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Final Report On Line Of Sight Intervisibility Metrics (LOSIM)

Rhonda L. Freeman

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INSTITUTE FOR SIMULATION AND TRAINING

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August 5, 1994

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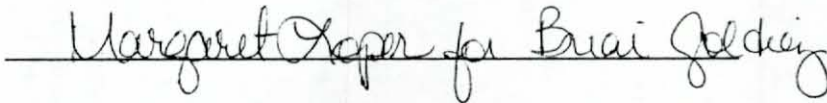
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Line of Sight (LOS) Intervisibility Metrics for Terrain and Features

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1. Introduction

The goal of this task was to develop a metric which would grade the extent to which the rendered images of two terrain databases correlate on the basis of intervisibility. Intervisibility is defined as the ability of a viewer at one sample point on the terrain database to see a target located at a different position on the database. By seeding a terrain with sample points and testing the visibility of targets at other sample points, statistics would be collected which would determine how well intervisibility correlates between different rendered images of a database. This correlation index would indicate the extent to which two opponents using different image generators will have the same LOS intervisibility. This difference in LOS intervisibility will impact the fairness of outcome of an engagement between opponents when they are performing tasks that involve concealment and direct fire weapons.

A four step approach was planned to accomplish this task. The first step was to perform research to determine the best approach from a human factors standpoint and a statistics viewpoint. The goal was to have a sufficient number of sampled data points to accurately perform the experiment and also to keep the number of points at a manageable level.

The second step was to develop a sampling procedure that was statistically useful and significant. Once this was accomplished, a software package which would provide sample data points and record the experiment's results would be developed. The next step was to develop a correlation methodology to contrast and compare the resulting data from the experiments conducted by fifty volunteer companies. The final step was to produce a report detailing the steps and the results.

This task was conducted over a period of 2 years, 1992 - 1994. This report serves to compile, explain, and detail the steps that were taken during this time period. This approach provided the opportunity for IST researcher review. As such, potential flaws in experiment design, assumptions, and process were identified and highlighted in the following paragraphs.

2. Research

Methods to limit or reduce the number of sample points that must be tested were researched. One way to do this is to eliminate those targets that are outside human visual acuity from any given test point. You must then assure that the displays and scenes rendered were finer than human acuity so that the human, not the display, is the limiting factor. If this was not done, the work is flawed. The goal is to remove possible error from the intervisibility index by testing only those points that the person can see. A set of guidelines were chosen called "Johnson's Criteria" for determining the maximum distance to place a given point. Calculations of the acuity thresholds based on Johnson's criteria are included in Attachment A.

Note that the equation for FOV provided in attachment A is only appropriate for small angles. A more appropriate and accurate equation would be to use $57.3(\arctan T/R)L/N$. An 18 degree

vertical FOV is more appropriate than 8 degrees. This equation must consider display MTF. TV lines only give an indication of optimal resolution. Lastly, the equation is based on profile views and it is believed that frontals would be more appropriate.

A second approach, called the "mathematical approach", is based on trigonometric calculations based on real world visual constraints. After lengthy discussions with Dr. Ed Rinalducci, nationally recognized vision scientist with UCF's Department of Psychology, the mathematical approach was chosen. It is a more generally accepted approach in the scientific community, and it is based on real world visual criteria. Attachment B provides the assumptions, constraints, and calculations involved in this study.

3. Sampling Procedure

A sampling procedure was developed in conjunction with faculty from UCF's Statistics Department. This procedure uses test pairs rather than test points. This would serve to dramatically reduce the sample size while still maintaining the statistical power of the original approach. Attachment C contains an explanation of this approach.

4. Software Developed

A Line of Sight Intervisibility Measurement (LOSIM) software packaged was developed by IST. LOSIM is a PC-based program developed in Ada. Its' goal is to assist DIS users, exercise managers, and developers in calculating line of sight intervisibility between image generators using similar source terrain data. This software provides a method to specify the extent to which participants' rendered images of the terrain correlate with respect to LOS intervisibility.

LOSIM randomly selects statistically-derived sample points on a rectangular gaming area or piece of simulated terrain defined by the user. From this user-provided gaming area, sample pairs are generated. These sample pairs represent a view point and target combination that is selectable by the user based on the simulation platforms of interest. The simulated platforms include dismounted infantry, tank, rotary wing aircraft, fixed wing aircraft, and others.

LOSIM executable and source code is included as Attachment D. LOSIM communicates with an image generator (IG) via serial communications. Communication protocols for the Silicon Graphics IG have been developed.

5. Correlation Methodology

Using the test data base a viewing point will be selected at either 0, 6, 50, or 300 feet above the

terrain (representing dismounted infantry, tank, rotary wing, and fixed wing, respectively). A perspective accurate target will then be placed at the second point at the appropriate elevation. The computer will then prompt the viewer as to the target's visibility and whether or not the target is occluded by the terrain or its features. The viewing points and target points will then be incremented until all points in the sample have been exercised. The test configuration will produce sixteen different combinations of four viewing points versus the same four entities and target points. The second comparative database will be tested in the same way. The differences between the two rendered images of databases in the number and types of targets visible at each viewing point will be examined. Special purpose software developed in Meridian Ada version 3.x for the PC controls and records the view points, target locations, observer responses, and study statistics. Correlation test only measure at 5m sample posts. This could compromise the validity of tests using objects smaller than the sample size.

