Optimization-based Agent Simulations for Evaluating the SPEYES[1] System

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[1]Sensing and Patrolling Enablers Yielding Effective SASO (Stability and Support Operations)

Outline

- Sensing and Patrolling Enablers Yielding Effective SASO – SPEYES
  - Stability and Support Operations – SASO
  - Quantifying SPEYES System
- Simulating SPEYES System
  - Mission Scenario
  - Blue Force Organization and Asset Allocation
- Optimization-based Agent for Distributed Dynamic Decision-making – DDD
  - System Architecture
  - Task Processing Phase
- Simulation Results
  - Calibration of Agent-Human Results
  - Quantifying Force Multiplying Effects of SPEYES System
  - SPEYES Component Technology Benefits
- Summary of Findings

Sensing and Patrolling Enablers Yielding Effective SASO – SPEYES
Stability and Support Operations – SASO

- Stability and Support Operations – SASO
  - Military activities during peacetime and post-conflict not involving force-on-force combat
- Key SASO challenges
  - Poor situation awareness (SA): low familiarity with mission environment
  - Difficult targets/enemy identification: Combatants intermingled with non-combatants
  - Lethal asymmetric threats: Improvised Explosive Devices (IEDs), Vehicle Borne IEDs, Rocket Propelled Grenades (RPGs), suicide bombers, snipers, …

SPEYES SASO challenge

Design and demonstrate an innovative force-multiplying SASO security system that enhances SASO effectiveness ⇒ provide security for forces, local population, and infrastructures

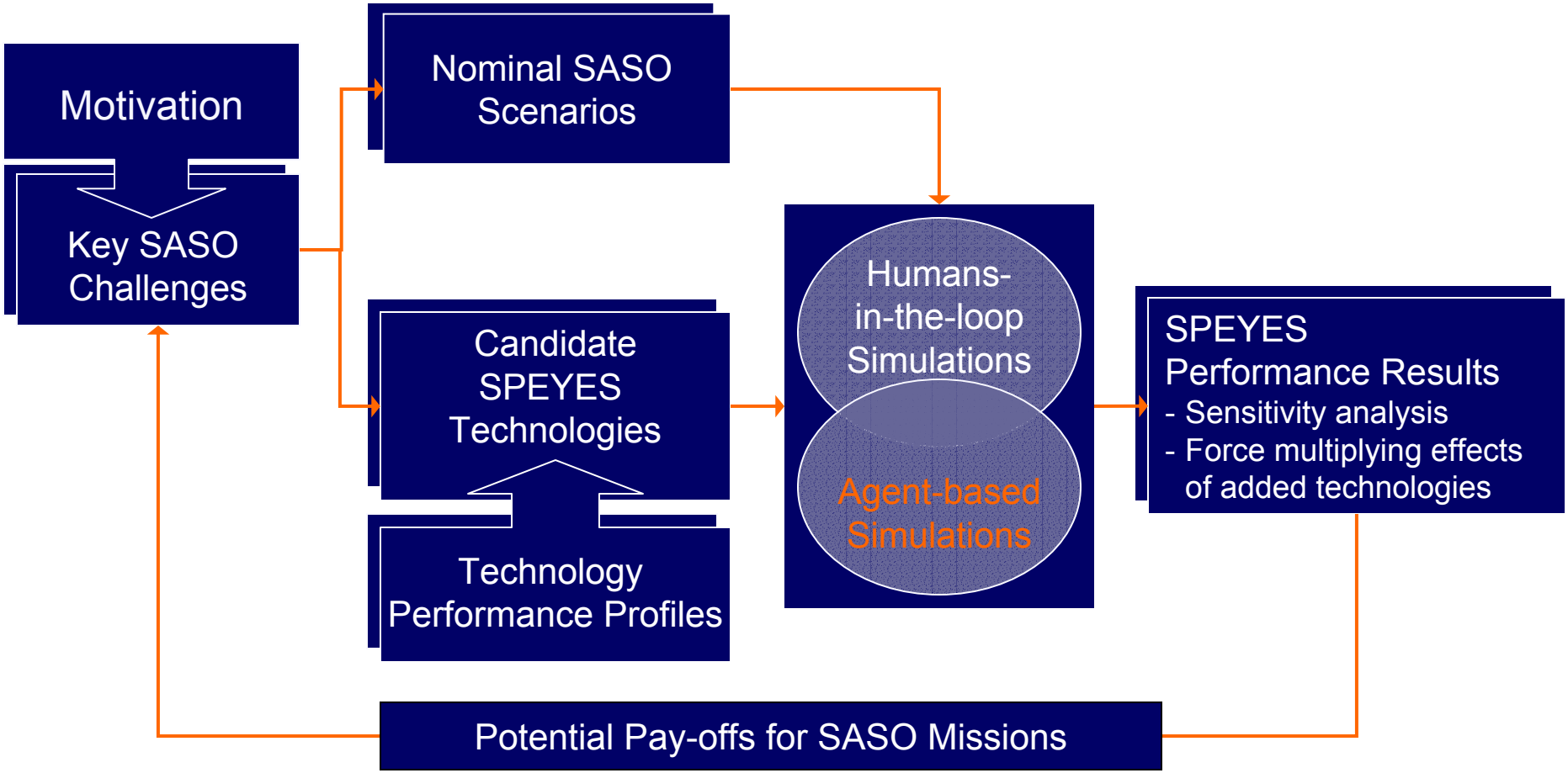
Utilize three component technology enablers for SASO oriented security system:

- Sensing technologies: low-cost, easily-emplaced, camouflaged sensors (video, acoustic, Infrared) to provide urban situation awareness
- Shaping technologies: non-lethal, and explosives ordinance disposal (EOD) tools to diffuse adversaries, crowds, and improvised explosive devices …
- SA/C^2 technologies: planning, dynamic resource management, simulation, mission rehearsal …

Quantifying Performance Improvement due to SPEYES System – 1

Challenge

Evaluate systematically the impact of each SPEYES technology ⇒ Quantify the force multiplying effects



Sensing and Patrolling Enablers Yielding Effective SASO – SPEYES
Quantifying Performance Improvement due to SPEYES System – 2

Fundamental issues in SPEYES: resource allocation, deployment, and incidence forecasting
⇒ also fundamental issues in urban operations research
⇒ utilize the Square Root Law to show the improvements in timeliness, efficiency, and effectiveness due to SPEYES technologies

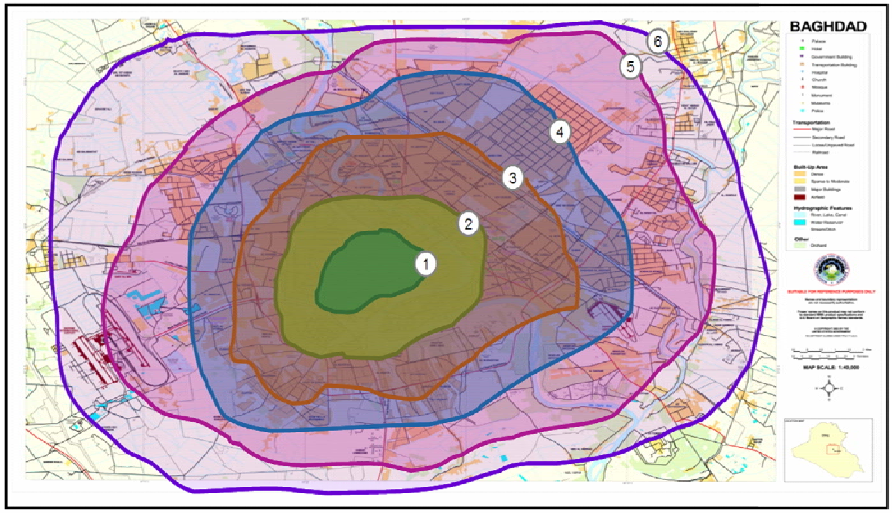
Square Root Law:

- The response-time T_r of N_0 patrol units is proportional to the square root of the effective area A

$$E[T_r] \approx \frac{E[D]}{v_c} = \frac{c}{v_c}\sqrt{\frac{A}{N_0(1-\rho)}}$$

- The effective area of coverage is proportional to the number of idle patrol units

$$A = \left[\frac{E[T_r]v_c}{c}\right]^2 N_0(1-\rho)$$



1 Troops
2 Non-Lethal Weapons
3 Multi-Spectral Cameras
4 Tracer RFIDs
5 Smart Scheduling
6 Swarming Unmanned Vehicles

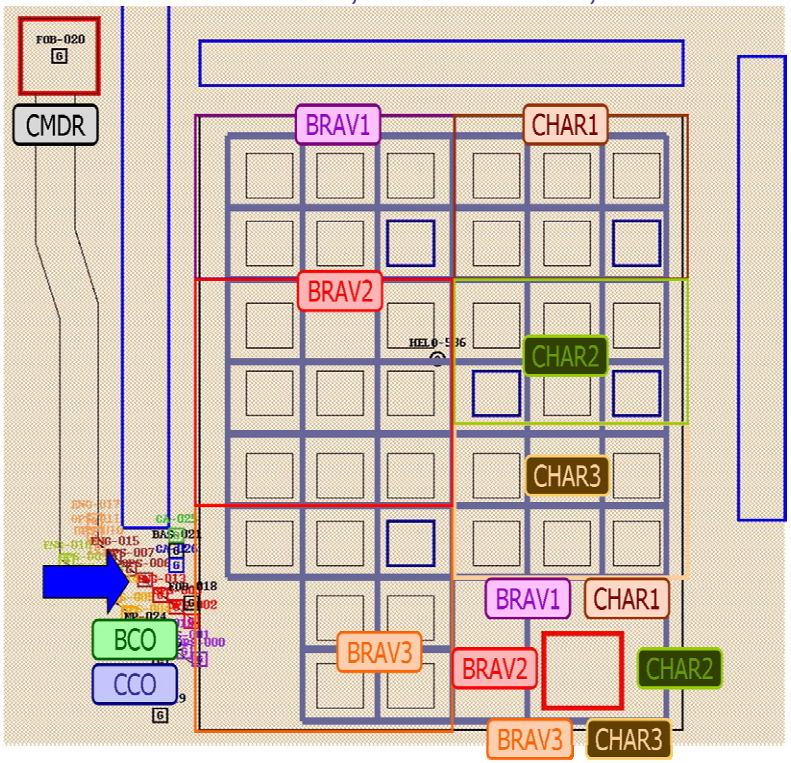
For equal response time with and without SPEYES technologies ⇒ the same number of forces with SPEYES technologies can cover a larger area ⇒ reduced size force can cover the same area

