U.S. Army Armament Research, Development and Engineering Center

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Method and Process For The Creation of Modeling and Simulation Tools for Human Crowd Behavior

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14. ABSTRACT

Commanders need tools for planning, decision support, and analysis related to crowd management with non-lethal weapons. This problem requires predictive crowd modeling and simulation tools for forecasting human behavior. The Target Behavioral Response Laboratory (TBRL) has worked to develop new methods to provide modeling and simulation operational planning tools to provide commanders with the capability to predict crowd response to military control force tactics, techniques, and procedures. The TBRL has developed processes based on behavioral science experimental methods and objective measurements under controlled conditions. These methods and measures include motion capture of subjects in a laboratory environment to derive coefficients for equations which quantitatively model a crowd's behavior, which are can be validated at more than one point in the process. This technique can model a crowd's path deviation response to different weapon, device, or control force emplacements as the crowd moves towards an objective of positive valence, which might aid a commander in choosing and positioning those weapons. The TBRL has gathered a large data set from a variety of human crowd experiments using non-lethal energies and devices to determine effectiveness. These data serve as the input and validation tools for model building. The process comprises of several modules that work together to produce simulated data for crowd locomotive behavior; estimating crowd responses to several non-lethal technologies and their surrogates. The process yields models that accurately estimate crowd behavior for baseline and a Medium Range Acoustic Device condition and partially estimates crowd behavioral response for area denial technology (ADT) and hand-held standoff non-lethal weapons. Building on human behavioral data allows the model to capture the behaviors, range, variability, probability, and uncertainty, the dynamic nature of human behaviors. Starting with the gathering of data on human behavior allows one to configure the test to gather data on the information relevant to building the models and simulation to answer the commander???s question. This process increases the availability of data on human behavior, facilitates the development of architecture-free, reusable, composeable, interoperable human behavioral models and simulation, and provides objective verification and validation metrics. It provides decision support to commanders, specifically with quantitative information based on human behavioral data gathered under controlled conditions.

15. SUBJECT TERMS

Human Behavior Modeling and Simulation, Mathematical Model, Computational Model, Non-lethal Weapons, Human Experimentation, Empirical Data, Behavioral Models, Target Behavioral Response Laboratory, Crowds, Predictive Crowd Modeling, Motion Capture

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Overview

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ARDEC's Role


RESEARCH


DEVELOPMENT


PRODUCTION


FIELD SUPPORT


DEMILITARIZATION

Advanced Weapons:
Line of sight/beyond line of sight fire; non line of sight fire; scalable effects; non-lethal; directed energy; autonomous weapons

Ammunition:
Small, medium, large caliber; propellants; explosives; pyrotechnics; warheads; insensitive munitions; logistics; packaging; fuzes; environmental technologies and explosive ordnance disposal

Fire Control:
Battlefield digitization; embedded system software; aero ballistics and telemetry

ARDEC provides the technology for over 90% of the Army's lethality and a significant amount of support for other services' lethality

Introduction

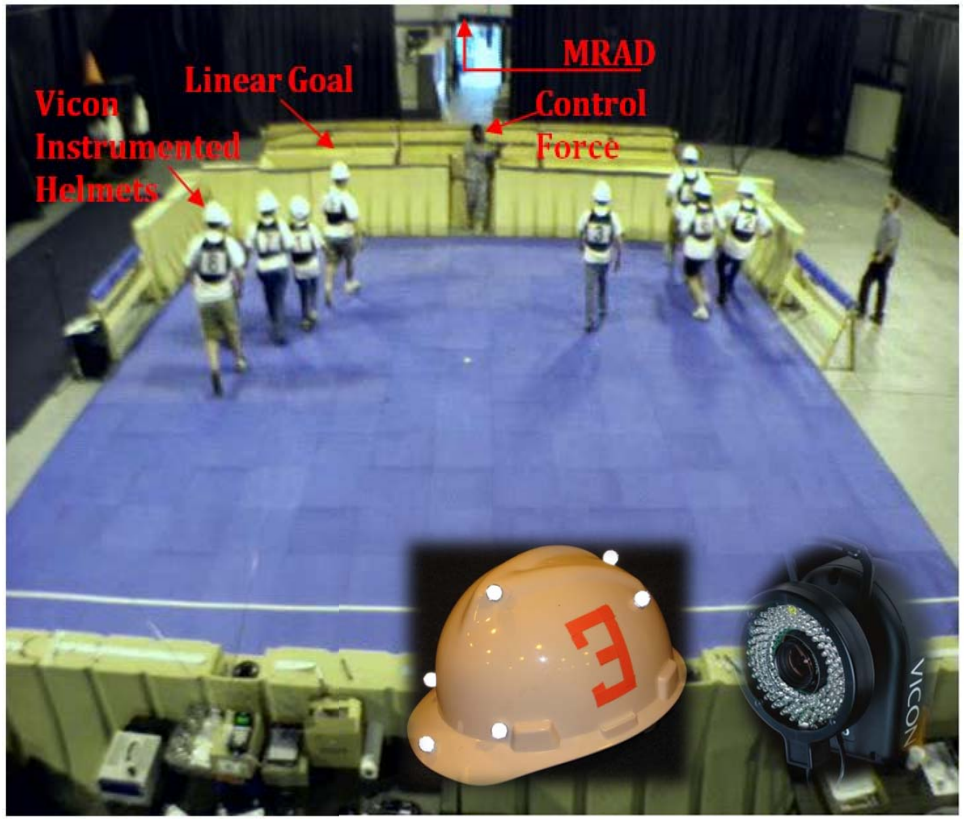
Military Need for Crowd Behavior Research

