient target energy impinge on a detector element to create a "hot spot" on the system display. Spot detection is also referred to as "star" detection. In some cases, application of the spot detection methodology to strongly cued targets in nonuniform application of the spot detection methodology to strongly cued targets in nonuniform backgrounds may be appropriate. The spot detection methodology applied in is equivalent to that used in the 1975 NVL Static Performance Model. Target spot detection range is calculated using either Minimum Detectable Temperature Difference (MDTD) or Minimum Detectable Contrast (MDC) and threshold signal-to-noise ratio.

Distribution

ACQUIRE is available by written request to NVESD. Foreign requests must be submitted through official channels. Direct inquiries to:

Director, NVESD
ATTN: AMSEL-RD-NV-SSAD
10221 Burbeck Rd., Suite 430
Ft. Belvoir, VA 22060-5806

Appendix A-3

AMSAA Technical Report No. 609

A Target Misidentification (Mis-ID) Methodology

Appendix A-4

Battlefield Identification Architecture Ranking Methodology

BI Architecture Ranking Methodology

Introduction

One of the complicating factors of this Analysis of Alternatives is the unwieldy number of alternatives. With such a large number of candidate systems, the possible combinations of systems that could be used to provide an integrated solution is very large (much too large to permit force-on-force modeling of every possible alternative). The purpose of this approach, therefore, is to define a manageable set of the most promising integrated Combat Identification Architectures, on which cost/performance analysis can be performed. This section describes the methodology that was used by AMSAA to do the paring of all possible Architectures to a manageable list.

Terminology

The following terminology is used in describing the methodology.

Term	Definition
Architecture	**A combination of specific Systems, one assigned to each Link, to provide an integrated combat ID solution.**
Dominated Architecture	**An Architecture whose Cost, Performance, and Risk ratings are all worse than at least one other Architecture.**
Link	**A specific shooter-target pairing. For example, helicopter-to-vehicle.**
System	**A device given to all shooter and target platforms on a given Link for the purpose of increasing combat identification capabilities on that Link beyond those capabilities provided by the Baseline.**
Shooter Device	**The device given to shooter platforms when a given System is applied to a given Link. For example, in an interrogation and reply system this is the interrogator. For some systems, there may be no difference between Shooter and Target Devices.**
Target Device	**The device given to target (non-shooting) platforms when a given System is applied to a given Link. For example, in an interrogation and reply system this is the responder. For some systems, there may be no difference between Shooter and Target Devices.**

Table A-4.1 - Definitions of Terms

Methodology

The following outlines the steps taken by AMSAA in determining the data that will be used in the non-linear program, running the program, and providing the results to TRAC.

1. Define Systems and Links for Study.
2. Develop Matrix of which Systems are feasible for use on each Link.
3. Provide System list and necessary item-level performance data to TRAC for force-on-force modeling of each System.
4. Develop performance estimates for each System/Link pair from the force effectiveness and fratricide rate results provided by the force-on-force modeling.
5. Develop 20-year Life Cycle Cost estimates, as a function of the number of Shooter and Target devices acquired, for each System.
6. Perform technical and schedule risk assessments on each system.
7. Run non-linear program to identify initial feasible (those not dominated) Architecture set.
8. Examine non-dominated Architecture set for Architectures that are infeasible for reasons other than performance, cost, and risk. For example, an Architecture that requires 5 more emitters be added to any given platform should be considered infeasible.
9. Provide final Architecture list and the associated Life Cycle costs to TRAC for cost/performance trade-off analyses.

Performance Shortfall Parameter Estimation

The performance shortfall of each System was estimated in terms of the changes in force effectiveness and fratricide rates, from the digitization baseline results, observed in the force-on-force modeling for that System (see the main body of the report for details on the CASTFOREM runs). If the force effectiveness was reduced by adding a specific System to the digitized baseline, then that System was penalized in the performance objective function, proportional to the drop in force effectiveness. If the force effectiveness was not reduced by adding the System, then the System was rewarded in the performance objective function based on the change in force effectiveness. The System was further rewarded or penalized based on a corresponding reduction or increase in the fratricide rate seen on each Link on which the System is used. Note that for architectures that reduce fratricide and contribute to an increase in the number of Red vehicles killed, this measure will be a negative number. Performance Shortfall, rather than performance, is measured in order to allow the non-linear program to minimize all the objective functions.

20 Year Life Cycle Cost Estimates

20 Year Life Cycle Cost estimates were developed for each System as a function of the number of shooter and target devices bought. The cost functions account for fixed and variable components of the Life Cycle Costs so that economies of scale are exploited in the analysis when considering the purchase of the same System for more than one Link.

Risk Assessments

System risk was assessed according to the standard risk assessment methodology used by AMSAA. Figure E.1 shows the matrix used to support technical risk assessment.

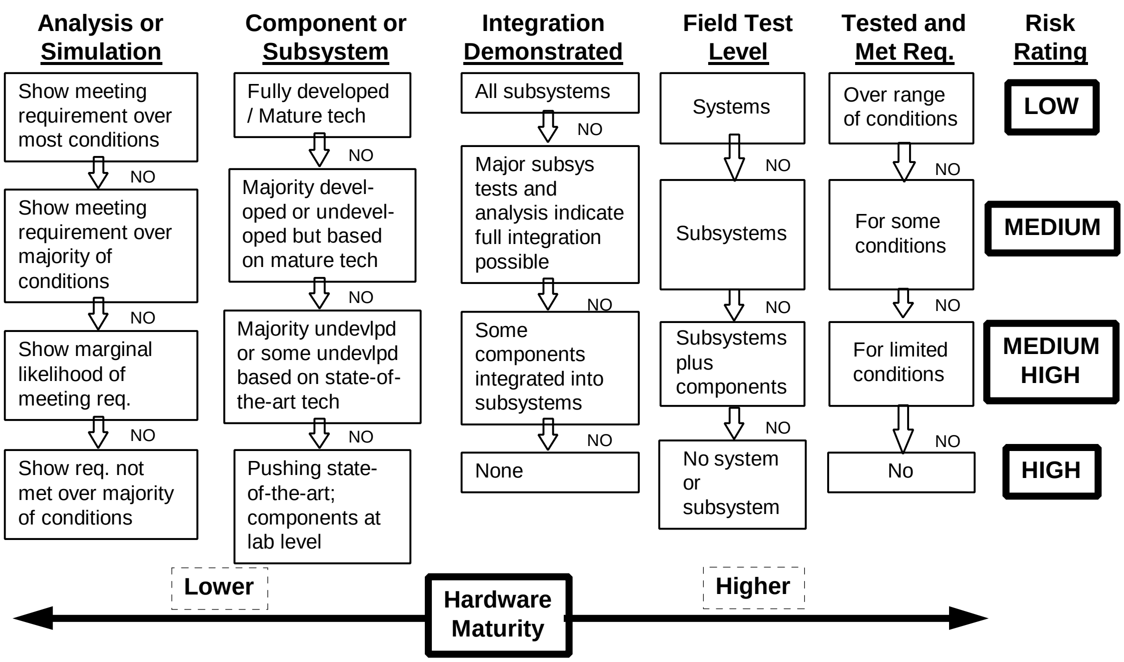

Figure A - 4.1 - Risk Assessment Guidelines

Non-linear Program Description

AMSAA designed and coded a computer program to use a multiple-criteria, non-linear programming approach to determine the most promising Architectures. This approach uses multiple objective functions, based on the Cost, Performance Shortfall, and Risks associated with each Architecture. The goal is to produce a manageable list of Architectures (6 to 10) on which cost/performance trade-off analyses can be performed. The approach determines the objective function values for each possible Architecture in turn. A list of Architectures whose objective vector is not dominated by that of another Architecture is maintained. As each new vector is computed, it will be compared to the existing list of non-dominated Architectures. If the new vector is itself dominated by one on the list, the new Architecture is eliminated from further consideration. If the new Architecture dominates any already on the list, then it will replace the dominated Architectures on the list. If the new Architecture is neither dominated nor dominating, it will be added to the list. This process will continue until all Architectures have been examined.

The list remaining after this program has been run was then examined for further elimination of Architectures that are infeasible for reasons other than Cost, Performance, and Risk.

Objective Functions

The objective functions for the non-linear program are Cost, Performance Shortfall, and Risk. The function values for a particular Architecture were computed by summing the function values for the individual devices (Interrogators and Responders) included in that Architecture.

The Cost objective function for Device *i* has the following form:

$$C_i = \left(\frac{A}{B+1} N_i^{B+1} + CN_i + D \right) X_i$$

where, A is the first unit cost of Device *i*
B is the learning curve factor for Device *i* (which causes the per unit cost to drop as the number of units purchased increases)
C is the per unit Personnel, Operations and Maintenance cost for Device *i*
D is the fixed cost for Device *i*
N_i is the number of Devices of type *i* used in the Architecture
X_i is a Binary variable, set to one if Device *i* is in the Architecture zero otherwise

and where the number of devices required is determined by which links the system has been selected for in a given Architecture.

