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Military Operations Involving Crowds:
Agent-Based Modeling Using MANA and Non-Attrition-Based Assessment of Results

Dr. Peter Dobias

Presented to 24 ISMOR, Hampshire, UK

27-31 August 2007

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Outline

- NLW And Crowd Modeling in LFORT
- Crowd Confrontation Scenario
- Modeling Crowd Confrontation in MANA
  - MANA model
  - MOEs for Considered Scenario
  - Comparison Of MANA and CAEn Results
  - Strengths of MANA for Crowd Modeling
- More on MOEs:
  - Attrition vs. Non-attrition Based MOEs
  - Entropy
  - Fractal Coefficient
- Conclusions

NLW and Crowd Modeling in LFORT

- Supporting Crowd Confrontation Systems project aimed at acquiring non-lethal capability sets for the Canadian Forces.
- Different mixes composed of two kinetic non-lethal systems modeled at platoon and coy level.
- Study different from conventional war games in three major aspects:
  - Terminal effects of non-lethal weapons: physiological and psychological
  - Crowd behaviour not well understood: relying on a number of assumptions.
  - Local dynamics of crowds vs. global control of interactive war games.

NLW and Crowd Modeling in LFORT

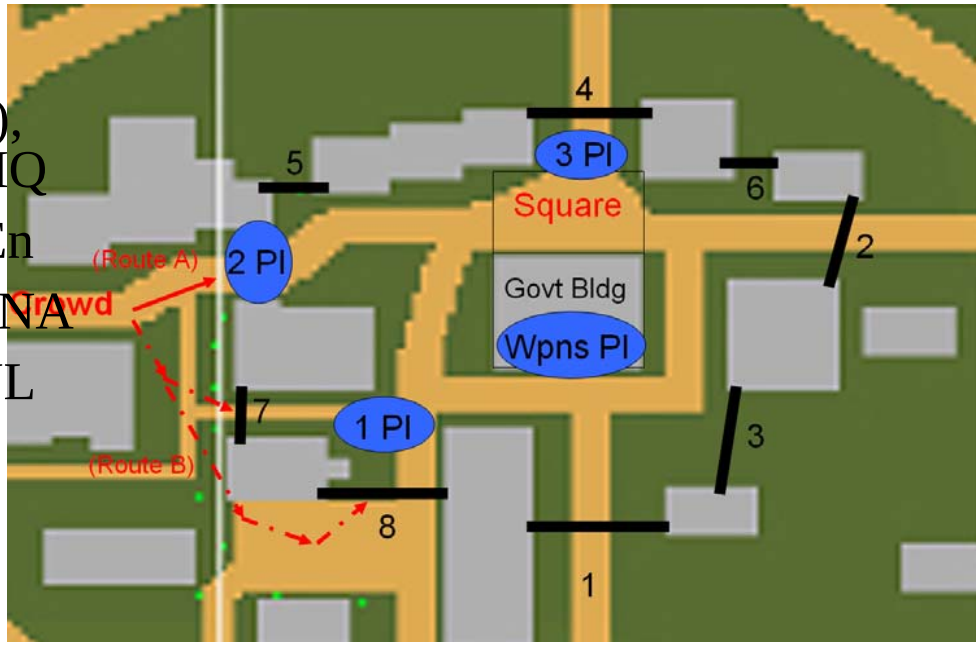
- Ten mixes of the two types of launchers modeled:
  - 6 mixes consisting of only one type of launcher
  - 4 mixes of both types
  - number of launchers between three and twelve
- Two phases:
  - Phase 1: CAEn war game to model a confrontation at platoon level (baseline)
  - Phase 2: MANA agent-based model to simulate platoon level and coy level scenarios
  - Note: Phase 2 also to assess the applicability of MANA to this type of scenario.

Crowd Confrontation Scenario

- Crowd Confrontation Operation performed by the Canadian Forces
- A company of light infantry called in to support local law enforcement.
- To avoid further escalation of violence, non-lethal weapons to be used to suppress the riotous crowd.
- The desired end state was:
  - **The crowd dispersed** with no apparent plan to regroup;
  - The crowd did not reach the desired area;
  - **No** BLUE or RED (i.e. crowd) **casualties**;
  - No lingering hostility toward Canadian troops;
  - No bad publicity; and
  - No property damage.

Crowd Confrontation Scenario

- BLUE Force
  - Three platoons (36 pers. Each), Weapons Pl. (21 pers.), Coy HQ
  - Only 2 Platoon gamed in CAEn
  - 1 and 2 Platoon gamed in MANA
  - BLUE issued a NLCS (incl. NL launchers)
  - Lethal firebase



- RED Force
  - Total of 100 people (300 for Coy-level scenario)
  - Two main parts:
    i. 60%: elderly men, women, and children.
    ii. 40%: young males forming gangs
  - Crowd armed with rocks and sticks
  - Gangs armed with rocks, sticks, machetes, Molotov cocktails and handguns.