- The motivations underlying adversarial behavior
- Behavior of contested populations
- How the behavior of populations varies cross-culturally
- What is innate human behavior that extends across cultural boundaries?

Introduction

Crowd Behavior Research at TBRL

- Human behavior can be explained as attractions and repulsions toward and away from goals (Lewin, 1935)
- Crowd Behavioral Test Bed used to gather:
  - locomotive
  - psychosocial
  - effectiveness data
- Data gathered to develop models that use vector regression methods to identify attributes of a crowd that influence predictive variables



Data Collection

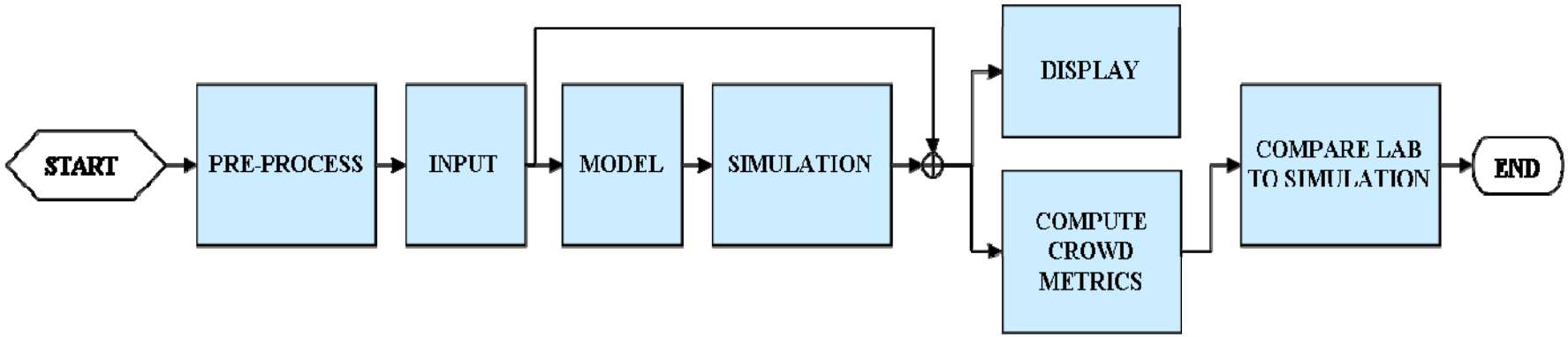
Experimental Conditions

- Crowds with up to 25 subjects during a trial throwing simulated rocks into a linear target while the target was defended by a non-lethal device:
  - No Defense (Baseline)
  - MRAD
  - Handheld stand-off NLW operated by Control Force
    - Simulated Projectile Weapon
    - Simulated Handheld Directed Energy NLW (VDE)
  - Simulated Invisibly located Directed Energy NLW (IDE)

M & S Process

Model Building

- **MATLAB modules for developing software to:**
  - Automate the creation of mathematical models for motion of individuals in a crowd from the data collected in TBRL crowd experimentation
  - Run simple simulation of the above model to generate simulated data
  - Calculate crowd level metrics from laboratory and simulated data
  - Compare simulated data with observed data