$$A_2 = A\left[\frac{T_{r1}}{T_{r2}}\right]^2$$

Note:
- D is distance
- c is a constant
- ρ is utilization rate
- v_c is patrol speed

Simulating SPEYES System – 1
Mission Scenario

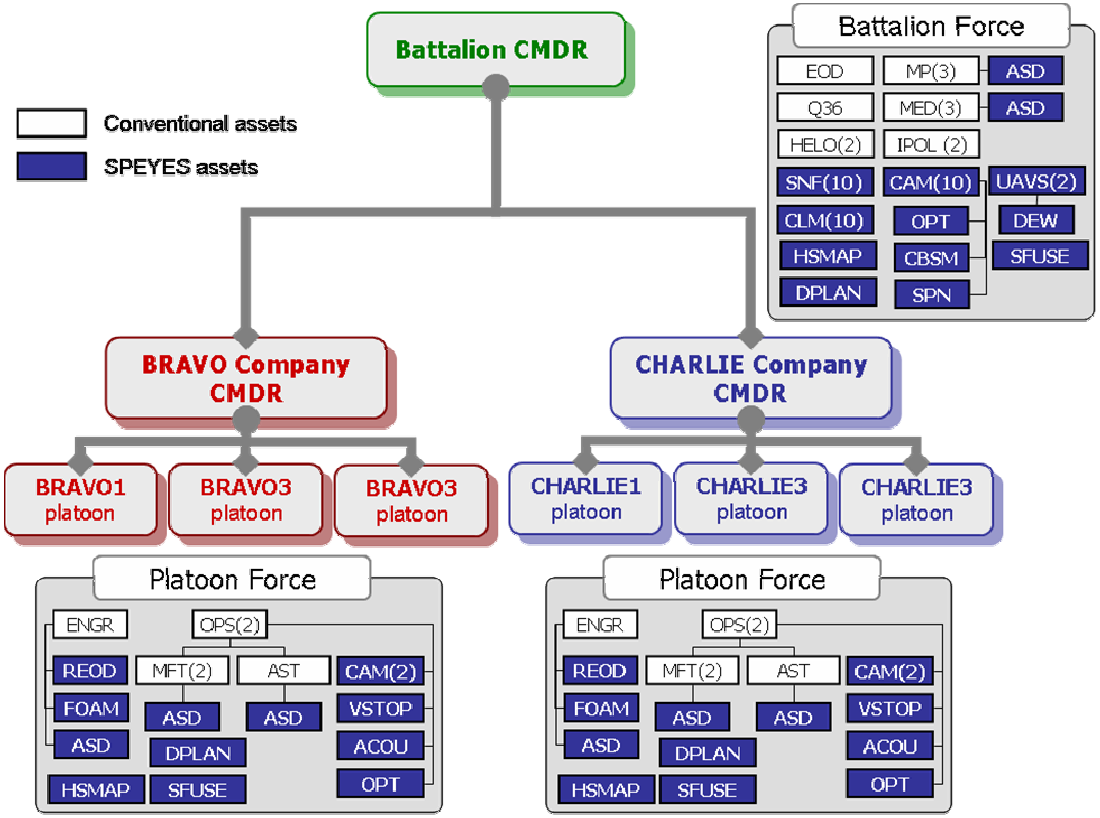
- Objective
  - Demonstrate force multipliers for Cordon and Search missions through simulation-based approach in DDD environment
- Distributed Dynamic Decision-making (DDD) Simulator
  - Distributed Discrete-Event Decision-Making Simulation tool
- Methodology
  - Calibrate agents' behaviors to those of human-in-the-loop simulations
  - Utilize Monte Carlo simulation to generate performance measures, sensitivity analyses,..
  - Quantify performance improvements due to SPEYES technologies in terms of timeliness, effectiveness, and efficiency of operations