Modeling Crowd Confrontation in MANA

- MANA: non-interactive, agent-based model based on the cellular automata philosophy.
- MANA Crowd Control Model:
  - Results of Phase 1 used as a framework for the development of MANA scenarios.
  - Behavioural and technical parameters in MANA adjusted to achieve the best possible agreement for the test set from both models (4 out of 6 configurations with a single type of launcher).
  - Military judgments and insights from Phase 1 consulted to identify key distinct characteristics of the two non-lethal weapon systems
  - Platoon-level scenario repeated in MANA. Used configuration of forces and ROEs the same as in the CAEn model.

Modeling Crowd Confrontation in MANA

- MANA Crowd Control Model (cont.):
  - Interaction among crowd members, and between crowd and the BLUE force (agitation and discouragement) - fuel variable used
  - The crowd's reactions to BLUE weapons modeled so that the outcome corresponded to the desired ROE
  - Baton modeled as a very short-range direct fire weapon, with an extremely low single-shot incapacitation probability, and a large amount of ammo
  - Non-lethal launchers modeled as direct fire weapons. Parameters encompassed technical aspects of weapons and some aspects of the tactics (fire discipline, range of engagement)
  - Barricades used to reinforce the BLUE B&S line of 1 Platoon (at access Route B), modeled as a new terrain feature

MOEs for Considered Scenario

	Dispersal of Non-Gang Component of Crowd	
Dispersal of Gangs	At least 15 % of the crowd incapacitated	Less than 15 % of the crowd incapacitated
At least 50 % of gang members incapacitated	Full Success	**N/A**
Less than 50 % of gang members incapacitated	Partial Success	**Mission Failure**

Rank	**Measure of Effectiveness**	**Weight (%)**
1	Mission Success	35
2	Non-lethal Incapacitations	20
3	Lethal Casualties	15
4	Baton and Shield Incapacitations	10
5	Time to influence the crowd	7
6	BLUE Fratricide	3
7	BLUE Residual Combat Strength	5
8	Ammunition Expenditure	3
9	System Effectiveness	2
	TOTAL	100

Comparison of MANA and CAEn Results

		Ammunition		Incapacitations			Mission Success	
		Expended	Effectiveness	Lethal	Non-Lethal	Baton	Full	Partial
Mix 0003	CAEn	30.0	0.43	1.3	12.8	3.0	0	90
	MANA	28.7	0.44	6.7	12.6	2.4	1	99
Mix 0006	CAEn	25.6	0.40	10.6	10.4	0.5	10	90
	MANA	50.6	0.44	6.4	22.4	1.4	64	36
Mix 0008	CAEn	38.8	0.53	6.2	20.7	1.9	30	70
	MANA	55.0	0.43	7.1	23.6	0.7	66	34
Mix 0300	CAEn	57.2	0.35	0.0	19.9	1.4	0	100
	MANA	54.3	0.40	2.4	22.0	1.5	34	66
Mix 0600	CAEn	72.8	0.40	0.0	29.3	2.1	60	40
	MANA	69.0	0.42	2.2	28.7	0.4	76	24
Mix 0800	CAEn	55.9	0.43	0.0	23.8	0.4	5	95
	MANA	73.2	0.42	2.4	30.5	0.2	87	13
Mix 0606	CAEn	63.0	0.54	0.0	33.9	0.3	70	30
	MANA	74.7	0.42	1.9	31.3	0.3	91	9
Mix 0603	CAEn	71.1	0.43	0.0	30.6	2.2	40	60
	MANA	68.8	0.44	1.7	30.3	0.4	87	13
Mix 0306	CAEn	51.5	0.55	0.0	28.1	0.9	0	100
	MANA	65.5	0.42	1.9	27.5	0.6	68	32
Mix 0303	CAEn	31.5	0.63	5.3	19.9	0.9	40	60
	MANA	61.3	0.43	1.9	25.8	0.9	52	48

Strengths of MANA for Crowd Modeling

- Computational effectiveness: MANA allowed testing of a number of excursions addressing various aspects of scenario
- Modeling human behaviour in the context of crowds:
  - consistency in crowd behaviour between different options
  - bottom-up approach more appropriate in crowd context
  - consideration of some intangibles such as fear or aggression.
- Capability to model large numbers of individuals