M & S Process

Model Building

- **Pre-Process Module**
  - Separates modeling and validation data
  - Restructures the location data file
    - Data for each participant at sample time is grouped and appended to preceding time steps
- **Input Module**
  - Parses the formatted data from the previous step into three elements:
    - Header vector
    - Output matrix
    - Predictor matrix

M & S Process

Model Building

- **Modeling Module**
  - Accepts the predictor and output matrices
  - Performs non-linear regressions to determine the relationship between predictor/input and predicted/output variables.
    - [beta, r, J, COVB, mse] = nlinfit(X, y, fun, beta0)
    - Regression of velocity vectors in both ‘X’ and ‘Y’ axes against the predictors, generating model coefficients for change in location in ‘X’ and ‘Y’ coordinates
  - Model errors were fit to Weibull distribution

M & S Process

Simulation

- **Simulation Module**
  - Execute a time stepped simulation of each subject's location based on:
    - derived model
    - starting conditions
    - average time between samples
    - duration of simulation
  - Calculate the following for each subject at each time step and appended to a simulated data file
    - delta distance traveled
    - delta position
    - velocities
  - Incorporate Control Force effects by transforming the coordinates of the baseline model to fit that of the CF model

M & S Process

Crowd Metric Analysis

- **Crowd Metric Module**
  - Calculates aggregate metrics of crowd behavior as a whole
    - Leading edge (LE): location of the forward most crowd member
    - Trailing edge (TE): location of the crowd member that is furthest back
    - Centroid: location of the crowd member that is midway between the LE and TE
    - Geometric center: mean of the LE & TE
    - Dispersion: average displacement in the ‘X’ and ‘Y’ direction

M & S Process

Model Validation

- **Model Comparison**
  - Compares, statistically, the crowd metrics of simulated and observed data
    - two sample Kolmogorov-Smirnov (K-S) goodness of fit (GOF) test
    - Determine if the simulated data follows the same distribution as the observed data, the asymptotic p-value, and k-statistic
  - 5% significance level
  - Unequal alternative hypothesis test

Results

Model Verification

- **RMSE comparison**
  - Comparison between the expected values calculated from the regression equation and the data observed in the laboratory

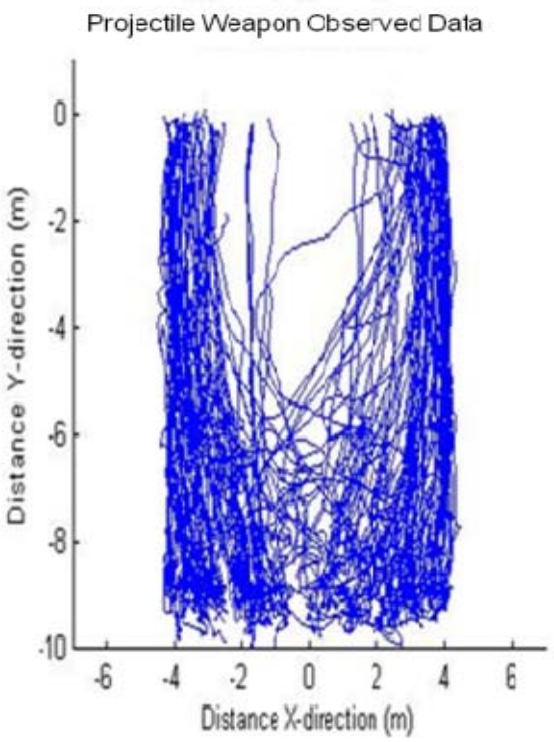
Conditions	RMSE (Radial) [meters]	RMSE (Tangential) [meters]
Baseline	0.5	
Projectile Weapon	0.65	0.54
Visible Directed Energy	0.47	0.36
MRAD	0.37	0.26
Invisible Directed Energy	0.37	0.38