The Performance Shortfall objective function for System *i* has the following form. Note that this measure DECREASES as the System increases force effectiveness and decreases fratricide.

$$P_i = \left[\sum_{j=1}^{7} \left(F_{ij} + f_{ij} \right) X_{ij} \right]$$

where, P_i is The performance shortfall in the Architecture due to System *i*.
F_{ij} is Force effectiveness change for System *i* on Link *j* (see figure E.2 for description of Links). This is measured as the decrease in the number of Red platforms killed from the Baseline runs, plus the increase in the number of Blue platforms killed from the Baseline runs.

f_{ij} is Change in fratricide for System *i* on Link *j*. This is measured as the number of Blue on Blue kills in the System *i* runs on Link *j* minus the number of Blue on Blue kills in the baseline runs.

X_i is a Binary variable, set to one if System *i* is in the Architecture zero otherwise

The Risk objective function for System *i* has the following form:

$$R_i = r_i X_i$$

where, R_i is Risk associated with System *i*

r_i is Risk rating for System *i*, assigned integer values of zero for low risk, one for medium risk, two for medium/high risk, and three for high risk.

X_i is a Binary variable, set to one if System *i* is in the Architecture zero otherwise

Total Architecture Risk is computed by summing the technical and schedule risks for the systems assigned to each of the seven Links.

ANNEX B

United Kingdom

Annex B: United Kingdom

At Appendix B-1 is a paper containing a description of the Assessment Tool for LAnd Systems (ATLAS) model. ATLAS is a force-on-force constructive simulation that is the primary tool used for operational analysis.

Appendix B-1

Assessment Tool for LAnd Systems (ATLAS)

ATLAS Description

Introduction

The purpose of this report is to provide information on the verification and validation status of the Assessment Tool for LAnd Systems (ATLAS).

Model name and overview description

ATLAS is a stochastic, event-sequenced, all-arms tactical battlefield simulation. Individual vehicles and small groups of dismounted troops are represented, and the battle is played out on a digitised terrain. The primary purpose of ATLAS is the study of systems effectiveness; typically, this will involve a comparison of the effectiveness of contender weapon systems within a simulated all-arms battlegroup.

Software/model custodian/points of contact

Software Model Custodian:
CDA (Land), DERA Fort Halstead e-mail: cda_land@dera.gov.uk

Model management authority and intellectual property rights

IPR on ATLAS is wholly owned by DERA and model management authority is vested in the Wargame and Simulation Centre (WSC).

Position within the wider model hierarchy

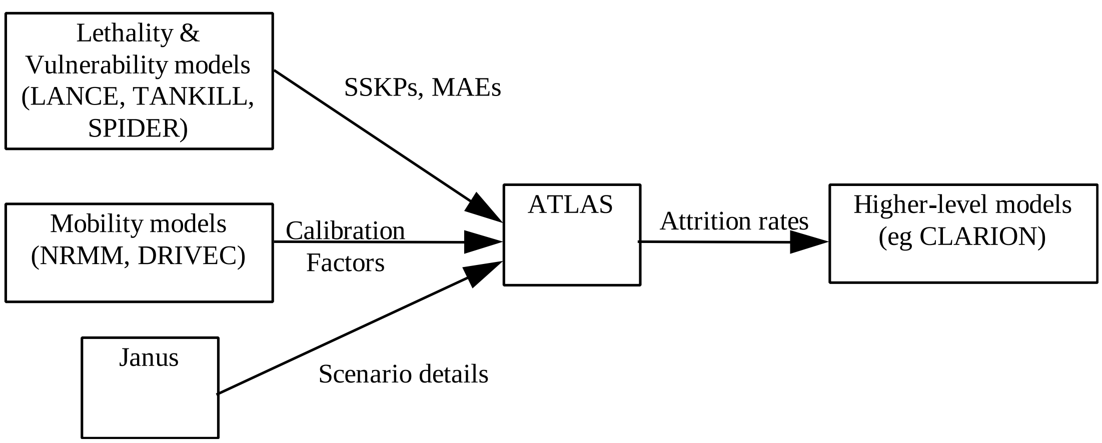

Figure 1: Position within the wider model hierarchy

Some of the key functions of ATLAS are performed by independently validated sub-models. These are:

The Night Vision and Electro-Optical Laboratory (NVEOL) model of detection and target acquisition (part of the NATO standard EOSAEL suite).
The vehicle mobility model, GOGO97, was developed specifically for ATLAS by the CDA(Land) mobility team at Chertsey. GOGO97 includes calibration parameters to match the speeds and acceleration profiles to the outputs of NRMM (NATO Reference Mobility Model) and DRIVEC.

ATLAS requires data from a number of models. These include:

Lethality and vulnerability data: SSKPs from TANKILL and Lance (used for direct fire systems and indirect fire bomblet and APGM), Mean Areas of Effect (MAEs) from Spider for fragmenting rounds.
Scenario data (ORBATs, routes and orders) are normally derived by analysis of Janus (BGWG) games.

ATLAS outputs have been used to provide attrition rates for higher-level models (e.g. CLARION).

Intended domain of use

ATLAS is an entity-level battlegroup model, concentrating on the direct fire battle in an all-arms context. Initially intended to represent the armoured vehicle battle, it has now been extended to provide a reasonable representation of dismounted troops.

Hardware requirements

Minimum configuration is a VAX processor and X-Windows terminal. This may be a single VAX workstation, or a separate VAX server and X terminal. Recommended configuration is a single Alpha workstation for data input, scenario development and graphical replay. Multiple Alpha processors are recommended for fast turn-round of study production runs.

Running the simulation requires considerable amounts of virtual memory - existing study accounts are typically allocated a quota in the region of 400MB.

Software requirements

Production:

OpenVMS version 6.2 operating system (VAX or Alpha)
Motif version 1.2

It is likely that a study will also require access to a development suite (see below) for support and debugging.

Development: As production, plus:

DEC Ada (including Professional Development Option) 3.2-12
DEC Code Management System (CMS) version 3.5 (VAX) or 3.8 (Alpha)
DEC Source Code Analyser (SCA) version 4.0
ICS Builder eXcessory (BX) version 3.5.1

History of development

Development of ATLAS was begun during 1989, although much of the initial specification was done before this date. ATLAS was intended as a replacement for WEBS (Weapons Effectiveness Battle Simulation). To span the gap while ATLAS was developed, EDECSIM was developed from DECSIM.

Study funded by QWG AOR SWP/MOTA (Special Working Party on Modelling Of Target Acquisition) to investigate alternative methods for representing STA within battle models. The study attempted to answer the question “does a more correct representation of STA make a measurable difference to battle outcome, and would it have an impact on the conclusions of a systems comparison study”. Version: Pre-release

Ease of use

All data input to ATLAS is via ATLAS Data Input System (ADIS), which uses Motif forms for all data entry and editing. ADIS includes a number of other features to improve ease of use, such as context-sensitive help and database commit/rollback.

ADIS supports a concept known as data layers, which allows the data for a run to be split into several files, known as "base" and "variant" files. These files can be loaded separately, with data present in the later layers occluding similar data in earlier layers. Typically, a study will use a single base layer, consisting of the standard systems performance data, one or more scenario variant files (one per scenario to be considered in the study), and several additional system performance variant files for the various study cases. A complete data set would consist of the base layer, a scenario layer, and a performance variant redefining some features of a study system. The use of data layers considerably simplifies the process of data management for a study.

Basic levels of expertise with ADIS can be gained in a few days, although understanding the effects of data changes within the simulation requires a much more detailed knowledge of the internal structure of the model.

ATLAS scenarios are usually derived from Janus wargames (see figure 1). The process of scenario transfer is both complex and time-consuming, and a fair degree of expertise is required to do this effectively. Some consideration has been given to providing some automated assistance, but the available outputs from Janus would make developing such a tool a difficult task.

Model code management systems

ATLAS makes extensive use of the Code Management System (CMS) product from DEC, which provides traceability of all changes to any element. All configuration items (specification, design documents, program code) are stored within CMS.

Requirements specification: The main requirement document is the Software Requirement Specification (SRS - ref. 1), which is held under CMS control. Only SMC can authorise changes to the SRS. The SRS is augmented by specifications for new models during their development.

Design documents: ATLAS is designed using the Jackson System Development (JSD) method. The JSD Entity Structure Diagrams (ESDs) and operations text documents are held under CMS control. Only the SMC or the development team leader can authorise changes to these documents.