Mission Scenario

- Cordon and Search at National Training Center in Ft. Irwin, California
- Order: assign a Battalion of 4 Companies to conduct multi-phase operations to maintain security and stability in Tiefort City (TC) ⇒ secure the power plant in TC and suppress an ongoing insurgency
- Companies CHARLIE and BRAVO assigned to cordon, search, and secure operations in TC ⇒ move from Forward Operating Base (FOB) to major entrance of TC ⇒ ready to commence operations

Simulating SPEYES System – 2
Blue Force Organization and Asset Allocation



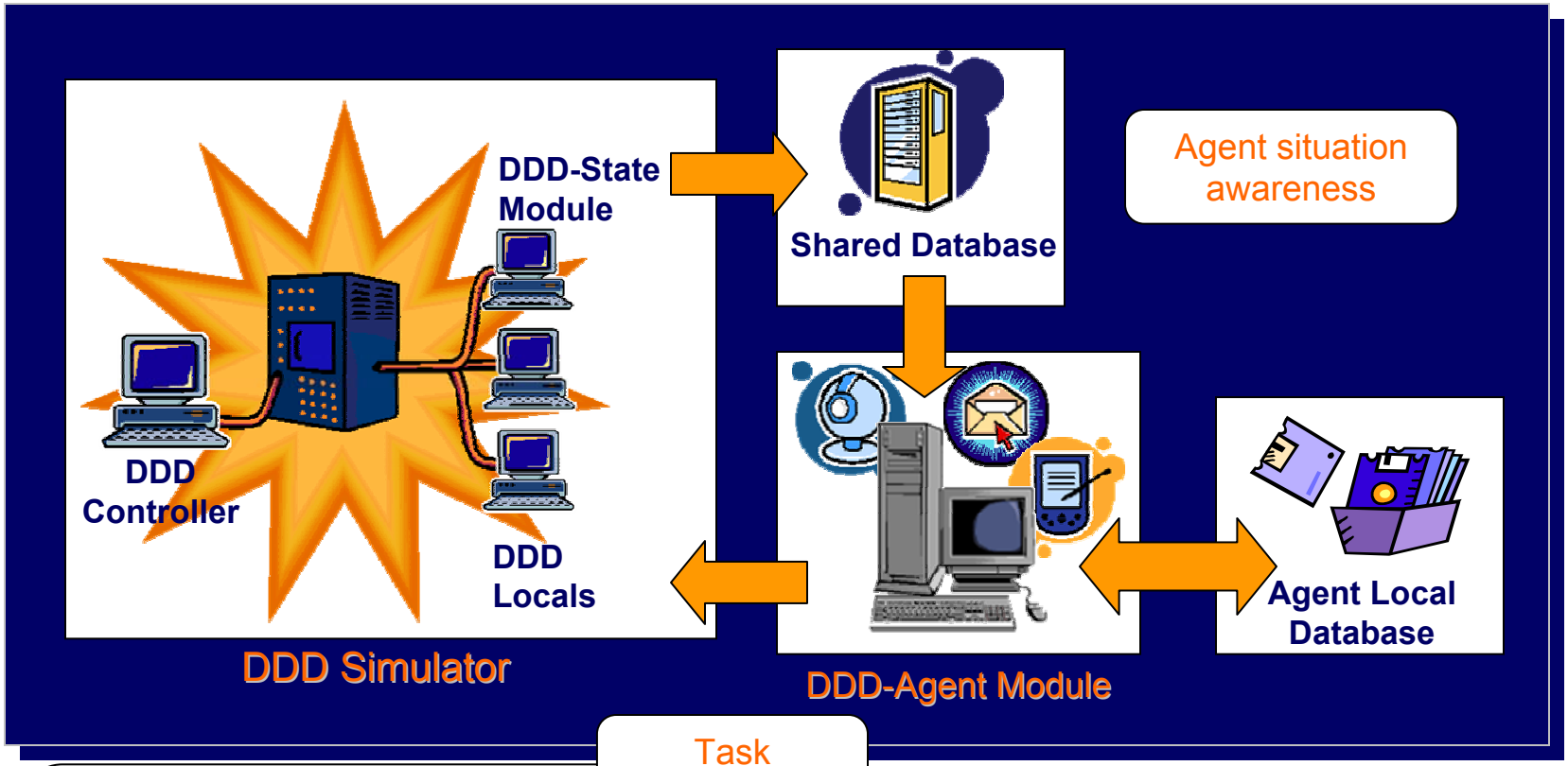
Organizational Assets

OPS: Operations squad (1 Tank + 1 Bradley)
AST: Anti-sniper team (2-3 soldiers)
MFT: Mobile fire team (5 soldiers)
ENGR: Engineer squad (8-10 soldiers)
MP: Military police squad (8-10 policemen)
MED: Medic squad (8-10 medics)
IPOL: Iraqi police squad (8-10 policemen)
EOD: Explosive disposal squad (5-8 soldiers)
Q36: Anti-mortar radar
HELO: Helicopter