6. Results

Fifty participants were sent the software and explanation documentation, see Attachment E. A list of these companies is provided as Attachment F. However, no response was ever received from any of them.

Dr. Lorrie Hoffman, a statistics professor with UCF, has prepared an experiment and supporting rationale to utilize the results of the LOSIM software to determine when a fair fight has occurred on differing simulators. This will require the collection of data from paired simulators. That data would consist of values which represent the mismatch of the simulated terrains/environments and also a number reflecting the skill level of the two warriors. Her paradigm considers not only the correlation between data points of two rendered images, but also the skill level of the two warriors involved (an individual difference component). Her experiment seeks to determine when the values for these components fall into a tolerable range so that the ultimate outcome of combat on dissimilar image generators is statistically indistinguishable from combat on identical image generators. This information is provided as Attachment G.

Attachment A: Intervisibility Study, Viewing Diameters by Target Type

ATTACHMENT A
Intervisibility Study

Viewing Diameters by Target Type

Johnson (1958) offered an approach for calculating the maximum field-of-view (FOV) at which a particular operation could be carried out (e.g., detection, recognition, identification). This approach was used as part of resolution and IG performance specifications written into the CCTT RFP.:

$$FOV = \frac{L \times 57.3}{R} \times \frac{T}{n}$$

Where:

FOV (in degrees)

L = Total system line number (a measure of display resolution, expressed as a number of TV lines per picture height.

R = range to target (in meters)

n = required number of TV lines across to render the minimum dimension of the target

T = target size across minimum dimension (in meters)

In this exercise, we are interested in R, since we are attempting to include only those targets that are visible from a given viewpoint. It makes little sense (and will lead to erroneous results) if we include targets say 15 km from a viewpoint and ask the subject if he/she can see it. Stated differently, we want our intervisibility index to be based on those viewable targets tested.

We can re-write the equation above, this time solving for R:

$$R = \frac{L \times 57.3}{FOV} \times \frac{T}{n}$$

For the purposes of this study:

L = 512 vertical lines (NTSC standard)

FOV = 8° vertical FOV. This was chosen to minimize difficulty with the BBN IG.

n is the required number of TV lines to render the minimum dimension of the target, and is based on values both published by and extrapolated from Johnson's work for target detection:

<u>Target</u>	<u>n</u>
DI	3.00
M1	1.39
AH-64*	1.80
A-7*	1.50

Lastly, T which is the target size across minimum dimension (in meters) was obtained using MIL-STD-1472D for target a, and measurements from the BBN S1000 modeling tool for targets b through d. An aircraft, helicopter, tank, and dismounted infantry were selected on the basis of their portability between the modeling software and the IGs of interest. These targets are listed below along with the dimension(s) selected, and the measurement itself:

<u>Target</u>	<u>Minimum Dimension</u>	<u>T</u>
a. DI	hip breadth	.367m
b. M1	trac to turret	2.37m
c. AH-64	wheels to top of fuselage (no hub)	3.07m
d. A-7	jet intake to top of fuselage	2.26m

By substituting, the equation can be solved for R, which represents the rendering threshold for each target:

<u>Target</u>	<u>Rendering threshold (m)</u>
DI	447m (.28 miles)
M1	6271m (3.89 miles)
AH-64	6271m (3.89 miles)
A-7	5537m (3.44 miles)

Attachment B: Line of Sight Study, Assumptions and Constraints

LINE OF SIGHT STUDY

Assumptions and Constraints

(Rev 2/5/92)

Background

This study seeks to provide a methodology and metric for determining the extent to which intervisibility between sample points on one terrain data image generator combination compare with the intervisibility between those same sample points in another terrain data base image generator combination. The eventual goal of this study is to provide recommendations to DIS exercise managers regarding the extent to which participants' rendered images correlate with respect to intervisibility.

Given

- an approximate 12 km x 12 km terrain database from Indian Springs AFB, NV constructed from 100m DMA data.
- targets and their static heights (i.e., z) include:
 - dismounted infantry (DI) (0m)
 - M1 (0m)
 - AH-64 (15.25m)
 - A-7 (30.5m)

The latter three targets were chosen because of their portability between image generators.

- viewpoints and their static heights (i.e., z) include:
 - | dismounted infantry eye height for 50 percentile extrapolated from MIL-STD-1472D (1.62m)
 - | M1 (1.83m)
 - | AH-64 (15.25m)
 - | A-7 (30.5m)

- critical target vertical, horizontal, or diagonal sizes were measured using BBN's S1000 modeling tool. Below are the critical target sized along with the dimension measured:

<u>Target</u>	<u>Dimension</u>	<u>Value</u>
DI	Hip Breadth (horiz)	.367m
M1	Trac to Turret (diag)	2.37m
AH-64	Wheels to top of fuselage (diag)	3.07m
A-7	intake to canopy top (vert)	2.26m

Discussion

- two adjacent database "sample points" (i.e., x, y) are 5m apart. Given the 12km² terrain, this assumption produces 5,760,000 possible test points $(12,000/5)^2$.