More on MOEs

- Weak point: evaluation of results
- MOEs traditionally attrition-based (LER, RCS, etc.)
- Attrition-based: suitable for force-on-force operations, limited applicability in instances involving non-combatants
  - Preferred end state: no casualties at all
  - Inherent complexity of crowd dynamics
  - Considering human factors in the model
  - Attrition a global factor, crowd governed locally
- Relationship between MOEs and ROEs - attrition the driving force behind the doctrine

Entropy

- Shannon: $$S = \sum_i p_i \ln \frac{1}{p_i}$$
- Carvalho-Rodrigues: for the *i*-th force

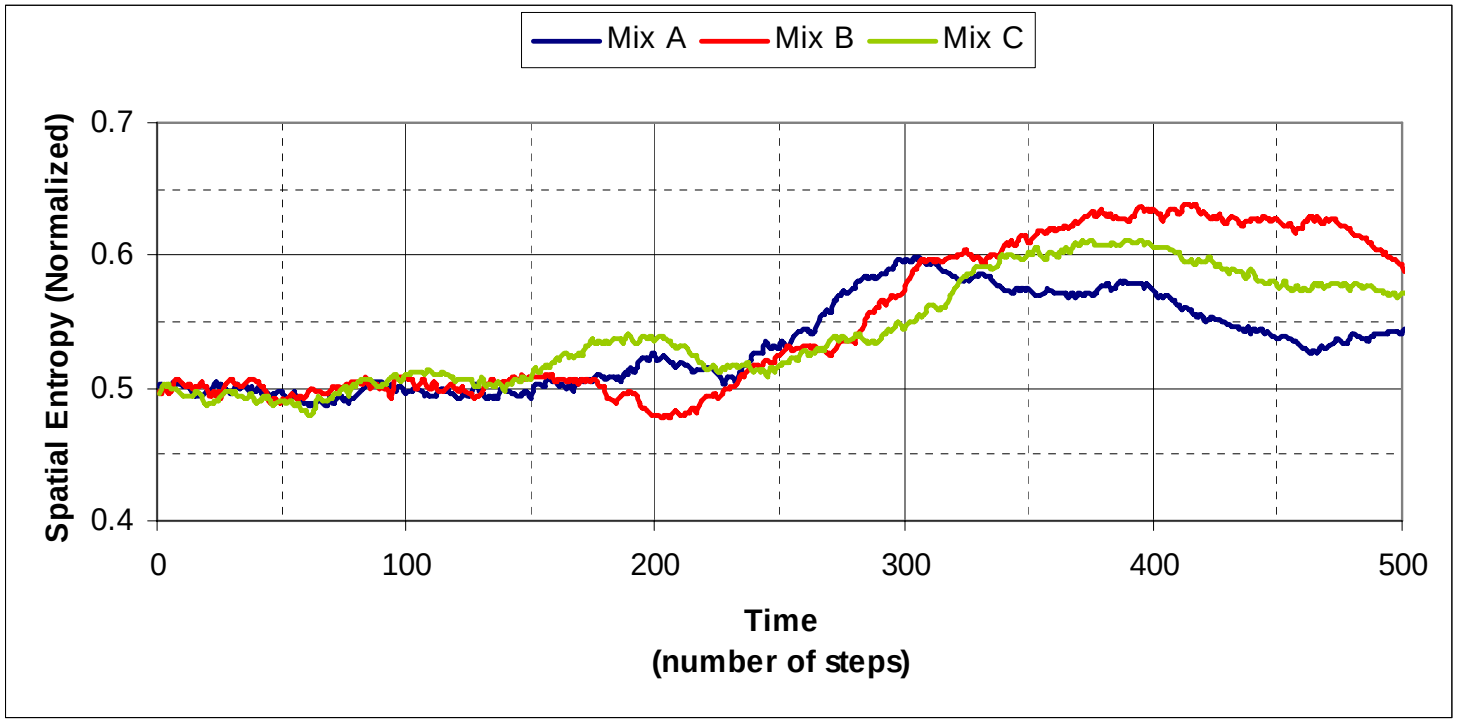
$$S_i = \frac{C_i}{N_i} \ln \frac{N_i}{C_i}$$

- C-R some of the limitations as other attrition-based MOEs
- Ilachinski: spatial distribution of soldiers.

$$S(b) = \frac{1}{2\ln(B/b)} \sum_{i=1}^{(B/b)^2} p_i(b) \ln\left(1/\, p_i(b)\right)$$

- Characterizing spatial dynamics

Entropy - example



- Three selected mixes
- Temporal system dynamics captured
- Possible consideration of various factors on dispersal