SPEYES Technologies

CAM: Camera/sensor cluster
UAVS: SPEYES UAV
ASD: Acoustic sniper detection
OPT: sniper optics detection
DEW: Directed Energy Force
FOAM: Non-lethal foam calmative dispenser
REOD: Robotic explosive ordinance disposal
ACOU: Acoustic force projection

Optimization-based Agent for DDD – 1
System Architecture



Task Processing

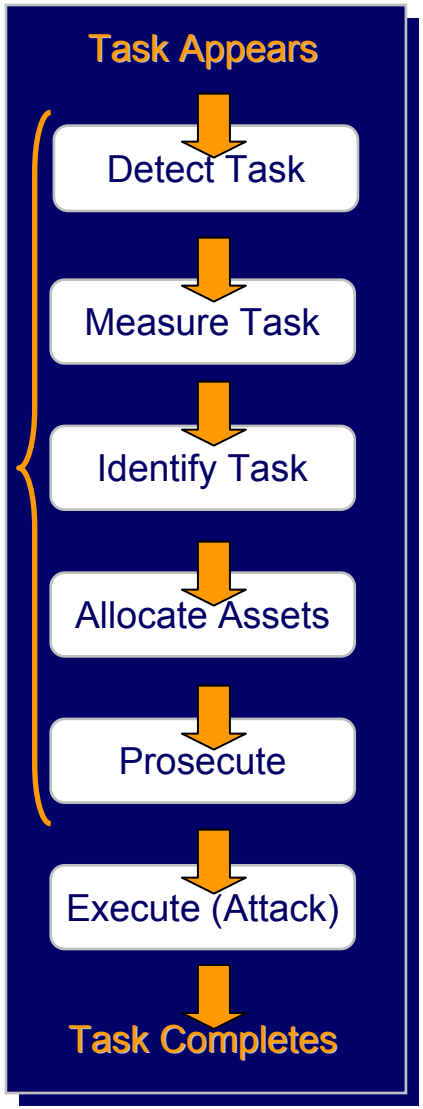
- Flexible mid-fidelity team-in-the-loop simulator
- Scenario controller: dynamic events and data updates, mission tempo & rhythm, execution processing …

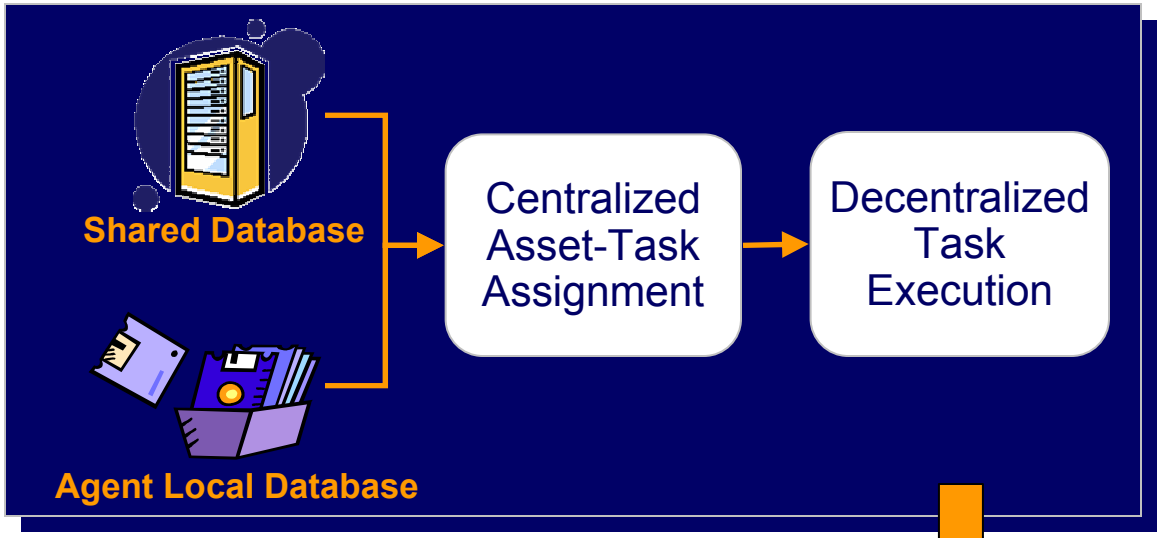
- Maintain situation awareness
- Generate event-based schedule
- Distribute DM-task assignment
- Conduct task processing