From this population of test points we choose a random sample of points. The size of that sample is based on statistical sampling theory. By increasing the distance between two test points from 1m to 5m, and by increasing our acceptance error from $\pm .1\sigma$ to $\pm .2\sigma$, we can decrease the sample size from 384 to 96 for at 95% confidence interval (5/100 error rate). At the 99% confidence interval (1/100 error rate) we can decrease sample size from 666 to 166.

- each target will be tested at each and every viewpoint. For example, DI vs DI DI vs M1, DI vs AH-64, DI vs A-7, and so on. Therefore, for any given test point, there will be 16 separate comparisons made.
- Based on b and c above, the subject will be required to make 145,920 comparisons $((96*95)*16)$. This number of comparisons can be further reduced by testing only those targets that are at or inside the subjects visual acuity. If we test points outside this range, the correlation index will be biased. Using this technique, we should be able to reduce the number of required comparisons even further.

Calculating Viewing Distance Thresholds

Mathematical Approach. The relationship between visual angle (θ), target size (t), and distance (d) is represented by the equation:

$$\tan \theta = t/d$$

A 1° visual angle was chosen here for θ because it generally represents the recognition acuity of the normal 20/20 observer.

Since we are interested in rendering and testing only those targets within human visual range at any given time, we solve for d , where:

$$d = t / \tan 1^\circ$$

Then, by substituting the target sizes presented previously, we can calculate the maximum viewing distance for each target:

$$DI = .367 / .0003 = 1.2\text{km}$$

$$M1 = 2.37 / .0003 = 7.9\text{km}$$

$$AH-64 = 3.07 / .0003 = 10.2\text{km}$$

$$A-7 = 2.26 / .0003 = 7.5\text{km}$$

Johnson's Criteria. This approach for calculating the maximum viewing distance is based largely on characteristics of the visual display and its field-of-view (FOV). In Johnson's equation:

$$FOV = \frac{L}{n} \times \frac{57.3}{R} \times T$$

Where:

FOV (in degrees)

L = Total system line number (a measure of display resolution, expressed as a number of TV lines per picture height).

R = range to target (in meters)

n = required number of TV lines across to render the minimum dimension of the target

T = target size across minimum dimension (in meters)

We can re-write the equation above, this time solving for R:

$$R = \frac{L \times 57.3}{\text{FOV}} \times \frac{T}{n}$$

For the purposes of this study:

L = 512 vertical lines (NTSC standard)

FOV = 8° vertical FOV. This was chosen to minimize difficulty with the BBN IG.

n is the required number of TV lines to render the minimum dimension of the target, and is based on values adapted from Johnson's work for target detection:

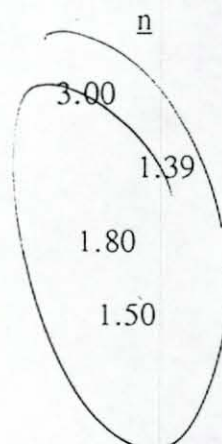
Target

DI

M1

AH-64*

A-7*



By substituting, the equation can be solved for R, which represents the maximum viewing distance for each target:

Target

DI = .45km

M1 = 6.3km

AH-64 = 6.3km

A-7 = 5.5km

Method Selection. We have chosen to use the viewing distance thresholds represented in the mathematical approach since those values are based on extensive empirical data from real-world vision research. Moreover, the final intervisibility metric will be based on real-world (as opposed to simulated or "rendered world") criteria. Thresholds calculated using both approaches are presented below:

<u>Target</u>	<u>Mathematical Approach</u>	<u>Johnson Criteria</u>
DI =	1.2km	.45km
M1 =	7.9km	6.3km
AH-64 =	10.2km	6.3km
A-7 =	7.5km	5.5km

* These measures are extrapolations based on Johnson's work.

Attachment C: Sampling Approach, Line of Sight Intervisibility

Sampling Approach

Line-of-Sight Intervisibility

The key idea is to estimate the probability that two data bases agree on line of sight intervisibility given a randomly select pair consisting of an observer and a target.

Consider pairs of randomly selected sites $(x_{1a}, y_{1a}), (x_{1b}, y_{1b}), \dots, (x_{ka}, y_{ka}), (x_{kb}, y_{kb})$. We will imagine for now that site a is the observer and site b the target. Each pair of sites is then compared for line of sight using both data bases. It will be convenient to summarize the results in a table, as follows:

		Data Base II		
		Sees	Doesn't See	
Data Base I	Sees	n_{11}	n_{12}	r_1
	Doesn't See	n_{21}	n_{22}	r_2
		c_1	c_2	n

The notation is intended to be suggestive: for n_{ij} , the i represents the row of the table, the j represents the column; r_i represents the sum of entries in "row i "; c_j represents the sum of entries in "column j "; n is the total number of line of sight checks.

If the data bases agree perfectly on the n test cases, then $n_{21} = n_{22} = 0$ and $n_{11} + n_{22} = n$. For partial agreement, the quantity $(n_{11} + n_{22})/n$ estimates the proportion of agreement of the two data bases. This proportion may be a suitable metric for comparing data bases. Qualitatively, it has similar properties of the correlation coefficient, but not its inherent flaws.