Test plan and sensitivity analysis: The only test plan documentation currently extant is the Verification Cross-Reference Index (VCRI). This area probably requires additional formality, with more detailed records of test carried out and the results. No sensitivity analyses have been carried out other than those normally associated with studies.

User Guide: There is currently no ATLAS User Guide. In 1997, work began on producing a User Guide to ADIS, the ATLAS Data Input System, but currently this is little more than a description of the various forms and what data is found on each form.

Technical guide: A Technical Guide to ADIS exists (refs. 2-5), held within CMS. No Technical Guide to ATLAS exists as yet 19. ATLAS is developed in accordance with EASAMS configuration management system (which is ISO 9001 compliant).

In general, changes to any part of the system are requested by the raising of a standard DERA BMS Preventative and Corrective Action Note (PCAN). These are held on file by SMC; duplicates are handed to the team leader for action. Once the PCAN has been completed and tested, the PCAN register is updated to indicate the new status.

Where a major development is in required, a simple PCAN of the form “Changes to implement <document reference>“ is produced.

All specification changes must be authorised by SMC; minor bug fixes do not require such authorisation, unless they are believed to have impact on other parts of the model. In the latter case, a PCAN is raised.

Data

Data input

As described in paragraph 15, all input to ATLAS is via ADIS. There are a total of approximately 100 forms, covering:

systems performance;
scenario;
environment;
model control.

Systems performance data describe platform (vehicle or fire team) and component (weapons, ammunition, sensors, DAS, etc) capabilities. It includes the physical dimensions, automotive performance and signature of the platform, lethality of ammunitions against platforms, load times, ammunition stowage, etc. Data sources include other parts of CDA and DERA.

Scenario data includes the ORBAT and the terrain, routes and orders for each group of vehicles, together with artillery missions and their triggers, location of minefields, etc.

The environment forms define the meteorological visibility, wind speed and direction, etc.

Model control forms provide information that is essential to the running of the simulation, but do not represent any physical reality. For example, the effect of drifting smoke screens on Line of Sight is recomputed using a regular poll; the frequency of this poll is part of the control information.

The use of data layers (paragraph 14) enables the data set to be split into files of more manageable proportions. It also allows the use of common systems performance and model control data with different scenario and environment data (so changes to systems performance data need not be carried out for different scenarios).

Data output

There are only two output files from the simulation, one of which is used only for debugging and simulation monitoring. For most users, the only output file of any importance is the simulation log file. This log file is a record of every action (change of model state) that occurred in the run (although mechanisms exist to filter the actions that are sent to the log file to reduce its size to manageable proportions).

The simulation log file is used to drive the analysis tools, of which there are currently two:

Post Simulation Graphics (PSG) provides a graphical replay of a single replication. This is extensively used during scenario development to ensure that vehicle are behaving in a sensible fashion.
Post Simulation Analysis (PSA) is the primary numerical analysis tool. A number of different tables can be generated, including:
Coroner's table – a list of every shot that occurred, giving time, range, firer and target types, and the result of the shot.
Killer/Victim tables
Shots and Kills by range
Detections and identifications by range
Total losses

Utilities

A number of utilities exist to aid data preparation. These include TERRGEN, which translates a Janus (BGWG) format terrain file into an ATLAS format file, and AEFGEN which is used to import SSKP tables from simple text files into ADIS.

Analysis methods: assumptions and limitations

The key assumptions and major limitations of ATLAS are:

ATLAS is primarily intended to represent the armour/anti-armour battle; as such, the representation of dismounted troops is limited in some respects.
Only high-intensity conflicts can be represented; ATLAS models only two sides, and rules of engagement (RoEs) are somewhat simplistic. The more complex situations that are typical of Operations Other Than War (OOTW) are currently beyond the capability of the model.
No explicit representation of fatigue, morale or nationality factors. Some elements of these human factors could be represented by appropriate data changes.
Scenarios are (generally) taken from Janus or a similar source. The internal tactical decision-making is simplistic; hence, if the simulation deviates too far from the source of the scenario, the results are likely to be unrealistic.

Size of the battle: ATLAS is intended to play up to battlegroup level actions. There is no absolute limit on the number of pieces playable: the limit is that imposed by available memory and performance considerations. In practice, the largest battle yet played has had approximately 250 pieces (vehicles and fire teams) spread between the two sides.

Terrain: A raster terrain representation is used, with ADIS using the MILGRID co-ordinate system. The terrain resolution is flexible, but 100m is the norm. Spot heights are required at the corners of the grid, with culture type, culture height and cone index (a measure of soil shear strength, and hence rolling resistance) specified for each cell. LoS is computed on the basis that culture is completely opaque, except in the special case of the grid squares containing the observer and target. The terrain is may either be generated from a variant of the Masterpiece program from DFAD/DTED data, or a Janus(BGWG) terrain file can be converted to the ATLAS format. The latter is the preferred option, as the DFAD source data is frequently missing small areas of vegetation and urbanisation, which can be corrected with the Janus terrain editing package.

Weather: Weather is limited to wind speed and direction, and those factors directly used by the NVEOL STA model - humidity, meteorological visibility, sky:ground contrast ratio, etc. Implementation of the night model is due for completion early in FY98/99.

Artillery: Indirect fire is represented, and may be either completely pre-scripted, or “Target Of Opportunity” (TOO). The latter allows missions to be generated automatically using information passed from designated observers (e.g. Forward Observation Officers, Recce units, etc) to the Fire Support Co-ordination Centre (FSCC). Although TOO missions have been generated during testing, such fire has not been used for a study; should it be intended to do so, careful scrutiny of the generated missions will be necessary to assess their validity.

Minefields: ATLAS includes a representation of minefields, including automated vehicle responses to minefields when encountered. Considerable flexibility is available in mine fusing. An assessment of the minefield model has been carried out by OA staff with specialist knowledge of engineering, which has identified a number of enhancements that would be required before the model can be used for studies where mines or minefield counter-measures could be used as a study system. It should be noted that anti-personnel mines cannot be represented at this time.

Helicopters/fixed wing: There is a very crude representation of helicopters; it is likely that ATLAS would require enhancement in this area before it could be used for a study that required a detailed representation of attack helicopters. There is no representation of fixed wing aircraft.

S&TA: ATLAS represents individual sensors and observers, and explicitly tracks the field of view of sensors whenever they are being used. Target contrast may either be represented as a constant, or may be computed by comparison of the target and background values. The use of an explicit field of view and computed contrast was the result of a study into the best representation of S&TA carried out under the auspices of SWP/MOTA (paragraph 17). There is also a representation of cueing devices – unmanned sensors that are used to direct observers to possible targets.

Command, control and communications: The only areas of C3I represented in ATLAS are:

Minefield knowledge: When a group realises it is in a previously unknown minefield (a mine detonates or a mine is detected prior to detonation), this knowledge is passed to other formations. There are communications delays built in to this passage of information.
Artillery: Any battlefield entity can be designated as an observer for the Fire Support Co-ordinate Centre (FSCC). When such an entity wishes to report new targets to the FSCC (or report changes of state of existing targets), a communications delay is built in. The FSCC itself analyses such reports, using a simple data fusion process, to generate possible artillery shoots (see paragraph 49 above). There is a further communications delay between the FSCC and any batteries under its control.

Tactics: All routes and orders are prescripted. However, it is possible to include decision nodes on routes, where groups are allowed to change their order stream and/or their route according to a number of battlefield conditions.

Progress of the battle: ATLAS is event sequenced, although certain continuous activities (such as observation) are processed by scheduling regular poll events.

Logistics: There is no representation of logistics, beyond maintaining a list of available ammunition types and quantities for each battle element and battery.

Nationality: There is no explicit representation of nationality factors.

Verification

The Software Requirements Specification (SPS) is a regarded as a configuration item in the ATLAS configuration control system, and any changes to the specification must be authorised by SMC.

The VCRI (an annex to the SRS) defines a list of all requirement statements within the SRS, and includes a datestamp of when the test was performed with references to any test data and results. In practice, many of the tests are performed using the DEC debugger, which means that results of tests cannot be recorded.

The current SRS is now out of date with respect to three models (revised minefields model, a new infantry model, and battlefield engineering).

Study pressure has led to a state where the SRS (and hence the VCRI) is now significantly out-of-date. It is intended that the SRS will be brought up to date during FY98/99.

Model validation

Validation by review

All model specifications have been reviewed by scientific staff. However, much of this work was carried out before the conversion to agency status and the adoption of proper QA procedures, and hence this information has not been properly recorded. Review records exist since 1995.

Models developed recently have also been reviewed by military staff.