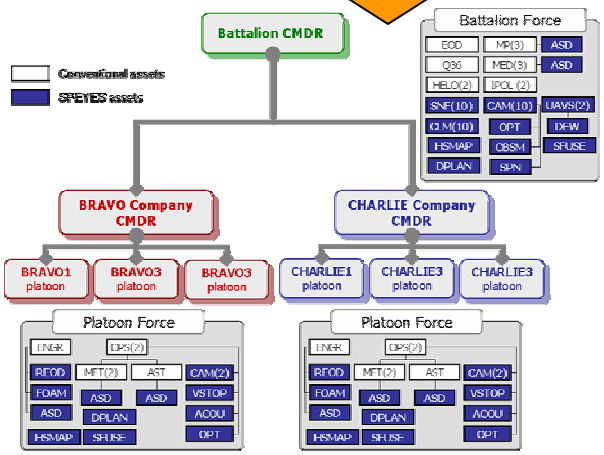
- Rules of engagements
- Execution monitoring
- Performance measures

Optimization-based Agent for DDD – 1
Task Processing Phase

Task Processing Stages in DDD

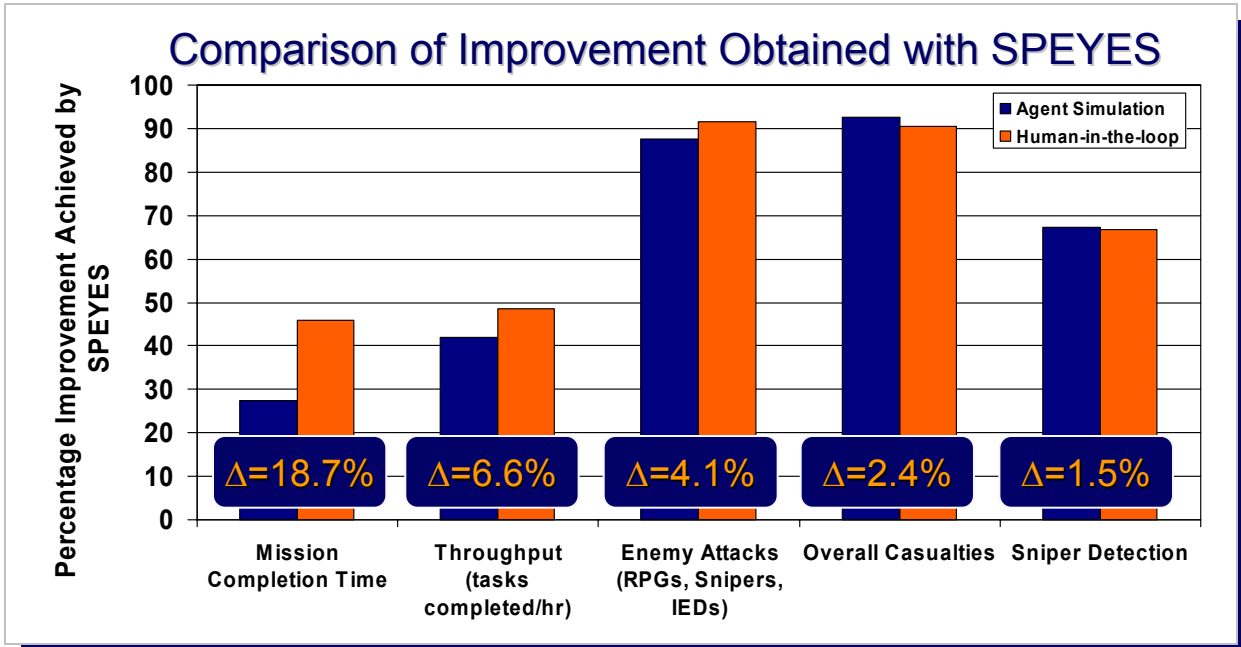






Note: Overall communication delay across the hierarchy is in general 5 mins (15 secs simulation time)

Analysis and Simulation Results – 1
Calibration of Agent-Human Results



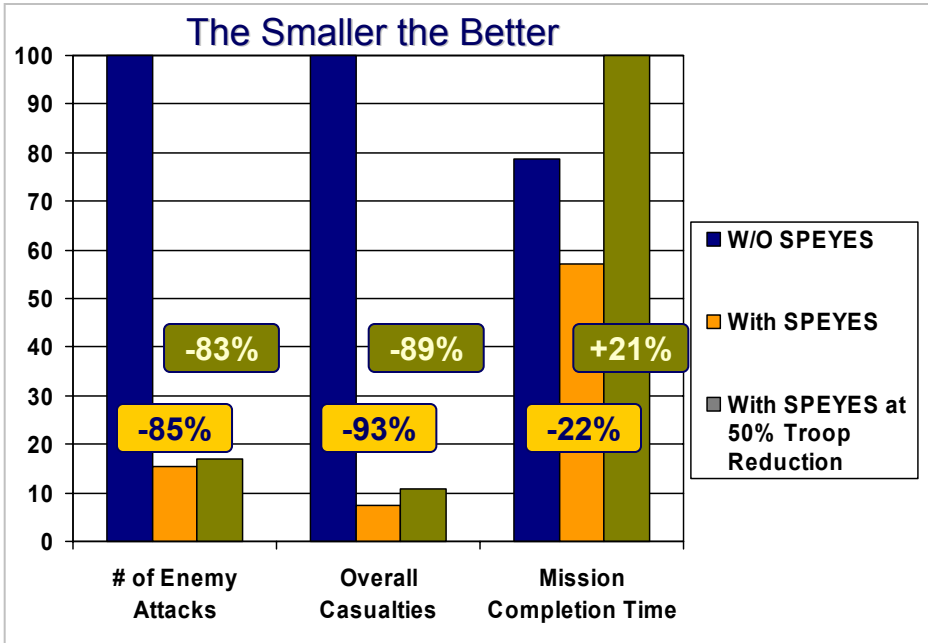
Agents' behaviors are comparable to those of human-in-the-loop simulations