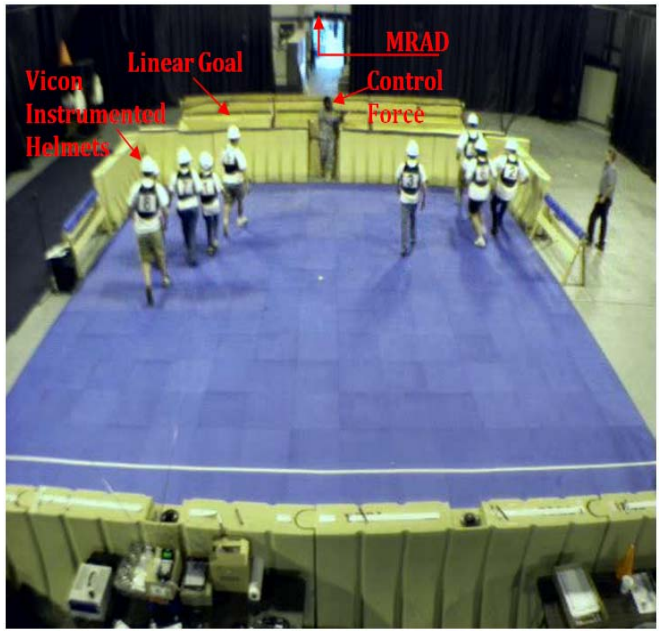
Root Mean Square Error: RMSE

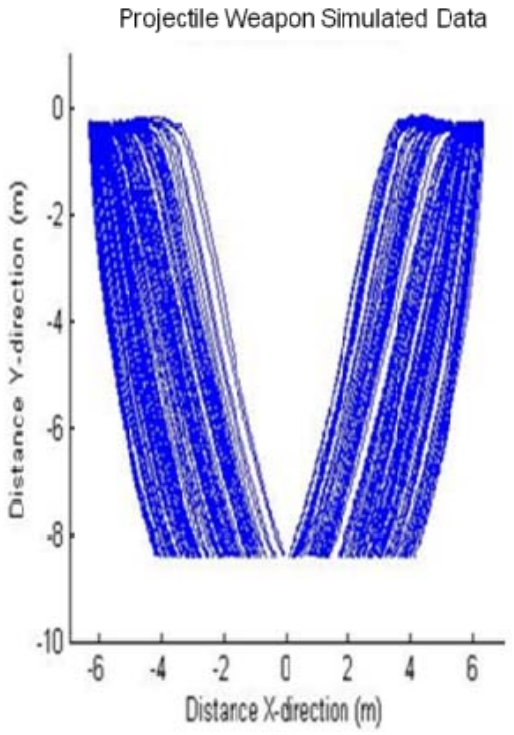
Results

Model Verification

- **Graphical Comparison**



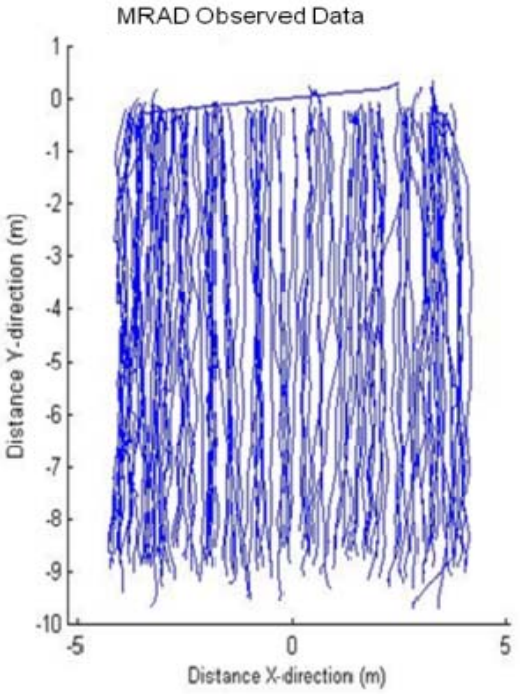


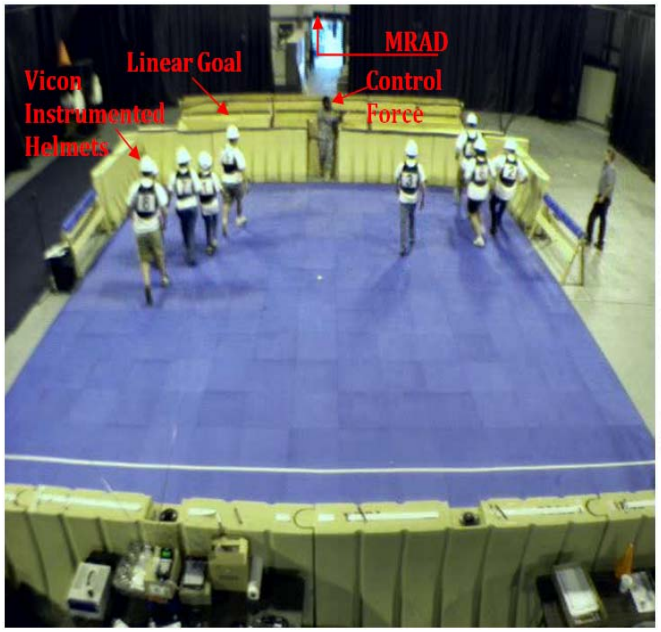


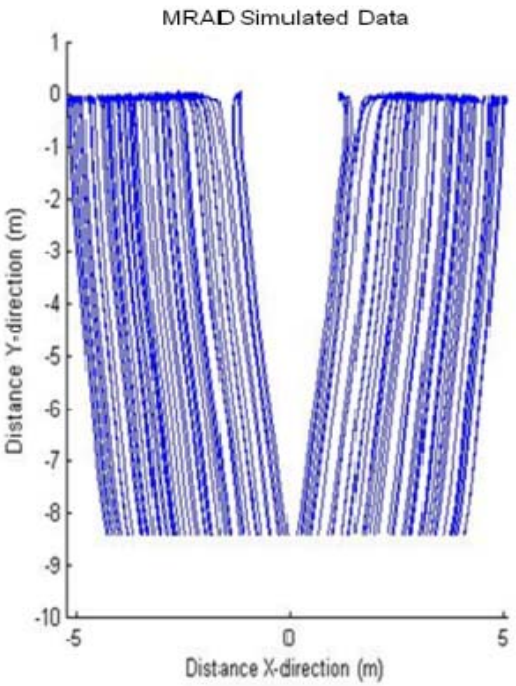
Results

Model Verification

- **Graphical Comparison Cont'd**







Results

Model Validation

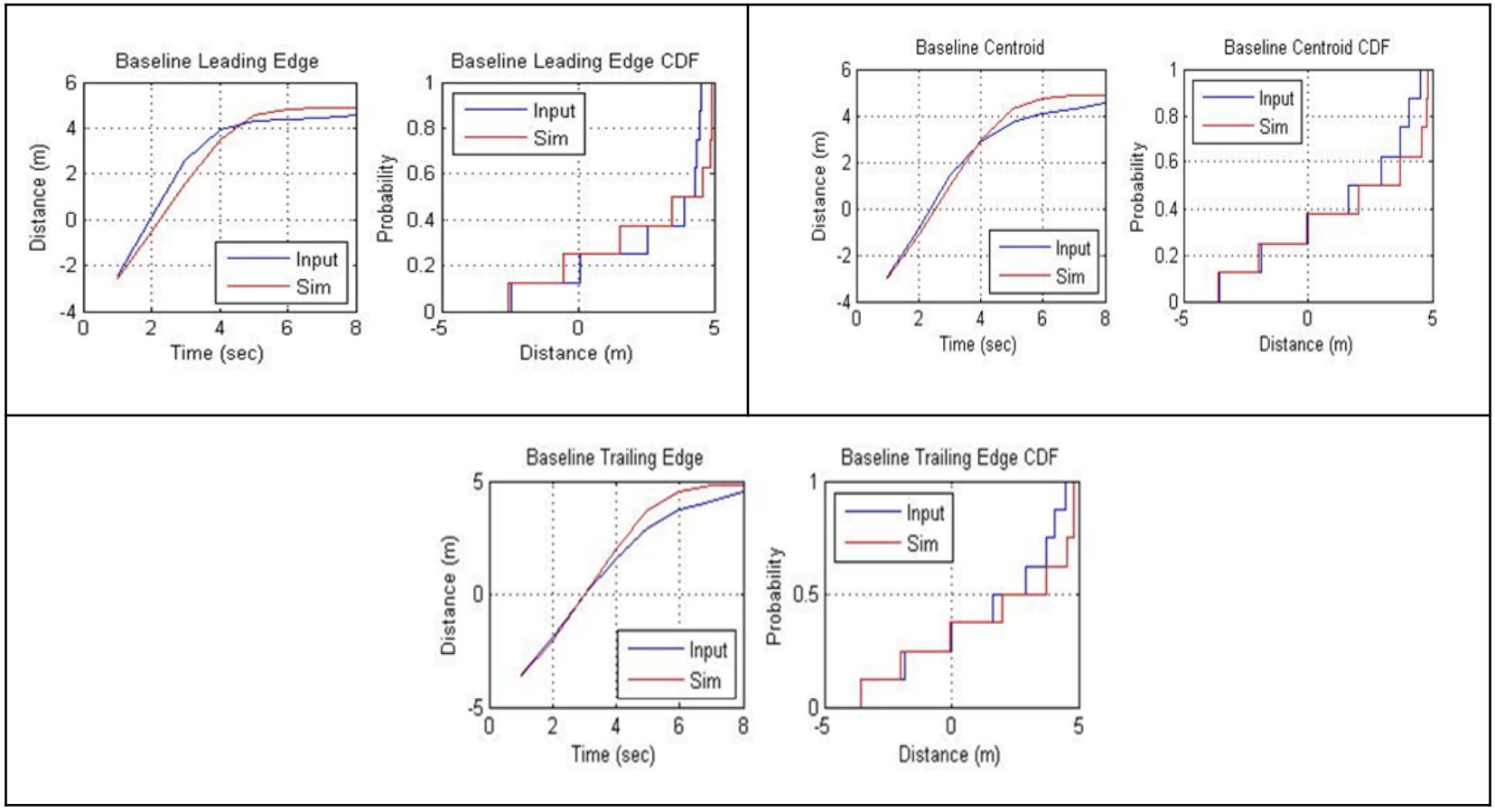
- **K-S GOF Test**

Conditions	Measures	H [Accept(0) /Reject(1)]	P-value	K-S Statistic
Baseline	LE	0	0.188	0.500
	Centroid	0	0.519	0.375
	TE	0	0.519	0.375
MRAD	LE	0	0.883	0.286
	Centroid	0	0.883	0.286
	TE	0	0.883	0.286
Projectile Weapon	LE	1	0.001	0.714
	Centroid	1	1.19E-04	0.786
	TE	1	1.87E-05	0.857
Visible Directed Energy	LE	0	0.077	0.667
	Centroid	1	1.19E-04	0.786
	TE	1	1.87E-05	0.857
Invisible Directed Energy	LE	1	1.87E-05	0.857
	Centroid	1	2.50E-06	0.929
	TE	1	2.86E-07	1.000