We will mention one potential concern and its possible resolution. This formulation inherently presumes that agreement with both data bases providing line of sight and agreement with both data bases indicating no line of sight are of comparable merit. Perhaps it is critical in some application, that if one data base reports line of sight, the other ought to as well. The quantity $n_{11}/(n_{11} + n_{21} + n_{12})$ estimates the proportion of cases that the two data bases agree on line of sight, given that one data base has indicated that line of sight exists. A similar expression, namely,

$n_{22}/(n_{22}+n_{21}+n_{12})$ estimates the proportion of cases that the two data bases agree on the absence of line of sight, given that one data base has indicated this absence.

To develop a scheme for determining the sample size in estimating the various proportions, a binomial model is proposed. In this model, the test cases should be independent (one outcome does not influence other outcomes) and the outcome has a constant success probability. The selection of pairs of sites using a uniform distribution over the region will insure the critical independence condition.

Sample size considerations. An obvious question is how many pairs of observer-target points must be sampled to accurately estimate the proportion of agreement between the two data bases? Letting this proportion be denoted p , we would hope that it is close to 1 which represents perfect data base agreement. Of course, we do not know the population proportion, so we must estimate it with \hat{p} , the sample proportion as given above. For fairly large samples ("large" will be defined shortly), \hat{p} will follow an approximate normal distribution. In particular, n larger than $9p/(1-p)$ will suffice. Taking a fairly extreme value of p , say 0.99, yields $n = 891$. For convenience in converting between counts and relative frequencies, $n=1000$ is recommended. For a true p less than 0.99, 1000 pairs will insure that our approximation procedure is valid.

Sample results. For illustration, suppose that 1000 samples of pairs of points are generated and line of sight determined. The sample proportion of agreement \hat{p} gives a natural estimate of p . How well do we know this quantity? A confidence interval provides an answer. The $100(1-\alpha)\%$ confidence interval for p is given by:

$$\hat{p} \pm z_{\alpha/2} \sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$$

Suppose we observe $\hat{p} = .80$; a 95% confidence interval is (0.775, 0.825). With this type of calculation, we would expect that about 95% of similarly constructed intervals (based on new samples) would contain the true proportion of agreement p .

Another potential use of this statistical methodology is to test the sample proportion against a standard value, such as 0.90 which (you) have suggested. A one-sided test is appropriate, as follows:

$$H_0: p = p_0 \text{ vs.}$$

$$H_A: p < p_0$$

The value p_0 is the standard value for agreement (perhaps 0.90). Sample proportions above p_0

offer no problems. For those below the prescribed value, are they sufficiently lower so that mere chance does not account for them? The testing procedure is easy:

1. Compute
$$z = \frac{\hat{p} - p_0}{\sqrt{\frac{p_0(1-p_0)}{n}}} .$$

2. If $z < -z_\alpha$, then reject the null hypothesis H_0 in favor of the alternative hypothesis H_A .

The value z_α is obtained from a standard normal table (e.g., $z_{.05} = 1.645$). As an example, suppose $\hat{p} = 0.86$. We calculate $z = (0.86-0.90)/\sqrt{[0.9\cdot0.1]/1000} = -4.21$. Since the condition $-4.21 < -1.645$, we would reject H_0 and conclude that the differences in the data bases are real and not due to chance variation.

Attachment D: Line of Sight Intervisibility Measurement Software

Attachment E: Requirements for Line of Sight Intervisibility Metric Program

REQUIREMENTS FOR LINE-OF-SIGHT INTERVISIBILITY METRIC PROGRAM

1. The system that the Intervisibility Metric Program will run on shall consist of a control computer (386 PC) feeding information to an image generator/simulation computer. The program will be initially executed on the control computer. The program shall be written in well documented Ada code with loosely coupled packages. The Windows program may be used to simplify the user interface on the control computer. All screens shall contain the option to Return To Previous Menu. All option selections shall accept keyboard cursor control using the arrow keys or mouse control. All targets shall be colored international orange.

All data entry fields shall be validated for legal user input and shall display an error message when invalid input occurs. In cases where user input or selection is required, a message shall appear on the screen when the user fails to input or select telling the user that they must input or select something and not allowing the user to continue until input or selection occurs. An alternative to this is to allow the user to continue but display a warning message on the screen indicating that the exercise cannot be run without the input or selection. At this point, the user should be forced to press the <ENTER> key to acknowledge the warning message, and then be returned to the program.

The system may be menu driven, where all references to key input can be accommodated by a menu item except where data must be entered in a field. References to pressing the <ENTER> key may be implemented by mouse click on the appropriate menu item or area of the screen.

2. Upon initial execution of the Intervisibility Metric Program, the control computer shall display a menu of the following options:

- Create Sample Points
- Display Sample Points
- Select Intervisibility Options
- Begin Intervisibility Observations
- Display Intervisibility Numbers
- Change View/Target Heights
- Transfer Files To Disc
- Exit To Operating System

2.1 For the Create Sample Points option, the control computer shall request the desired number of sample points. The user will enter the desired number based on tables in the User Manual. Arrays shall be sized for up to 1000 test points. The computer shall then compute a uniform distribution of sample points, starting from a randomly selected start point chosen by the control computer. When the sample points have been computed, the screen will display a message notifying the user and ask the user to press <Enter> to return to the previous menu.

