Network Science and Crowd Behavior Metrics

Target Behavioral Response Laboratory
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26th Army Science Conference
Orlando, FL
December 2, 2008
# Network Science and Crowd Behavior Metrics

**Presented at the 26th Army Science Conference, December 1-4, Orlando, Florida.**

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**Abstract:**
ARDEC’s Target Behavioral Response Laboratory is currently conducting research on methods for crowd laboratory experiments, specifically crowd behavior metrics. Crowd metrics based on topological data were derived using motion capture methods. Sociometrics were based on coded videotaped communications. The preliminary results suggest that these crowd metrics, including those produced by network science methods, should be considered for further study. The results also suggest that crowd metrics, rather than only weapon characteristics, should be used to compare effectiveness of non-lethal weapons from different technologies.

**Subject Terms:**
network science, sociometrics, non-lethal weapons, crowd, motion capture, effectiveness metrics, control force, human behavior, human experimentation, Target Behavioral Response Laboratory, Kurt Lewin, field theory, topology
The Problem

- Large numbers
- Heterogeneous
- Individual Actors
- Interdependence
- Language Barriers

- Empirical testing is difficult
- Social behavioral research has been lacking
- Simulations require models based on real data, otherwise they are fiction.
Method

- Groups of 12 individuals
- Controlled motivations toward goal & away from control force with money
- Manipulated type of weapon, size of control force and the ROE.
- Two tactical constructs
  - Approach / Keep away
  - Occupy / Go Away
- Recorded spatial data
- Video recording

Gather empirical data on real people and real groups in tactically relevant situations
Test Setup
Data Measurement

- Vicon V8i system
- 24 cameras
- 120 fps
- Optical tracking of retro reflective markers (Ø14mm)
- Marker error <10mm
- Subjects
  - Unique Helmets
  - XYZ location + 3DOF orientation of head
- Control Force
  - Head & Torso
  - Capability for weapon

Courtesy Vicon
**Individual Metrics**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>$S_{t,sa}$</td>
<td>Distance covered in interval</td>
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<tr>
<td>$V_{t,sa}$</td>
<td>Instantaneous Velocity</td>
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<tr>
<td>$ID_{t,sa,sa}$</td>
<td>Interpersonal Distance between any pair of subjects</td>
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<tr>
<td>$CD_{t,c,sa}$</td>
<td>Distance between control force-subject pairs</td>
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<tr>
<td>$CID_{t,c,c}$</td>
<td>Interpersonal Distance between any pair of control force</td>
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## Crowd Metrics

<table>
<thead>
<tr>
<th>Index</th>
<th>Metric Description</th>
</tr>
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<tbody>
<tr>
<td>(C_{g_t})</td>
<td>Geometric Center- middle of extrema</td>
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<tr>
<td>(C_{d_t})</td>
<td>Centroid- mean of subject positions</td>
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<tr>
<td>(D_t)</td>
<td>Dispersion- mean subject radii from centroid</td>
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<tr>
<td>(LE_t), (TE_t)</td>
<td>Leading/Trailing edge- max/min along the approach axis</td>
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<tr>
<td>(\rho_t)</td>
<td>Density- (\rho_t = \frac{N}{\pi D_t^2})</td>
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<tr>
<td>(CD_{min_t})</td>
<td>Minimum distance between any subject-control force pair</td>
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<tr>
<td>(\sigma_{O_t}), (\sigma_{V_t})</td>
<td>Deviation of Orientation/Velocity- StDev of all subjects head orientation or velocity</td>
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<tr>
<td>(V_{c_t})</td>
<td>Bulk velocity of crowd- rate of change of centroid</td>
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</table>

Defined time periods based on events dependent on the construct or scenario used.
Leading Edge of Crowd

- No Threat Condition
- Threat Condition

Location (m)

Time (s)
Closest Distance between Control force and Subject

- Hand-to-hand
- Stand-off

Distance (m)

Time (s)
Outcome

• Probability Distributions
  – Identify the distribution & parameters
  – To be used in Stochastic models of both the aggregate (crowd) level or at the individual level

• Regression Equation
  – $y = (\beta_1 x_1) + (\beta_2 x_2) + (\beta_3 x_3) + \ldots + (\beta_{12} x_1 x_2) + \ldots + \epsilon$
  – Identify covariates (interacting & confounding)
  – Determine distributions for coefficients to use in stochastic models
  – Determine coefficients to use in deterministic models
Social Network Analyses

• Videotapes coded for pairwise social interaction among crowd members
  – Verbal communication, physical contact, gestures, non-verbal auditory signaling
  – 30-sec epochs at beginning and end for two groups

• 12 x 12 matrix submitted to networking analysis software (ORA Version 1.9.5.2.9)

• Sociometric Data outputted
  – #subgroups, isolates, linkages among nodes
Adjacency Matrix

Intercommunications among Crowd Members

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<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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Crowd A at Beginning of Experiment

Subject 12
Subject 11
Subject 10
Subject 9
Subject 8
Subject 7
Subject 6
Subject 5
Subject 4
Subject 3
Subject 2
Subject 1
Crowd A at End of Experiment

Subject 5

Subject 10

Subject 12

Subject 11

Subject 1

Subject 2

Subject 3

Subject 4

Subject 6

Subject 7

Subject 8

Subject 9
Crowd B at End of Experiment

Subject 1
Subject 2
Subject 3
Subject 4
Subject 5
Subject 6
Subject 7
Subject 8
Subject 9
Subject 10
Subject 11
Subject 12
# Results

## Crowd Level Sociometrics

<table>
<thead>
<tr>
<th>Variable</th>
<th>CROWD A</th>
<th>CROWD B</th>
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<td>Beginning</td>
<td>End</td>
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<td>Node Count</td>
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<td>Link Count</td>
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<tr>
<td>Number of Quads</td>
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<td>4</td>
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<tr>
<td>Number of Triads</td>
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<td>Number of Dyads</td>
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<tr>
<td>Density</td>
<td>0.1667</td>
<td>0.1591</td>
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Network Analysis
Control Force – Crowd Member Distances
Conclusion
Crowd Behavior Metrics

- Empirical data collected and analyzed under controlled laboratory conditions
- Motion capture analyses yield quantitative methods for analyses of crowd responses
- Network analyses yield quantitative methods for crowd psychosocial characterization
- Both individual and crowd level analyses
The Way Forward

- With the development of crowd measures and metrics and wide variety of applied, practical, and tactically relevant questions can be explored
- Target selection
- Threat assessment
- Input into modeling and simulation investigations
- Comparisons of effectiveness of a variety of non-lethal weapons and systems and tactics, techniques, and procedures
Backup Slides
Theoretical Model

Mechanisms of Non-Lethal System Effects on Crowd Members

- Perceived Cost of Behavior
- Perceived Benefit of Behavior
- Perceived Probability of Success

Influences on Motivation

Motivation (Strength of Force toward Goal) Intrinsic/Extrinsic

Alternatives (Strength of Force toward Others Goals) Intrinsic/Extrinsic

Capability (Cognitive/Perceptual/Motoric)

Influences on Behavior

Frequency/Probability of Behavior to Reach Goal

Goal/Purpose

Crowd Member Initial Behavior