Results

Model Validation

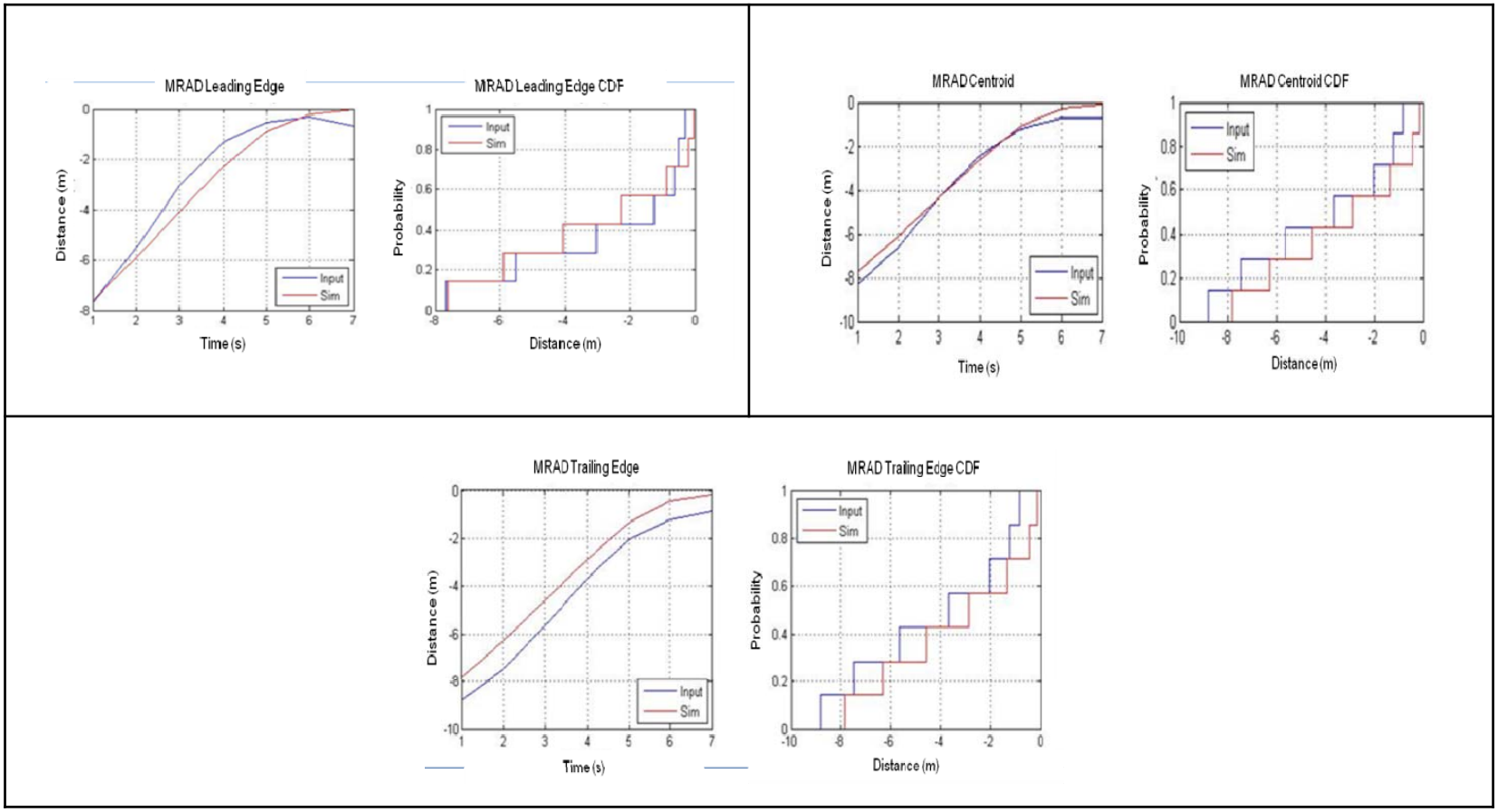
- **K-S GOF Test - Baseline**



Results

Model Validation

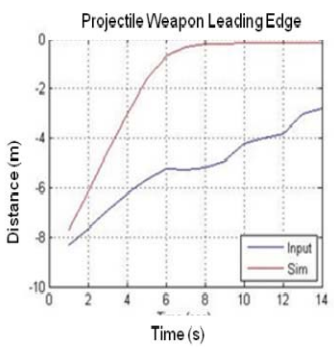
- **K-S GOF Test - MRAD**

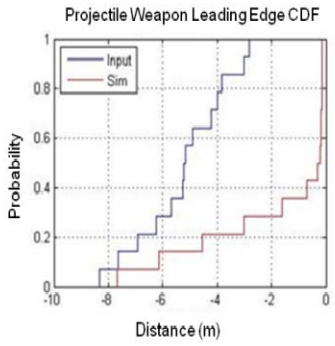


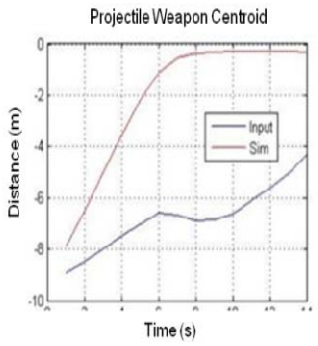
Results

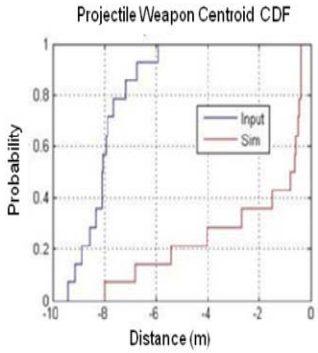
Model Validation

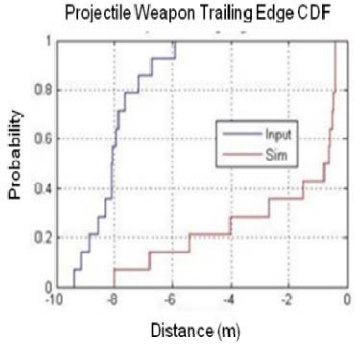
- **K-S GOF Test - Projectile Weapon**











Conclusion

- There are several identified areas for improvement which include:
  - Using additional or new regression methods that yield more accurate models reflected by smaller RMSE
  - Accounting for error during simulation and making necessary adjustments to produce data that more closely represent observed data
  - The incorporation of crowd metrics for the observed data set into the model development process to improve the goodness of fit for the observed and simulated data
  - Using additional goodness of fit tests to validate the model

Summary

- The model development process created has successfully
  - created models from Laboratory collected data
  - simulated models over time to generate crowd data per condition
  - performed analysis of observed and simulated data
  - compared simulated and observed data against crowd behavioral measures

- The process allows for quantitative means for validation of both the mathematical and computational models against empirical data
- The models created for the baseline and the MRAD weapon conditions successfully estimated crowd locomotive behavior
- Some of the models created still need refinement based on the graphical comparison of the simulated and observed data in addition to the K-S GOF test