2.2 For the Display Sample Points option, the control computer shall display the following options:

- Display Sample Points on Terrain Model (God's Eye View)
- Display Sample Points In Tabular Form
- Return to Previous Menu

For the God's Eye View, the Computer Image Generator computer shall display the terrain model, place a dot on each sample point and allow the user to zoom in and out and move left, right, up and down. For the tabular form option, the control computer shall display a list of test points and their X Y coordinates. The screen will display a message asking the user to press <ENTER> to return to the previous menu upon completion of viewing the test points.

2.3 For the Select Intervisibility Options, the control computer shall present the following options:

- Select View Type Options
- Select Target Type Options
- Return to Previous Menu

2.3.1 For the Select View Type Options option, the control computer shall list the options:

- DI
- Tank
- Rotary Wing
- Fixed Wing
- Other No. 1
- Other No. 2
- Other No. 3
- Other No. 4
- Selection Complete

and ask the user to select the desired options using either mouse or keyboard. The program will also allow the user to unselect items using the mouse or keyboard. Set the view (V) values for use in 2.4. When the user selects Selection Complete, the program shall return the user to the previous menu.

2.3.2 For the Select Targets option, the control computer shall list the options:

- DI
- Tank
- Rotary Wing
- Fixed Wing
- Sphere (1m dia.)
- Sphere (2m dia.)
- Sphere (4m dia.)
- Sphere (8m dia.)
- Sphere (16m dia.)
- Sphere (32m dia.)
- Sphere (64m dia.)
- Selection Complete

and ask the user to select the desired options using either mouse or keyboard. The program will also allow the user to unselect items using the mouse or keyboard. Set the target (T) values for 2.4. When the user selects Selection Complete, the program shall return the user to the previous menu.

2.4 For the Begin Intervisibility Observations option, the control computer shall present the following options:

- Begin Observations
- Display Current Options
- Continue Observations From Earlier Session
- Prompt User For Break
- Return to Previous menu (with or without saving)

2.4.1 For the Begin Observations option, the control computer shall display the following message:

The targets you have selected can be viewed at the following distances with the following magnification:

Distance (m)

<u>Target</u>	<u>Naked Eye</u>	<u>Optics</u>			
		<u>3x</u>	<u>5x</u>	<u>7x</u>	<u>9x</u>
DI	XXX	XXX	XXX	XXX	XXX
Tank	XXX	XXX	XXX	XXX	XXX
Rotary Wing	XXX	XXX	XXX	XXX	XXX
Fixed Wing	XXX	XXX	XXX	XXX	XXX
Sphere (1m dia.)	XXX	XXX	XXX	XXX	XXX
Sphere (2m dia.)	XXX	XXX	XXX	XXX	XXX
Sphere (4m dia.)	XXX	XXX	XXX	XXX	XXX
Sphere (8m dia.)	XXX	XXX	XXX	XXX	XXX
Sphere (16m dia.)	XXX	XXX	XXX	XXX	XXX
Sphere (32m dia.)	XXX	XXX	XXX	XXX	XXX
Sphere (64m dia.)	XXX	XXX	XXX	XXX	XXX

You will only be shown targets at test points that fall within these ranges. Please select the desired optics for viewing targets by (clicking with the mouse or using the arrow keys to position the cursor and pressing <ENTER> over the desired optic or via a pulldown/popup menu).

The control computer will allow the user to use arrow keys or mouse point and click to select and unselect an optics choice. A message displayed at the bottom of the screen will ask the user to press <ENTER> when the selection is complete. Only the targets selected in 2.3.2 above will be listed. Default selection will be the Naked Eye.

The control computer shall then display the following message, which will also appear in the Quit with/without saving option:

Enter name to be given to this set of observations:

Observations Name (8 Characters Max) _____

Enter your name:

Your Name (24 Characters Max) _____

The Observations Name must be unique, so the program must compare it to existing saved observation file names. After the user enters the names, the control computer will ask the user to press <ENTER> to start the observations.

2.4.1.1 For the observation tests, the image generator/simulation computer shall follow the logic listed below:

- For each view point
(Position the view screen perspective at V feet above the terrain, starting with the first sample point)
- For each view type for that view point
(Starting with the highest view type)
 - For each target point for that view type and view point
(Selecting the second sample point as the first target point)
 - For each target type for that target point, view type and view point
(Limit targets to those that can be seen at that range from the view point)
 - Place a correctly sized target (Prone Soldier, Tank, Helicopter, Aircraft, Ball; starting with the highest target type selected) at a point T feet above the terrain at the target point
 - Display view point and target point coordinates, view type and target type on control computer
 - Rotate view such that target is in the middle of the screen
 - Control computer asks the observer if the target is visible
 - Control Computer accepts user response by mouse or keyboard
 - Control Computer records observer response
 - Increment to next target type until all target types have been viewed for that target point, view type and view point
 - Increment to next target point (skip viewpoint as target point) until all target points have been viewed for that view type and view point
- Control computer shall record the number of each type of target visible at that view point for each view type (See Figure 1 for example)
- Increment to next view type until all view types have been viewed for that view point
- Increment to next view point

If the user has selected to have program breaks, the control computer will interrupt the observations by displaying a message specifying that this is a rest break and asking the user to hit <ENTER> when they want to resume observations.