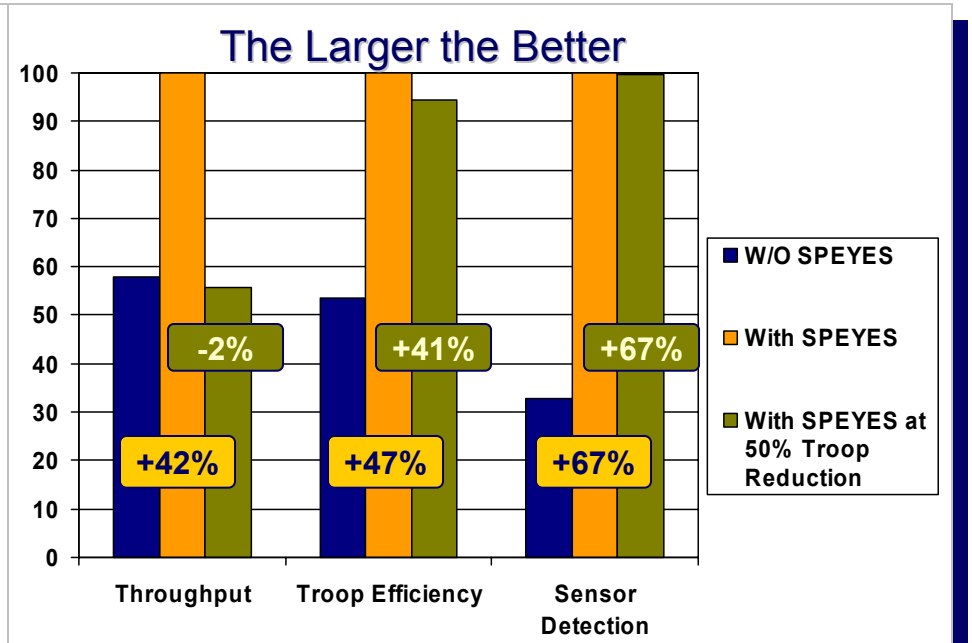
- Agents perform same task sequences as human players
- Consider % performance improvement with SPEYES relative to without SPEYES
- Difference in performance improvements are within 2–19% for individual metrics

One-to-one Comparison of Human and Agent Simulations

Metrics	Human		Agent	
	W/O SPEYES	With SPEYES	W/O SPEYES	With SPEYES
Mission completion time (hours:min)	11:57	6:24	11:48	8:30
# MFT Engagements	73	29	47	20
Total Throughput (tasks per hour)	9.4	18.3	8.1	14.1
# Enemy Attacks (snipers, RPGs, IEDs)	24	2	13	2
Troop efficiency (# troops per troop task)	1.07	2.08	1.07	2
# Casualties	41.5	4	21.9	1.6
Sniper Detection Rate (# of snipers detected/hr)	3.6	10.9	4.5	13.7

Analysis and Simulation Results – 2
Quantifying Force Multiplying Effects of SPEYES System