Target Behavioral Response Laboratory
MORSS Presentations

- Virtual Employment Test Bed: Operational Research and Systems Analysis to Test Armaments Designs Early in the Life Cycle
- Method and Process for the Creation of modeling and Simulation Tools for Human Crowd Behavior
- Squad Modeling and Simulation for Analysis of Materiel and Personnel Solutions
- The Squad Performance Test Bed
- Crowd Characteristics and Management with Non-Lethal Weapons: A Soldier Survey
- Effectiveness Testing and Evaluation of Non-lethal Weapons for Crowd Management
- Effects of Control Force Number, Threat, And Weapon Type on Crowd Behavior

Questions?

US Army - Target Behavioral Response Lab

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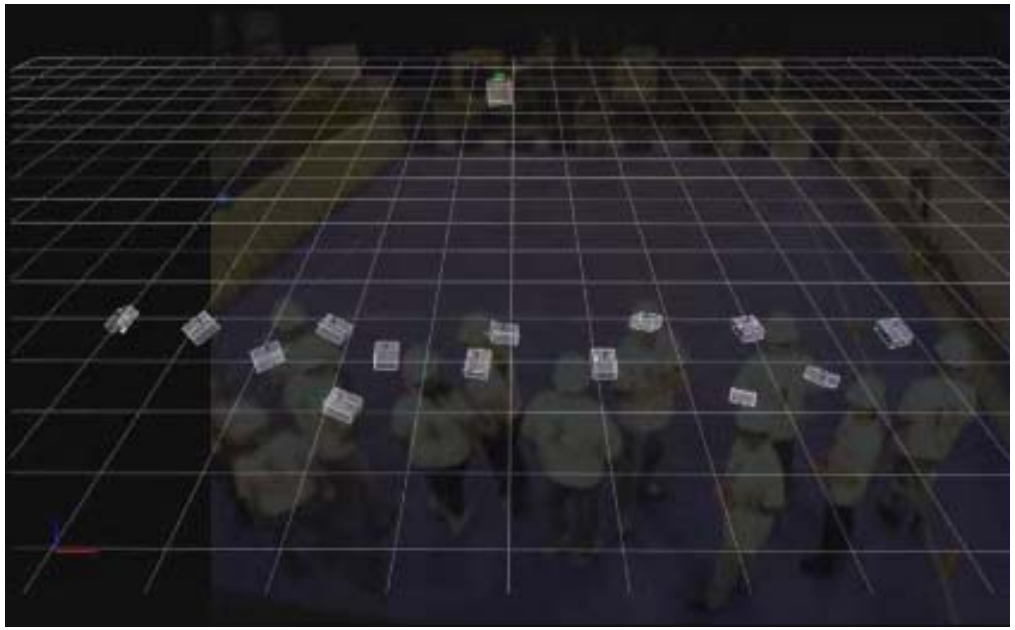
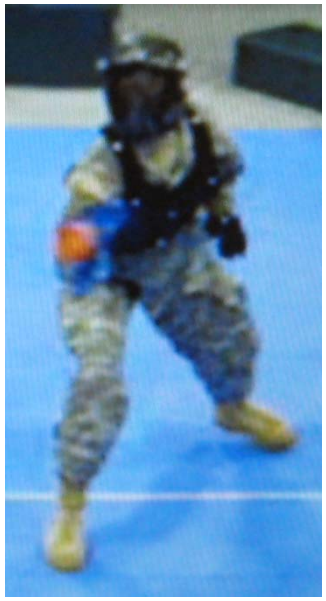
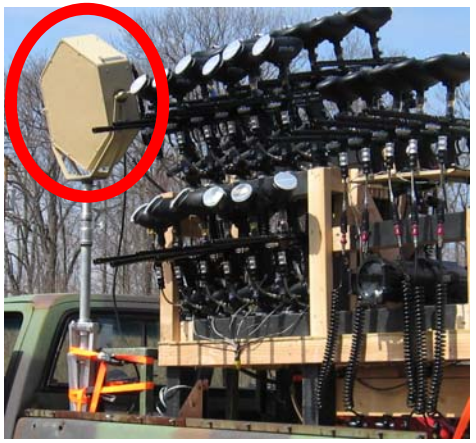
BACKUP SLIDES

Data Collection

Crowd Behavior Test Bed







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