When the user completes all observations or ends session, the control computer will save the file (under user-specified name), containing date, time, user name, viewpoint types, target types, view heights, target heights, magnification, coordinates of test points, number of targets visible at each viewpoint by view type and target type, and flag indicating observations complete or incomplete.

Provide the user with the option to end the session at any time. If the user selects this option, the control computer will save the file with an incomplete flag, and save the information listed in the previous paragraph.

Once information has been saved, the control computer will prompt user to return to previous menu.

2.4.2 For the Display Current Options option, the control computer will list the optics options and whether the user has chosen to break and when. A message on the screen will ask the user to press <ENTER> to return to the previous menu.

2.4.3 For the Continue Observations From Earlier Session option, the control computer shall list all incomplete files and allow the user to select/unselect the desired one by positioning the cursor with arrow keys or the mouse. The control computer shall then prompt the user for his name and ask him to press <ENTER> to start the observations. Upon starting observations, place the user at the last viewpoint and target from the file and continue processing as described in 2.4.1.1.

2.4.4 For the Prompt User for Break option, the control computer will display a message asking if the user wishes to have the observations interrupted. If the user responds yes, the user will be allowed to choose the time between breaks: 5 min, 10 min, 15 min, or 20 min. The user may select or unselect a time and return to the previous menu without making a selection. In this case, no breaks will occur.

2.4.5 For the Return to Previous Menu (with/without saving) option, the control computer will prompt the user for their name and the observation name as described in 2.4.1. If the information was entered in 2.4.1, it will be displayed when the user selects this option. A message will be displayed asking if the user wishes to save the file. If the user responds yes, another message will appear stating that the file has been saved and asking the user to press <ENTER> to return to the previous menu.

2.6 For the Display Intervisibility Numbers option, the control computer shall display a menu of the following options:

- Display Tables
- Display Numbers on Terrain
- Return to Previous Menu

2.6.1 For the Display Tables option, the control computer shall display Figure 1. An option to return to the previous menu shall be displayed.

2.6.2 For the Display Numbers on Terrain option, the Image Generator computer shall display the same God's eye view of the terrain (see 2.2) with view points marked by dots. The control computer shall prompt the user to select the desired viewpoint, view type and target type. It shall then display the number of that type of target visible at each target point from that view point and view type combination. An option to return to the menu shall be displayed.

2.7 For the Change View/Target Heights option, the control computer ask the user to select the heights they would like to change, (V)iew or (T)arget? The control computer shall then display the following table for each type of height:

<u>TYPE</u>	<u>HEIGHT ABOVE TERRAIN (Meters)</u>
Dismounted Infantry	0
Tank	0
Rotary Wing A. C.	15
Fixed Wing A. C.	100
Sphere (1m dia.)	0
Sphere (2m dia.)	0
Sphere (4m dia.)	0
Sphere (8m dia.)	0
Sphere (16m dia.)	0
Sphere (32m dia.)	0
Sphere (64m dia.)	0

The control computer shall allow the user to indicate which of the heights are to be changed by using arrow keys or the mouse to select the target type and then positioning the cursor on the height field. The user can then enter a new height or escape from selection. The control computer will then ask the user if they want to change the other height table before returning to the previous menu. The heights shown above shall be used as default initial

heights for both view points and target points each time the program is executed.

2.8 For the Transfer Files To Disc option, the control computer shall display Figure 2 and prompt the user to select the view type / target type combination desired. The test point data will be saved on micro floppy disc in a format compatible with SSPS statistical analysis package or summary table.

ASCII Codes shall be created for the following types and these codes shall be used when writing the data to the disk and when storing the data on the hard drive:

Types

IG: 1 = SIMNET, 2 = Silicon Graphics, 3 = E & S

TARGET TYPE/

VIEW TYPE: 1 = Dismounted Infantry
2 = Tank
3 = Rotary Wing A. C.
4 = Fixed Wing A. C.
5 = Sphere (1m dia.)
6 = Sphere (2m dia.)
7 = Sphere (4m dia.)
8 = Sphere (8m dia.)
9 = Sphere (16m dia.)
10 = Sphere (32m dia.)
11 = Sphere (64m dia.)

VIEW HEIGHT: Height in meters

TARGET HEIGHT: Height in meters

VISIBLE: 0 = No, 1 = Yes

A method of archiving the data files on the hard drive must also be established.

Figure 1
TARGET VISIBILITY NUMBERS

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Attachment F: LOSIM Software Distribution List

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Attachment G: Discerning a Fair Fight on Dissimilar Simulators

Discerning a fair fight on dissimilar simulators

Objective

The goal is to determine when a fair fight has occurred on differing simulators. This will require the collection of data from paired simulators. That data would consist of values which represent the mismatch of the simulated terrains/environments and also a number reflecting the skill level of the two warriors. We need to be able to determine when these values fall into a tolerable range so that the ultimate outcome of these two warriors' combat would be essentially (at least statistically insignificantly) indistinguishable from a combat scenario run on identical terrains.