Validation by comparison with other models

Some work has been done to compare the results of ATLAS with those obtained in the base Janus game and EDECSIM. This work was complicated by the fact that the subset of Janus elements modelled in ATLAS was different to the subset modelled in EDECSIM (the EDECSIM and ATLAS versions of the scenario were transferred for different studies, and hence for a different purpose). After allowance had been made for this, the comparison showed that the ATLAS results fell between those for Janus (fewer shots and kills than ATLAS) and EDECSIM (more shots and kills than ATLAS).

The ATLAS mobility model, GOGO97, includes calibration parameters to ensure that vehicle acceleration profiles are a close match to those generated by DRIVEC and NRMM.

Validation based on real events

Some work was carried out during Feb/Mar 1996 to represent Medenine (German tank assault against British anti-tank guns, Tunisia, 1943). However, due to lack of resources, this work was not completed. A number of problems were discovered in ATLAS, but as the work was carried out with a development version of the model this is not regarded as cause for concern.

A scenario to represent Hill 112 (part of Operation Epsom, Normandy, 1944) has been developed as part of a Corporate Research project into the passage of time within simulations. Although not specifically intended as historical validation, this study addressed many related issues. It showed that battles ran much faster in ATLAS than in reality (overall, about three time real speed). However, the casualties suffered were in line with predictions from historical research (D Rowland’s equations for attacker casualties per defender). Further work is necessary to identify mechanisms in ATLAS that can be employed to slow the battle to more realistic rates.

The ATLAS S&TA model uses the NVEOL algorithms which are based on laboratory experimentation, and have been successfully tested with trials.

Data validation

No attempt has been made to validate the data “globally” for ATLAS. The standard systems performance database is used in most studies, with additional study-specific data generated from sources agreed with the customer. It should be noted that ADIS carries out a wide range of data verification tests, which significantly reduces the number of data errors.

Model internal parameters

There are very few hard-coded parameters built-in to ATLAS. Those that do exist are:

Factors involved in the computation of rolling resistance during mobility computation. The current factors were provided by the CDA(Land) mobility team at Chertsey.
Speed degradation factors required to convert from the speed computed by the mobility model and the actual achievable tactical speed (taking micro-terrain into account). The current factors were provided by CDA(Land) at Chertsey.
Conversion of meteorological visibility (optical waveband) to the equivalent value for thermal waveband. This conversion is part of the NVEOL model, and as such is part of the NATO-standard EOSAEL suite of programs.
Target selection algorithm. The target selection algorithm in ATLAS takes a number of factors into consideration, including target priority (user specified), the time taken to lay onto the target, the threat posed by the target and the SSKP of the firer against the target. This computation includes a number of weighting factors that are not user-configurable. The current values were generated at the same time as the basic algorithm, and are chosen to match the results from a survey of military opinion.

Systems performance data

In general, scenarios for ATLAS derive from Janus scenarios, and this is reflected in the systems performance data - where possible, ATLAS uses the Janus data tables directly, or a simple derivation of them. Where additional data are required (e.g. where variant platforms are played) an appropriate technical source (such as TANKILL) is used. All data used are recorded in a dedicated data file for the study.

The base systems performance library has been extensively checked by inspection over several studies. Study-specific data is checked by inspection after data entry.

Scenario data

After the initial scenario transfer (e.g. from Janus) is complete, a single replication of ATLAS is performed, and demonstrated to military staff (often the players of the source Janus game). Any comments they may have concerning timings, etc are taken into account and the scenario data modified accordingly. This iterative approach continues until the military staff are satisfied that ATLAS is satisfactorily representing the Janus game.

Overall assessment

The core functionality of the model (armoured warfare between vehicles in an all-arms environment) is assessed to be sound overall, so long as the systems being assessed do not require a major change to the tactics used in the source game. The representation of dismounted troops is known to be less robust than is desirable (causing the simulation to fail) although this is improving with time. Some potentially important functionality is missing (for example, dismounted troops are completely immune to minefields), and such areas will need to be addressed as and when a study demands it.

Some elements of the systems performance library are legacy data, inherited from the Janus database and with little or no traceability beyond this point; and a number of data errors have been identified during the inspection process. However, the data are now internally consistent.

Some types of sensor are represented extremely poorly (i.e. radar and acoustic). It is hoped to address the radar modelling during FY 1998/99.

Fitness for purpose

Purpose

The purpose of ATLAS is to act as a tool to allow the comparison of battlegroup assets (primarily, but not exclusively, direct fire) in a high-intensity environment. Although it was initially intended for mounted armoured warfare, recent developments have extended its capability to include dismounted troops (and further development of troops on foot is ongoing).

It should be noted that the purpose of ATLAS is not the development of doctrine, as there is no human interaction after the simulation starts. Once military staff have explored and developed the doctrine (for example, with Janus), the doctrine can then be implemented in ATLAS.

Fitness

Due to the complexity of the all-arms battle, it cannot be claimed that ATLAS is a fit or appropriate tool for any and all direct fire purposes, or even for all battlegroup-level scenarios. The fitness (or otherwise) of ATLAS can only be assessed on a study-by-study basis. The assessment of fitness is a judgmental one, and takes into account the aims of the study, the likely MoEs, and the technological novelty of the systems in play. It is common for the result of the assessment to be provisional - that ATLAS would need a specified list of changes before ATLAS can be deemed appropriate for the study.

In general, however, ATLAS can be regarded as a logical first port of call for studies requiring high-intensity battlegroup level simulation. The specification has been reviewed by appropriate technically competent authorities; the design has been reviewed against the specification; and the VCRI is used to record test results against the specification. What historical work has been done (Hill 112) indicates that the results of ATLAS are broadly in line with the real world (although, as is common, the simulated battle runs faster than reality).

This statement of fitness for purpose is subject to the following constraints, however:

In its current form ATLAS cannot be regarded as an appropriate tool for most OOTW scenarios; ATLAS cannot represent multi-sided conflict, nor can it handle the complex ROE that are typical of such tasks as peacekeeping, peacemaking, or counter-insurgency.

ATLAS is exclusively a rural model: the considerable complexities that are introduced by urban conflicts are currently beyond its capabilities. It may be that the changes required to allow ATLAS to handle urban conflicts are so extensive that it would be cheaper and easier to develop an urban model from scratch.

Proposals for future verification and validation

Some work has been carried out to compare ATLAS with the battle of Medenine (Tunisia, WWII), but this was never completed due to pressure of time. This work on Medenine should be completed; this would require a fairly modest outlay, as much of the work has already been done.

As both the existing historical scenarios (Medenine and Hill 112 – Op Epsom) are WWII, it would be sensible to consider a scenario based on a more modern conflict, perhaps from the Arab/Israeli wars. It is understood that CDA (HLS), has detailed information of a number of battles from this conflict, and may be able to advise on an appropriate scenario.

It is also expected that ATLAS will be the subject for a later phase of validation carried out under the umbrella of the model validation project currently being funded by DG(S&A).

There are some areas of input data which do not have reliable origins. These data fall into two categories:

Legacy data: Some systems performance data have been inherited from Janus and has poor traceability beyond this point. Some effort should be invested to identify which data fall into this category and to go back to the original source (often TANKILL or LANCE). Where possible, more up-to-date figures should be obtained.

Operational data: Some elements of the ATLAS data relate to the operational use of systems, rather than their technical capabilities, and such data may be suspect. For example, although the sensor performance data has a reputable source, the sensor usage rules (which specify how the crew use the sensors) do not have such a reputable source. These operational areas should be identified, and better sources found. If no better sources are available, a set of ATLAS runs could be performed to identify optimal operational use.

Glossary

Ada	Programming language
ADIS	ATLAS Data Input System
AH	Attack helicopter
Alpha	High-performance computer manufactured by DEC (the replacement for VAX computers)
ATLAS	Assessment Tool for LAnd Systems
BGWG	Battle Group War Game
C3I	Command, Control, Communication and Intelligence
CDA	Centre for Defence Analysis
CMS	Code Management System
COEIA	Combined Operational Effectiveness and Investment Appraisal
CR2	Challenger 2 Main Battle Tank
DAS	Defensive Aid Suite
DEC	Digital Equipment Corporation
DERA	Defence Evaluation and Research Agency
DFAD	Digital Feature Analysis Data (terrain file format providing culture data)
DG (S&A)	Director General(Scrutiny and Analysis)
DTED	Digital Terrain Elevation Data (terrain file format providing spot heights)
EM	Electro-Magnetic
EOSAEL	Electro-Optical Systems and Atmospheric Effects Library – NATO standard algorithms for S&TA
FET	Future Engineer Tank
FSCC	Fire Support Co-ordination Centre
FY	Financial Year
GUI	Graphical User Interface
HE	High Explosive
Janus	Computer wargame, originating from US and developed by UK
IPR	Intellectual Property Rights
LANCE	CDA(Land) vulnerability model
LoS	Line of Sight
MAE	Mean Area of Effect
Mb	Megabyte
MILGRID	Map co-ordinate system in use by the British Army
MLI	Mid-Life Improvement
MMI	Man-Machine Interface
MQ	Master Question
NATO	North Atlantic Treaty Organisation
NVEOL	Night Vision and Electro-Optical Laboratory
OOTW	Operations Other Than War
Op Epsom	UK operation in WWII – Normandy, 1944
ORBAT	ORder of BATtle
PCAN	Preventive and Corrective Action Notice
PSA	Post Simulation Analysis – ATLAS statistics package
PSG	Post Simulation Graphics – ATLAS graphics replay utility
QWG AOR	Quadripartite Working Group, Army Operational Research
RoE	Rules of Engagement
S&TA	Surveillance and Target Acquisition
SMC	Software/Model Custodian
Spider	Indirect fire lethality model
SRS	Software Requirement Specification
SSKP	Single Shot Kill Probability
SWP/MOTA	Special Working Party on the Modelling Of Target Acquisition – international operational analysis working party.
TANKILL	CDA(Land) vulnerability model
TL	Technical Leader
TM	Technical Manager