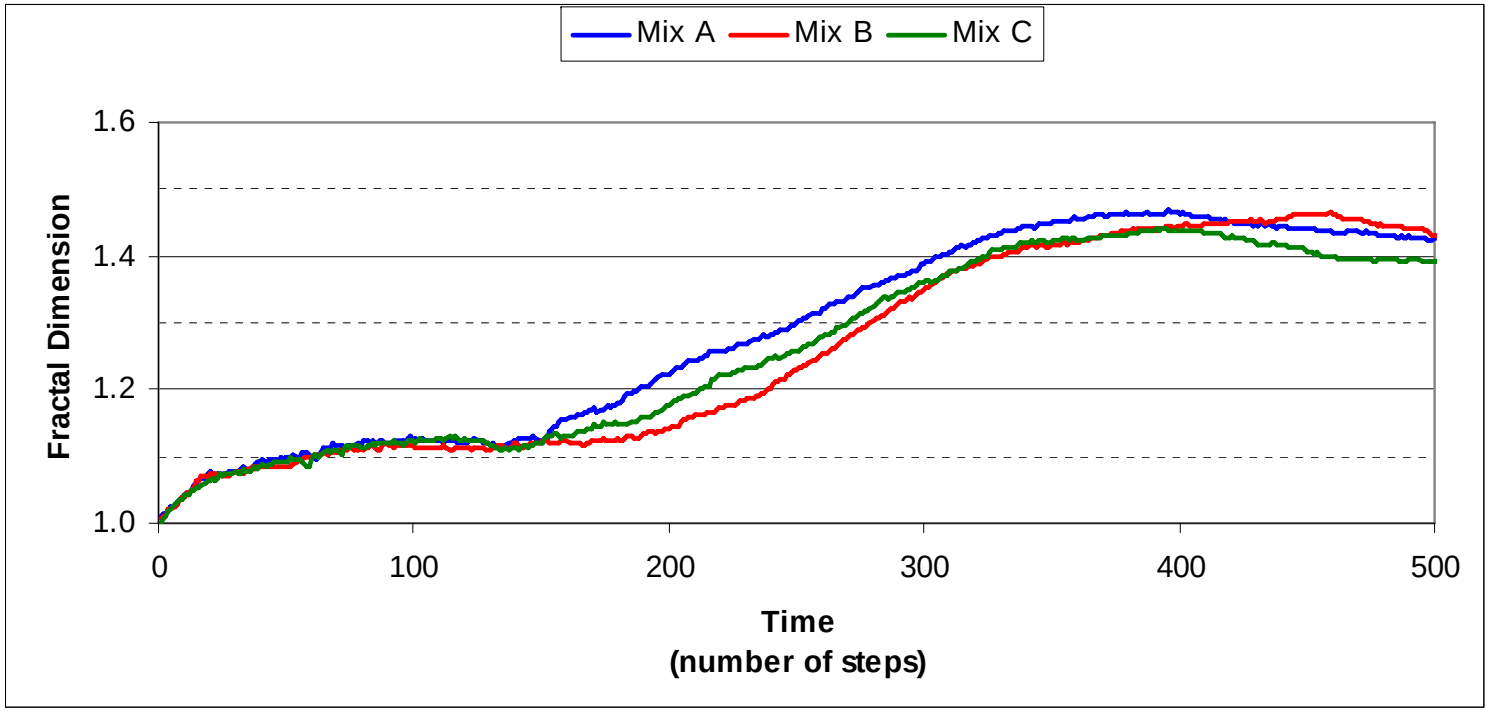
Fractal Dimension

- Measure of spatial distribution of units
- Relationship between size of a box and minimum number of boxes needed to cover all the agents

$$D_F = \lim_{\varepsilon \to 0} \frac{\ln N(\varepsilon)}{\ln L/\varepsilon}$$

- Maximum value of D_F restricted by accessible area

Fractal Dimension



- Advancing crowd, low fractal dimension was low
- Dispersal began, the fractal dimensions increased
- Maximum value at approximately $D_F = 1.5$.

Conclusions: ABMs and Crowd Modeling

- Modeling of crowds a challenge
- Agent-based models capture:
  - Complex, multilevel, nonlinear dynamics
  - System dynamics governed by local interactions
  - Apparent stochasticity on the global level
- Setback: high level of abstraction
  - Need for an external source to define parameters
  - External framing of parameters by interactive war games
- Advantage: simplicity and ability to run large numbers of replications

Conclusions: Measuring Effectiveness

- Attrition only a limited means of quantifying effectiveness Crowd Confrontation Operations,
- Two new MOEs, meant to supplement traditional attrition-based MOEs:
  - Shannon entropy; and
  - Fractal dimension.
- Examples of calculations
- Describing temporal dependence of crowd dynamics
- Independent of attrition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