Assumptions and Terminology

There exists software on the paired simulators which samples and compares the two simulators' terrain representation at varying sites or points. This sampling is done to classify points. In the terminology of M. Johnson's 1992 paper, there is a total of n sampled points where there will be $n(1,1)$ number of points where warrior 1 and warrior 2 both see a realistic portrayal of the environment characteristic (bush, valley etc.); $n(1,2)$ where warrior 1 sees it but warrior 2 does not; $n(2,1)$ where 2 sees it but 1 does not; $n(2,2)$ where it is missing for both. We infer that both $n(1,1)$ and $n(2,2)$ type points are agreement points. The $n(1,2)$ points are advantageous for warrior 2 since, for example, warrior 1 would be hiding behind a bush as portrayed on his simulator but warrior 2 would have a clear shot at him. We will assume that warrior 2 takes full advantage of this situation and earns a kill at these types of points. Let $k = n(1,2)/n$ (the proportion of advantage warrior 2 points) and $m = n(2,1)/n$ (advantage warrior 1). Once the combat has taken place assign the label "warrior 2" to the best warrior. Best is determined by the kill ratio of # kills/ total kills being .5 or larger. Call this value p^* . p^* is a representation of the true underlying p which is the probability that warrior 2 will kill warrior 1 when the environment is realistically portrayed. Note: p , of course, is unknown.

Approach to meet Objective

Sample n points from the terrain/environments of the paired simulators (sample size selection is discussed below). Calculate k (the proportion of advantage warrior 2 points) and m (for warrior 1). Direct warriors A and B to fight on the simulators. Record p^* , the kill ratio of the better warrior, ie. $p^* \geq .5$. Refer to this warrior as warrior 2. Define your version of a fair fight, that is, choose K so that $|(p^* - p)/p| < K$ is acceptable where p is the actual skill level, kill ratio for warrior 2. Generate bounds for k and m (which are obviously statistics since they are formed from sampled data).

$$\begin{aligned}kl &= k - z * \text{SQRT} ((k * (1 - k) / n)) \\ku &= k + z * \text{SQRT} ((k * (1 - k) / n)) \quad (1)\end{aligned}$$

$$ml = m - z * \text{SQRT} ((m * (1 - m) / n))$$

$$mu = m + z * \text{SQRT} ((m * (1 - m) / n)).$$

z is chosen from the standard normal tables, such as, let $z = 1.96$ if you wish to be at least 90% sure (since we are forming 2 confidence intervals via Bonferroni we can be at least $1 - 2 * \alpha * 100\%$ sure) that we are executing a fair fight via the K criteria. Note: if the lower bounds are less than zero then set them equal to zero, if the upper bounds are greater than 1 then set them equal to one. You will now compute four pairs of proportion interval endpoints using the following formulae (for use when $K < k + m$):

$$pl = k / (k + m + K)$$

$$pu = \min \{ k / (k + m - K), 1 \}$$

Using these four pairs for (k,m): (kl,ml), (kl,mu), (ku,ml), (ku,mu). To discern whether a fair fight via the K criteria has ensued check the following for each of the 4 intervals (pl,pu): 1) if $k + m \leq K$ then a fair fight is declared, or 2) if $pl < p^* < pu$ then a fair fight is declared. All four scenarios must result in a fair fight in order to insure that a fair fight, ie. that we are at least 90% sure (if $z=1.96$) that $|(p^* - p)/p| < K$ is assured for this engagement of these warriors on this pair of simulators. There may be times where an unfair fight has been declared but we are willing to alter our criteria. If appropriate, K (the criteria for allowable discrepancy between p^* and p) can be made larger. Or the z value can be made smaller in bounding the k and m proportions (meaning less confidence in our conclusion).

Example

We have paired simulators and we need to sample them and ascertain their level of agreement. We believe approximately that $m=k=5\%$ of the points on the simulators are in disagreement. A good estimate of the sample size is $9 * (1-m)/m$ which in this case is 171. We decide to sample 180 points. On these 180 points we find 10 which are advantage warrior 2 points and 8 which are advantage warrior 1 points. And 162 agreement points. So $k = 10/180 = .0556$ and $m = 8/180 = .0444$. Combat yields a kill ratio of $p^* = .583$. Now $kl = .0556 - 1.96 * \text{SQRT} ((.0556 * .9444)/180) = .022$ $ku = .0556 + 1.96 * \text{SQRT} ((.0556 * .9444)/180) = .089$ $ml = .0444 - 1.96 * \text{SQRT} ((.0444 * .9556)/180) = .014$ $mu = .0444 + 1.96 * \text{SQRT} ((.0444 * .9556)/180) = .074$

We desire a K value of .05.