TOO	Target Of Opportunity
VAX	Virtual Address eXtension – type of computer manufactured by DEC
VCRI	Verification Cross-Reference Index
VMS	Virtual Memory System
WSC	Wargame and Simulation Centre

10 February 1999

ANNEX C

Canada

Annex C: Canada

Close Action Environment (CAEN) is a combined wargame and simulation which represents the close combat battle. It represents close combat up to company strength. Current enhancements have made it multi-screen and multi-sided. Some possibility exists for fratricide. See Appendix D-2 for a description of CAEN.

Although CAEN has not been used yet to study combat ID, the multi-screen capability and future enhancements in the way the icons are to be displayed on the screen provide the potential for using CAEN to look at issues related to combat ID at a low level, considering only dismounted infantry and vehicles. Currently, at a predefined point in the detection/recognition/identification process, enemy icons appear on the screen as blue or red icons. Future enhancements will show a grey blob when an object is detected, a grey vehicle or man when recognition occurs, and a red or blue icon when identification occurs.

There is some possibility that Canada will use CAEN for some work on combat ID.

ANNEX D

Australia

Annex D: Australia

1.0 Introduction

Australia has a number of models including IUSS, CAEN, CASTFOREM, JANUS, and Illowra, that could be used for CID studies. Currently IUSS and CAEN are being predominantly used in support of small unit analysis, in particular the LAND 125 Soldier Combat System, and CASTFOREM and JANUS in support of task force level analysis, in particular Restructuring of the Army. Illowra is a Forward Looking Infrared performance model described in Appendix D-1, that could be used to provide data for input into CAEN and other models. CAEN is described in Appendix D-2.

2.0 Small Unit Analysis

The analytical methodology adopted for LAND 125 involves a Battlelab approach utilising a Model-Test-Model process. Given that LAND 125 has identified CID as a technology enhancement to the combat soldier/unit capability, it is expected that IUSS and CAEN will be further developed for analysis of the consequences of CID. Modelling will be developed and used to identify critical CID issues for investigation during field studies (given availability of mature CID technologies for trialling). Field studies will then provide a means of verifying model results as well as for the collection of significant data for input back into the models. In order to assess the impact of CID technologies on soldier/unit capability, a hierarchy of performance measures similar to those stated in Table 1 will be developed.

Table 1: Hierarchy of performance measures

Performance Hierarchy	Description	Examples
Measure of Performance (MOP)	Performance characteristics for specific items of equipment or human performance parameters.	In terms of CID, this would include characteristics such as: - ID range (probability of correct ID of >95%) - Time taken to make correct ID - Environmental characteristics (climate, vegetation etc) - Security
Measure of Effectiveness (MOE)	Performance measures for core skills as applied by individuals and teams or substantial portion or characteristic of activity.	Characteristics of core skills developed for LAND 125 (eg accuracy, efficiency, error rates) or characteristics of activities such as loss exchange ratios and resources used.
Measure of Outcome (MOO)	Performance measures for the conduct of basic infantry tasks from section up to platoon level.	Tasks at this level include the generic activities developed for LAND 125. MOO is generally success or failure as determined from component MOE's.
Measure of Capability (MOC)	An integration of the activities at the MOO level, based on strategic guidance, into an overall MOC.	Ability of a company to contribute to the "protect" operational dimension. Relative capability comparing different force options or equipment.

Note that Table 1 is similar to the hierarchy presented in SWP SSA's QAP 220 – 'Measures of performance, measures of effectiveness, measures of outcome and measures of capability for analysis of soldier system enhancement'.

Table 2 indicates likely MOE's that will be used for analysis of the impact of CID technologies in relation to soldier core skills and activities.

Table 2: MOE's for assessment of soldier's protection, surveillance and target engagement skills in relation to generic activities.

Core Skill	Definition	Measures of Effectiveness
Protection	Includes protection against hostile forces, fratricide and the environment (Includes technologies such as body armour, NBC, CID, etc). Generic activities in which the impact of CID is expected include ambush, assault, defend, observation post, fire support, & tactical movement.	- Reduction in number of Blue casualties due to Blue fire. - Loss Exchange Ratio - Increase in situational awareness - Increase in identification range - Increase in combat effectiveness
Surveillance	The ability of an individual to observe or detect enemy sign or other features of importance. Generic activities in which the impact of CID is expected include observation post & tactical movement.	
Engagement	Includes all weapons handling skills necessary to effectively engage a target; eg target assessment, acquisition, aiming and firing, as well as any skills specific to crew served weapons. Generic activities in which the impact of CID is expected include ambush, assault, defend, and fire support	

3.0 Force-On-Force Analysis

For force-on-force applications, further development and use of CASTFOREM for performing CID studies will possibly commence during FY 99/00, and will revolve around the developments made by the US, as stated in Annex A. Such modelling could be used to assess the consequences of CID on coalition operations.

APPENDIX D-1

The ILLOWRA FLIR Performance Model

The ILLOWRA FLIR Performance Model

1. INTRODUCTION

This paper describes the Illowra Forward Looking InfraRed (FLIR) performance model, which has been developed by the Defence Science and Technology Organisation (DSTO) and British Aerospace Australia (BAeA). The Illowra model enables calculations of system performance to be carried out for a wide range of FLIR technologies including thermal, photoconductive and photovoltaic detector based systems used in various staring and scanning detector geometries. Illowra can produce images of target/background scenes, showing spatial and noise effects introduced by a FLIR system. The performance of the human observer, in terms of target detection, recognition and identification probability, is calculated using the Oracle visual performance model developed by British Aerospace, UK. An outline of the structure and operation of the model is given, followed by a description of how Illowra has been used for various applications within DSTO. The paper concludes with a description of some of the most recent enhancements to Illowra.

In 1989 DSTO was tasked with providing advice to the Royal Australian Navy (RAN) on the provision of a FLIR system for the Seahawk helicopter. The FLIR would meet Navy's requirements for operation in the maritime regions off the North coast of Australia, an area that exhibits high humidity levels for significant periods of the year. A systems analysis approach was used to evaluate the performance of prospective systems in this region. Modelling of targets, backgrounds, atmosphere, and the performance of the sensor and the human observer was required. Although expertise on these topics existed within DSTO, and there was software on hand to model most of the above aspects it was decided that a single software tool capable of modelling the performance of the full range of present day FLIR systems should be developed.
Two models were developed and used to assess current FLIR technology. The models differed in their approach to the handling of target signature information and the modelling of the performance of the human observer. One of the two models, named Illowra, has been selected by DSTO for further enhancement and for use in other tasks. (The name Illowra is based on the Aboriginal word for sea-eagle, a reasonable approximation to Seahawk!)

The present version of the Illowra model caters for both maritime and land based scenarios and the modelling of novel detector scanning formats. Illowra can produce images of target/background scenes, showing spatial and noise effects introduced by a FLIR system. The performance of the human observer, in terms of target detection, recognition and identification probability, is calculated using the Oracle visual performance model developed by British Aerospace Ltd, Sowerby Research Centre, UK. From the original model, which ran on a microVAX, evolved an IBM RISC based version with a PC version to follow in the near future. Improvements have also been made in terms of the provision of a user-friendly menu system that allows for straightforward handling of parameter information, as well as control of execution of the model in its various modes. The Illowra model has also served as a basis for the development of other software tools required for separate tasks.