The 4 cases look like:

	<u>k</u>	<u>m</u>	<u>pl=k/(k+m+K)</u>	<u>pu=k/(k+m-K)</u>
(1)	.022	.014	since $k+m = .022+.014 < K=.05$, fair fight	
(2)	.022	.074	.15	.478
(3)	.089	.014	.58	1.0
(4)	.089	.074	.42	.79

Since $p^* = .583$ is not in interval (2) we can not be 90% sure that a fair fight under the $|(p^* - p)/p| < .05$ criteria has occurred. What if we were willing to tolerate a K of .10? The recomputations look like this:

	<u>k</u>	<u>m</u>	<u>$pl=k/(k+m+K)$</u>	<u>$pu=k/(k+m-K)$</u>
(1)	.022	.014	.036	<.10, fair fight
(2)	.022	.074	.096	<.10, fair fight
(3)	.089	.014	.44	1.0
(4)	.089	.074	.34	1.0

Now $p^* = .583$ falls in the intervals or $k+m < K$ so we can be at least 90% sure that $|(p^* - p)/p| < .10$ or $|(.583 - p)/p| < .10$, ie. $.530 < p < .648$.

Theory

There is a true underlying p which on a fight encounter is the probability that warrior 2 (the better skilled warrior) will kill warrior 1 when the environment is realistically portrayed. Let there be n opportunities (assume independence). In the simulated environment warrior 2 does not have probability p of securing a kill at each opportunity. In fact, let us assume that if the opportunity (site or point) is of the advantage warrior 2 type then the probability of a kill there is 1 and if it is an advantage warrior 1 point then the probability of a kill for warrior 2 there is 0. Only on agreement points is the probability of a kill equal to p . Designate there to be $k \cdot 100\%$ advantage warrior 2 points and $m \cdot 100\%$ advantage warrior 1 points. Initially, we will assume that k and m are parameter values (ie. exact proportions) rather than statistics garnered from samples. Then p^* which is the kill ratio on the simulated environment is $(pn(1 - m - k) + kn)/n = p(1 - m - k) + k$. We need to develop an error measure which quantifies the dislike for a p^* which misrepresents p (ie. develop a criteria for a fair fight). A reasonable measure is $|(p^* - p)/p|$. Note that this measure is more relaxed for higher values of p than for those near .5. For example, although a $p^* = .8$ and a $p = .9$ compared to a $p^* = .55$ and a $p = .65$ are both .1 in difference, their error measure is .111 and .154 respectively. This is intuitively appealing because it is important to keep errors low around $p = .5$ because this is the point where it may be difficult to discern who is the better fighter. We need to investigate the error measure surface to understand what values it takes on for varying values of p , k and m . $|(p^* - p)/p| = |(p(1 - m - k) + k - p)/p| = |(k/p) - (k + m)|$. The first pertinent question to ask is: what naturally occurring bound exists for this error measure? $|(k/p) - (k + m)| = |k(1 - (1/p)) - m| < |k(1 - (1/p))| + |m| < |k| + |m| = k + m$. So the criteria for acceptable closeness of p^* to p takes on a value no larger than $k + m$. So if we are willing to state that an error measure of $K = k + m$ is acceptable (which will only be feasible for small values of k and m) then p^* will adequately reflect p , ie. we have a fair fight. In the other case where $k + m$ is not small enough, we need to further investigate the surface of our error measure. The next valid question pertains to the values which make $|(p^* - p)/p|$ equal to zero. $|(k/p) - (k + m)|$ can be made to be zero either by

1) setting $p = k/(k + m)$ or

2) by setting $k = 0$. So our error measure is 0 at $(k, p) = (0, k/(k + m))$. Let us move slightly away from this point and investigate the consequences. Let us move to $(k, d(k/(k + m)))$, where d and k are some small positive amounts. The error measure at this new point is $!k/(d(k/(k + m))) - (k + m)! = !(k + m)/d - (k + m)! = !(k + m)((1/d) - 1)! = !k + m!!(1/d) - 1!$. To keep this less than some value K we need $!k + m!!(1/d) - 1! < K$ or $!(1/d) - 1! < K/(k + m)$ or $-K/(k + m) < (1/d) - 1 < K/(k + m)$ or $(k + m)/((k + m) + K) < d < (k + m)/(k + m - K)$. Putting this d value back in the point we move to which was slightly away from $(0, k/(k + m))$ gives us $(k, k/(k + m + K))$ and $(k, k/(k + m - K))$. Therefore, the p^* values close enough to p to insure $!(p^* - p)/p! < K$ are such that $k/(k + m + K) < p^* < k/(k + m - K)$ (2) and those will serve as bounds for kill ratios in a fair fight. Now, k and m are only estimates for the true underlying proportion of advantage warrior 2 points and advantage warrior 1 points. We need to develop confidence intervals about these estimates and use those bounds rather than the point estimates in inequality (2). Recall that k and m were generated out of a sample of size n . Assuming an underlying binomial and using a normal approximation to it yields the equations found in (1). Any (k, m) combination of the kl , ku and ml , mu is feasible based on these confidence intervals. That is why each of the 4 possibilities must be explored and our p^* checked in inequality (2) for the fairness of the fight. Lastly, we need to recommend an appropriate sample size, ie. how many points to check on the paired simulators. If k and m are truly not equal to zero we would like a high probability of detecting that and then to have ml and kl be positive bounds. If we were to form 99% confidence intervals about m and k the z -score is about 3. A guesstimate of the smaller of k and m will suffice in the standard deviation associated with these proportions and we would strive to make say, $m - 3 \cdot \text{SQRT}(m(1-m)/n) > 0$; solving yields $n = 9(1-m)/m$.

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