2. MODEL STRUCTURE AND CAPABILITIES

2.1 General

The Illowra model consists of software modules written in FORTRAN and C. FORTRAN modules describe the modelling of the target, background, atmosphere, FLIR and human observer, while the C modules create a Model Control Shell (MCS). A schematic of the overall program flow is shown in Figure 1. Illowra first produces target and background images using methods described in Sections 2.3 - 2.4. Atmospheric transmission and emission is taken into account at this stage. These images are then combined in the 'combination' module to produce a single image file. This image file also contains a header that holds relevant parameter information such as total and instantaneous field of view (ifov) sizes, range, and target, background and noise signal levels. This image file is then processed by each of the following modules that describe the FLIR sub-systems. At each stage the effects produced by the relevant sub-system on the image are calculated and the image header updated if necessary. Finally, the Oracle module takes the header information output by the Display module and uses it to calculate detection, recognition and identification probabilities as required. This modular approach results in straightforward updating and enhancement of the code, particularly if changes are only required to modelling of one of the sub-systems of the FLIR. Details of the calculations carried out by each module are described in Sections 2.3 - 2.8.

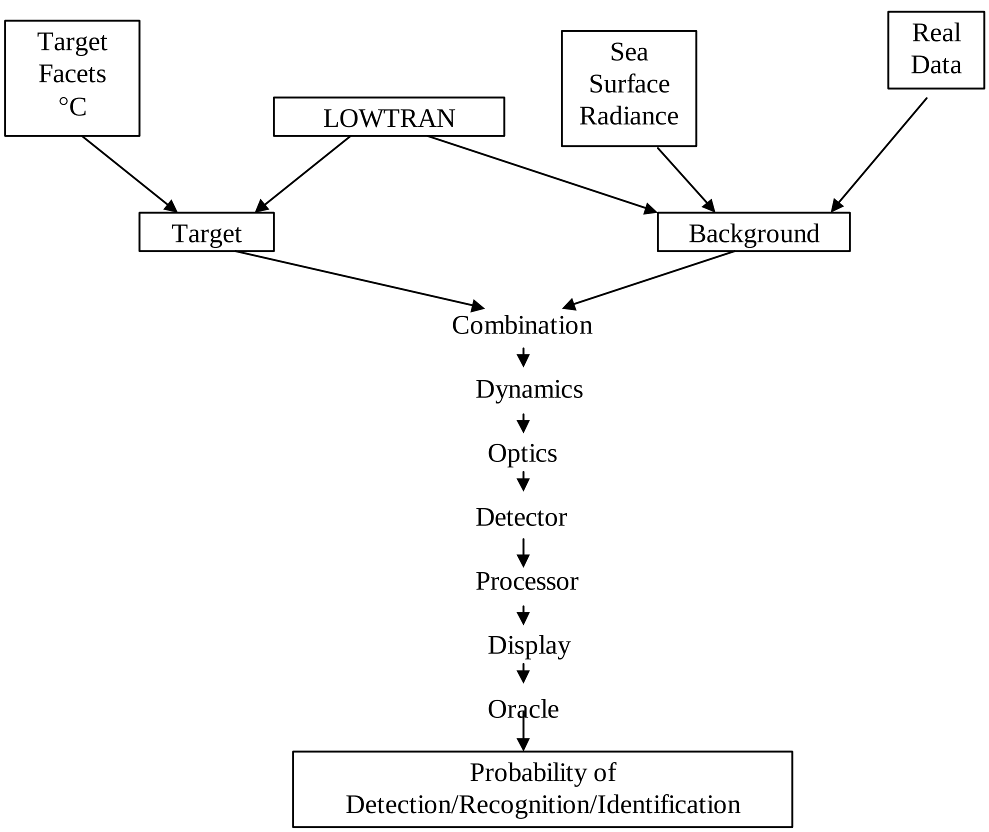

Figure 1: Overall flow of information through the Illowra model.

The Illowra model uses spectral properties of both the scene and the performance of the FLIR in its calculations. Spectral information relating to target and background signatures, atmospheric transmission, optics transmission and detector responsivity are used as inputs to the model. The calculation of the detector output signal (produced by the target, background or noise) then integrates this information over the waveband of operation of the FLIR system being modelled.

The present version of Illowra can handle a wide range of scenarios including modelling of various scanning and staring detector systems, and target/background/atmosphere combinations. Illowra can be run to model a single target-background-sensor scenario, or to automatically run a number of times as a specified parameter is iterated. The modular approach described above makes this task particularly simple - an 'execution configuration' file can be created to control the sequence and repetitions required for each of the modules of code during iteration. Figure 2 shows the currently available selection of parameters that can be automatically varied over a desired range under control of the MCS.

------------------------------ Illowra FLIR Model Control Shell -----------------------------

Execute Model Iteratively

	Select Parameter
Parameters	Range of target (m) Bearing of target (degrees from North) Ambient temperature at target (degrees K) Average emissivity of target (percent) Altitude of observer (m) Temperature of sea surface (degrees K) Wind speed (m/sec) Optics aperture diameter (mm) Optics focal length (mm) specific Detectivity D* (cm Hz [1/2]/W) Detector scan efficiency Acquisition time (seconds)

Press **Help** for instructions on using the Model Control Shell
Press **PF1** to exit the current menu level
Press **PF4** to exit the MCS at any time

Figure 2: Parameters available for selection for automatic iteration under control of the MCS.

Additional software is provided to allow inspection of the output data. Output from Illowra includes numerical and graphical data on the system performance, and images showing the effects on spatial resolution produced by the various FLIR sub-systems. These images are produced by first describing the spatial resolution effects with a Modulation Transfer Function (MTF) array, and secondly, convolving this array with an input image using a Fast Fourier Transform (FFT) technique.

Validation of Illowra has been carried out for many parts of the model. For example,

1) as part of the original study described in the introduction, outputs from the two models were compared for particular FLIR system/scenario combinations

2) suitable field data has been compared with the output of the model to provide additional 'spot checks'

3) a trial involving several different FLIR systems (see Section 3) has provided a significant database of well-characterised data on a variety of FLIR technologies. Data from systems operating in the 3-5 µm and 8-12 µm wavebands, including staring, parallel scanning, series-parallel scanning and SPRITE based systems was collected. Analysis of these results and comparison with Illowra's predictions resulted in reasonable agreement between model and trial results.

2.2 <u>Model Control Shell</u>

An early enhancement to the model was the addition of a 'user-friendly' menu system which was written in C to aid portability of the code. The Model Control Shell carries out all tasks associated with the input, output, storage and retrieval of parameter information, and controls Illowra's mode of operation. The menus controlling the input of parameter information are arranged in a tree structure. Figure 3(a)-(d) shows the menu path from the top level menu down to the parameter input level. In Figure 3, as an example, the route is traced for the detector module.

The parameter inputs entered in the Model Control Shell have been selected to give as many options as possible to the user for data input format. For example, in the menu describing inputs required to model the vibration environment of the sensor, there are no less than three different ways to specify the data.

These are:

1) Input an MTF, acquired off-line from Illowra, which describes line of sight jitter.

2) Input a single line of sight jitter value in units of µrad.

3) Input combinations of vibration spectra and information describing the dynamic response of the sensor mount.

In addition the user has the option not to calculate the vibration effects. This approach of allowing multiple forms of input data is directed at maximising the value of the often limited information that may be available from a FLIR manufacturer.

The Model Control Shell can also control which of three main modes of operation Illowra will use. These are:

1) Once Illowra has produced an input target/background image, only the 'header' information is used for remaining calculations. Full information on system and observer performance can be calculated from this information alone. This mode of operation results in the shortest execution time for the model.

2) Images are produced showing the accumulating effects of each FLIR sub-system, i.e., an MTF array/image convolution is carried out at each sub-system stage in sequence (Results in the longest execution time).

3) A final output image is produced, but no images showing the intermediate effects produced by the sub-systems are created i.e. Sub-system MTF arrays are combined and then convolved with the input image in a single step.

Illowra runs can either be executed in real time or as batch jobs. In both cases log files are generated which describe the execution of the model and include any run-time error reports.

Illowra FLIR Model Control Shell

Main Menu

Edit user parameters
Set all parameters to their default values
Save parameters in a specified directory
Retrieve parameters from a specified directory
Delete a parameter directory
List parameters to a file
List parameters on the printer
Generate Lowtran files
Execute the model once
Execute the model iteratively
Exit the Model Control Shell

Press Help for instructions on using the Model Control Shell.
Press PF1 to exit the current menu level
Press PF4 to exit the MCS at any time

Figure 3(a) Top level menu.

Illowra FLIR Model Control Shell

Edit Parameter

Edit atmospheric parameters (Lowtran-7)
Edit target parameters
Edit background parameters
Edit image interface parameters
Edit scene combination parameters
Edit dynamics parameters
Edit optics parameters
Edit detector parameters
Edit processor parameters
Edit display parameters
Edit oracle parameters
Edit general parameters

Press Help for instructions on using the Model Control Shell
Press PF1 to exit the current menu level.
Press PF4 to exit the MCS at any time.

Figure 3(b) First sub-menu level - headings for target, background, FLIR modules.

Illowra FLIR Model Control Shell

Detector Parameter

Edit starting CCD parameters
Edit microscanned CCD parameters
Edit staring XY array parameters
Edit microscanned XY array parameters
Edit parallel scanned linear array parameters
Edit parallel/serial scanned linear array parameters
Edit sparse/interlaced scanned array parameters
Edit single element detector parameters
Edit SPRITE parameters

Press Help for instructions on using the Model Control Shell.
Press PF1 to exit the current menu level.
Press PF4 to exit the MCS at any time.

Figure 3(c) Second sub-menu level - headings for specific detector technology/scanning options

Illowra FLIR Model Control Shell

Staring CCD Parameters

File containing detector responsivity	**512. DAT**
Specific Detectivity D* (cm Hz[1/2]/W)	7.80000e+09
F/number at which detectivity measured	1.5
F/number of cold shield of FLIR system	0
Electrical bandwidth of detector (Hz)	0
Frame rate of detector	30
Integration time for detector (seconds)	0
Interlace ratio of detector	2
Element size in X direction (mm)	1.62000e-02
Pitch of element s in X direction (mm)	2.60000e-02
Element size in Y direction (mm)	1.25000e-02
Pitch of element s in Y direction (mm)	2.00000e-02
Number of transfers in X direction for CCD	512
Number of transfers in Y direction for CCD	512
Transfer inefficiency of CCD	0
Depletion width of CCD (mm)	2.00000e-03
Diffusion length of CCD (mm)	5.00000e-02
Isoplanatism mode for MTF (OFF, MIN, MAX, or MEAN)	OFF
Number of phase steps for modelling Isoplanatism	0
Non-uniformity of detector elements (percent)	0

Figure 3(d) Third sub-menu level - headings for parameter inputs for staring CCD array.

2.3 Targets

Illowra uses synthetically generated facet models to represent targets. Illowra has a target data base containing a selection of facet models of both land and sea targets. Software is available to produce additional target models if required, including the 'posing' of human targets as desired - e.g. standing, prone. Targets are described by two files: one is a geometrical description of the target as a series of facets, the second is a temperature file which lists the temperature of each facet relative to the ambient temperature at the target. Illowra then constructs a 2-dimensional view of the target for any desired aspect. The target image data is quantified in terms of the signal arriving at the entrance of the FLIR system in photons/sec (the target is assumed to behave as a black/grey body - with a user supplied value of emissivity). Note that the target signature data is a series of effective temperature values which have been measured in the field - Illowra does not separately calculate emitted and reflected components of the target signature. The image of the target produced by Illowra can be displayed and inspected at this stage.

2.4 Backgrounds

Illowra can model backgrounds in two distinct ways:

1) Production of a maritime sea/sky background generated from a Statistical Sea Surface Radiance Model (SSSRM) developed at DSTO Salisbury.

2) Generation of a background using real data collected in the field with a suitable thermal imager and then digitised to 8-bits and formatted for input to Illowra.

Either type of background image can be displayed and inspected before target injection.

2.4.1 Statistical Sea Surface Radiance Model (SSSRM)

The SSSRM produces an image of the sky/sea surface in the desired part of the infrared spectrum, over the required azimuth and elevation range. Both emitted and reflected components of the sea surface signature are calculated. This is a statistical based model that describes a wind roughened sea surface with a time-averaged wave facet geometry. Input to this module consists of a series of parameters describing the sea surface, and a sky radiance file describing the azimuthal and elevation variation of sky radiance for the desired portion of the infrared spectrum. This sky radiance file will have been created previously using Lowtran 7 calculations. At present DSTO are involved in enhancing Illowra to give the user an option of calculating a dynamic sea surface made up of individual wave facets to permit modelling of sea glitter effects.

2.4.2 Real Backgrounds

Illowra deals with images consisting of square pixels. The total number of horizontal or vertical pixels must be a power of two up to a maximum of 512x512 (the model can be reconfigured by the user to accept larger image sizes if required). The horizontal and vertical fields of view of the image can be different as long as the square pixel and power of two requirements hold i.e. a system field of view of 6° x 3° made up of 512x256 pixels would be allowed. Images from various types of FLIR systems can be used as input to Illowra provided the extracted digitised information is of this form. The digitised image also has an 'Illowra' header attached to it containing relevant information on the real image.

Once Illowra reads in the digitised real image it first converts the 8 bit data to a temperature map. At the time of collecting the real imagery in the field, information on average scene temperature, and variation of temperature in the scene should be collected. This allows the correct scaling of the digitised values to temperature values. In this conversion from 8-bit data to temperature data the user may modify the average temperature, and the standard deviation in the temperature to effectively create a 'new' background. Additionally, the user can scale the background range of the image so that it can be used to represent a background for a different field of view or at a different range from the original real image. The user can also use this temperature map in a different infrared spectral region from that of the original data, although some care must be taken since effective temperature standard deviations can be significantly different in different parts of the infrared spectrum. However as discussed in Section 2.8, this practice is usually quite permissible.

2.5 Atmosphere

Atmospheric transmission and emission (within the 2-20 μm band) are calculated along the slant path between target and sensor using Lowtran 7. Illowra can use standard 'Tape7.dat' Lowtran 7 output files generated off-line from Illowra, but the Model Control Shell gives the user the added ability to carry out a range of Lowtran calculations from within Illowra, including the creation of sets of Lowtran output files describing transmission and emission for a sequence of slant ranges.

2.6 Scene combination

At this stage Illowra overlays the target against the real or synthetic background and produces the 'combined' image. The module first scales the pixel size used for the target to approximately match that used for the background. The target is then overlaid on the background at a position selected by the user. In the combined image some pixels around the edge of the target are generated using appropriate contributions from target and background image pixels. The combined image can be displayed at this stage.

2.7 FLIR Sub-systems

As each of the FLIR sub-system modules are run, calculation of the effects on target/background/noise 'signal' levels and on the spatial resolution of the system are carried out where relevant. The effect on spatial resolution is calculated using an MTF array which can be convolved with the input image to each sub-system stage, or combined with MTF arrays calculated for the other sub-systems to produce an overall 'system' MTF. If desired this 'system' MTF can be convolved with the input image to produce the system's output image in a single step.

2.7.1 Dynamics

The effect of line-of-sight jitter on spatial resolution is calculated in this module. An MTF array is calculated by one of the various routes described in Section 2.2 above.

2.7.2 Optics

Effects of transmission loss and blurring are calculated in this module. As with the other modules, there are data input format options. For example, a previously measured optics transmission and MTF can be used if available. Alternatively, a value of optics transmission calculated from a description of the optical design (optical material/thicknesses/number of elements), and a calculated MTF (including use of aberration coefficients) may be used.

2.7.3 Detector

One of Illowra's strengths is its ability to model several distinct detector technologies. This is achieved by taking a top level approach to the calculation of the detector performance. Illowra uses measured data rather than trying to model, for example, the specific noise sources of importance in a particular detector technology from first principles. The required inputs include data on detector responsivity, specific detectivity and bandwidth. Using this data in conjunction with information on the geometry of the detector(s) and the scan/staring format, Illowra calculates the spatial and noise effects. Figure 3(c) shows the current range of options. These not only include standard staring, parallel, serial, serial-parallel scanning and SPRITE based imagers, but also include options for systems using dither scan of certain formats and also one option 'Sparse interlaced scanned array' for a scan format of interest to in-house work at DSTO Salisbury. Additions or enhancements to any of these options are of course simplified by the modular approach used in Illowra.

2.7.4 Processor

Conversion of the detector output signal into a suitable video form is calculated in this module. There are various options for gain and offset correction of the detector signal. Modelling of specific scan conversion methods using LED and CCD technologies is implemented in Illowra. However, the user can also directly input MTF data values, allowing other scan conversion approaches to be modelled.

2.7.5 Display

This module calculates the spatial performance of the system's display screen and any viewing optics that may be used. The target, background and noise voltages calculated by the processor module are converted to luminance values, including corrections for (i) the reduction in image contrast due to the reflection of ambient light from the display screen and (ii) the transmission of viewing optics if they are present.

2.8 ORACLE - Human Visual Performance Model

Illowra contains a customised version of Oracle, a photopic visual threshold model developed by British Aerospace Ltd, Sowerby Research Centre, UK. The model calculates a visual lobe relating probability of detection to the position of the target on the retina. It can also calculate recognition and identification probabilities once the target has been acquired. This version of Oracle has been modified so that it can deal with ship, vehicle or human classes of targets. The effects of clutter on target detection can also be taken into account if required.

In section 2.4.2 comments were made stating that real imagery gathered in one region of the infrared spectrum could be used to generate a background in a different spectral region. The main problem in doing this is that the standard deviation of the apparent temperature in the scene could be quite different in the two spectral regions. However, Oracle bases its calculations of target detection recognition and identification on (i) the average illuminance gradient across the target edge and (ii) the number of retinal receptors falling across the edge. The illuminance gradient is calculated from the displayed luminance contrast of the target and background. Average target and background signal levels are used to provide this contrast value. If the user has direct average temperature information on the real background data when it was collected, and if the menu input for the standard deviation of the temperature in the generated scene is kept small, the user can be confident that the calculated average target/background contrast will be a realistic value.

2.9 Output from Illowra

Text output files containing details of the calculations are produced by each of the modules. In addition, for iterative runs, particular information of interest can be extracted from each iteration and combined in a single results file (e.g., identification probability or signal/noise ratio versus range).

Various data can be graphically presented:

1) Plotting of input data files, e.g., responsivity versus wavelength

2) Atmospheric transmission and emission versus range

3) Sub-system and overall system MTF data

4) Horizontal and vertical 'cross-cuts' of images (signal versus pixel number)

5) Oracle probability versus range or target aspect for example (Figure 4)

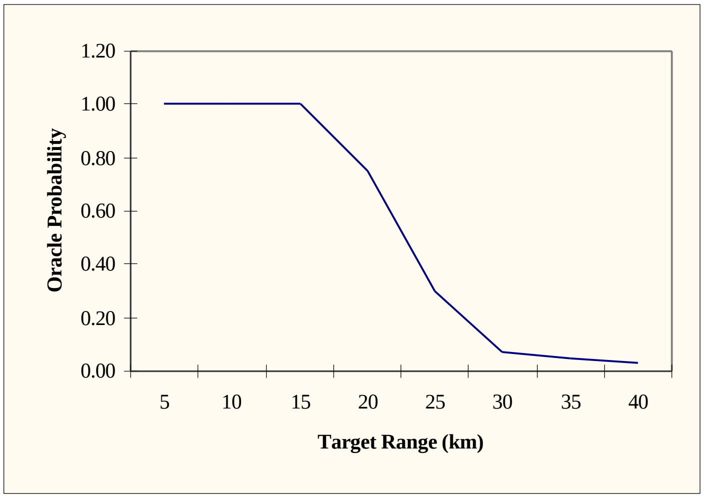

Figure 4: Example output from the Oracle module showing, for a particular target, background, atmosphere scenario, the probability of target detection versus target range.

As already discussed, Illowra allows the user to visually inspect images at input, sub-system and final output stages as required. Figure 5 shows (a) Input target image of landrover, (b) Output image showing landrover target overlaid against real background.

3. USE OF THE ILLOWRA MODEL

The model has been used within DSTO for a number of tasks including support of in-house infrared imager research, provision of advice on equipment procurement issues and upgrade options, and supply of system performance information for use by operational analysis groups in wargaming studies. For example, Illowra was used to assess FLIR technology for the RAN requirement mentioned in the Introduction. The assessment highlighted the 3-5 μm spectral region as the optimum waveband of operation but failed to identify existing equipment that would satisfy RAN's full requirement. Information from the study was used to help develop a specification for a suitable FLIR system, resulting in the production of a concept demonstrator that was successfully trialled in Sydney and Darwin during November-December 1992.

The applications mentioned above are all routine for a systems performance model. Of more interest is that there has been development of the original code for other distinct uses. A version of the model has been developed that can produce image sequences which are stored on video disc. These images are then replayed to provide a 'real time' sequence which can be used to exercise target recognition algorithms. Another application being developed is a mission planning aid for the Royal Australian Navy (RAN). A 'cut-down' version of Illowra will be produced, where the parameters describing the thermal imaging equipment used by RAN will be 'hard-wired' into the model. This leaves the RAN operator to input data on e.g. day-of-mission meteorological conditions and expected target type. The mission planning aid would then produce information on likely detection, recognition and identification ranges for an optimised direction and altitude of approach to the target.

Figure 5(a) Example target facet model used as input to the Illowra model.

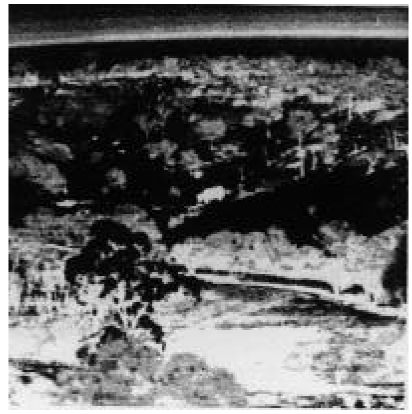

Figure 5(b) Example output image from Illowra. A synthetic target of a landrover has been overlaid on a real background (Target located at centre of image).

4. ENHANCEMENTS TO THE MODEL

As mentioned in section 2.7.3 a recent modification to Illowra has been the inclusion of modules to allow calculation of the effects of dither scan (sometimes termed 'microscan'). Dither scan is the 'scanning' of arrays of detectors by inter-pixel sized deflections to sample areas of the scene which none of the detector elements may originally have covered, or to create 'sub-frames' which can be added together to form a single image which will have increased spatial information content. In either approach the effect of the dither scan is to increase the spatial sampling rate over that available with the staring array itself. The algorithms used to model dither scan apply increased Nyquist cut-offs to the detector MTF (due to the increased spatial sampling rate). The detector noise calculations are adjusted to account for possible changes in detector dwell time. Both step/stare and continuous dither scan implementations of various forms can be modelled.

It should be noted that with Illowra's generic approach to the modelling of FLIR technologies it would not be effective to attempt to model aliasing. For example, detailed knowledge of the electronics design used in a FLIR system would be required in order to model the aliasing of noise. For that reason the detector MTFs used in Illowra have sharp Nyquist cut-offs (MTF=0 for spatial frequencies > Nyquist frequency). Also, the present version of Oracle that is used within the Illowra model is not designed to calculate the effects of sampling on human visual performance. Therefore caution should be exercised when utilising the Oracle module with FLIR systems which exhibit a Nyquist cut-off at spatial frequencies where the value of MTF is still significant.

The enhanced version of Illowra also includes estimates of the effects of non-isoplanatic behaviour on the detector MTF. Non-isoplanatism arises when, for example, in a staring system the perceived MTF measured for a test bar pattern changes as the relative positions of detector direction of view and pattern location move i.e. the MTF is dependent on the 'phase' between sensor direction of view and the pattern. Illowra can calculate the maximum, minimum and average MTFs that would be encountered in such cases. The algorithms used in Illowra are based on the work of Feltz et. al. These MTFs can be combined with the rest of the system information to produce a measure of the impact on the overall system performance caused by this effect.

5. SUMMARY

This paper has given an overview of the Illowra model, its capabilities and some of its more recent enhancements. To date its main strengths lie in its versatility in modelling many different FLIR technologies, its modular framework, its ability to produce images of the target/background scene, and its relative ease of use due to the presence of the Model Control Shell. In addition, Illowra contains a relatively complex human visual performance model which itself is undergoing further development. Finally, and of significant importance is that it has a rapidly increasing validation base which matches the model's inherent versatility.

APPENDIX D-2

The Close Action ENvironment (CAEN) Model

The Close Action Environment (CAEN) Model
A Description Of CAEN

Close Action ENvironment (CAEN) is a multi-screen, multi-sided close combat model that has been developed by the UK Defence Research Agency's (DRA) Operational Studies (Land) Department, based at DRA Fort Halstead.

The following information is based on their literature:

- The model has been successfully used as an operational analysis tool, and can be used either as an interactive wargame or as a simulation.

- Deployment can be up to company strength, with representation of individual infantrymen, crew served weapons and AFVs. Indirect fire support from artillery and mortars can also be represented.

- Digital terrain data is used, with culture and attributes added. For example, urban terrain with various types of buildings having multiple storeys, windows, doors, sloping roofs, internal walls, and basements; seven types of rural terrain including roads and rivers, and having culture defined by height and density; field defences and obstacles; etc. The terrain area is typically 5 km x 6 km at 10 m resolution.

- A number of complex models are used to calculate the various aspects of the battle. These autonomous models allow units to move and interact with each other in a realistic manner. They include movement, surveillance, suppressive fire, detection, acquisition and engagement, suppression, minefields, indirect fire, obscuration, weapon sharing, and fighting in buildings.

Currently fratricide is available as a pre-selected option. Two inputs are required in the unit data file: (i) a fratricide range, which is used to define the minimum safe distance range for small arms fire (given a default value of 300 m), and (ii) a fratricide probability, which is used to define the probability of attaining a false acquisition on a unit on your own side (given a default value of 0 %). At each acquisition the code will test for incorrect acquisition of a friendly unit by use of a random number against the fratricide probability. During the running of a scenario, the icons undergoing fratricide remain unchanged in colour. Upon completion of the wargame/simulation, the level of fratricide is determined through a database query.