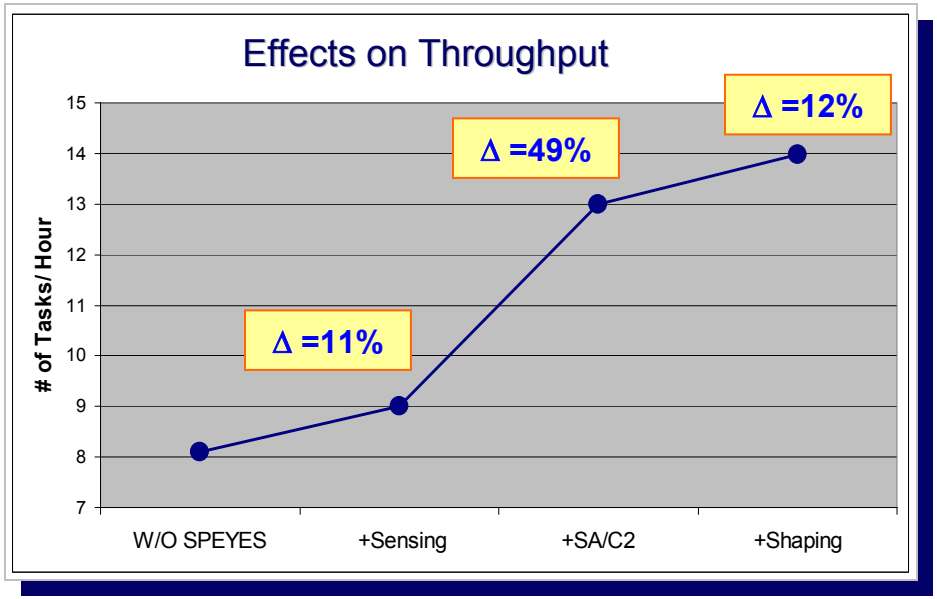
- # of enemy attacks: ⇓ by 85%
- Overall casualties: ⇓ by 93%
- Completion time: ⇓ casualties by 22%

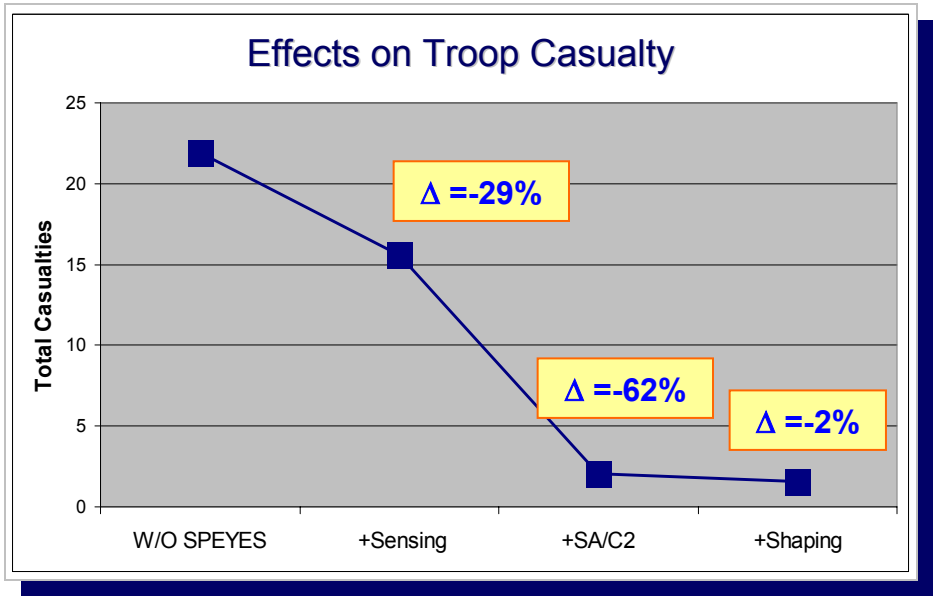
- Throughput: ⇑ by 42%
- Troop efficiency: ⇑ by 47%
- Sensor detection: ⇑ by 67%

- Integration of sensing, SA/C^2, and shaping technologies ⇒ significant performance improvements to the force across all measures

- Significant performance improvements (in 4 out of 6 measures) over regular SASO with a full force at 50%-reduced force ⇒ confirming the force multiplier effects of SPEYES technologies

Analysis and Simulation Results – 3
SPEYES Component Technology Benefits





Relative improvements due to SPEYES

- Sensing technologies: ⇑ throughput by 11%
- SA/C² technologies: ⇑ throughput by 49%
- Shaping technologies: ⇑ throughput by 12%

Relative improvements due to SPEYES

- Sensing technologies: ⇓ casualties by 29%
- SA/C² technologies: ⇓ casualties by 62%
- Shaping technologies: ⇓ casualties by 2%

Summary of Findings

- **Sensing and Patrolling Enablers Yielding Effective SASO – SPEYES**
  - Motivation: SASO challenges – poor SA, difficult targets ID, lethal asymmetric threats, …
  - Design an innovative force-multiplying SASO security system to enhance SASO effectiveness – SPEYES
  - Need to quantify the force multiplying effects of SPEYES technologies
- **Evaluating SPEYES System via Agent-based Simulations**
  - Mission Scenario: Assign Battalion of 4 Companies to conduct Cordon and Search Tiefort City – maintain security and stability, and suppress an ongoing insurgency
  - Platform: Distributed discrete-event decision-making simulation tool – DDD Simulator
  - Methodology: Calibrate agents' behaviors to human-in-the-loop simulations ⇒ quantify performance improvements in terms of timeliness, effectiveness, and efficiency of operations
- **Analysis and Simulation Results**
  - Agent Calibration: Agents' behaviors are comparable to those of human-in-the-loop simulations
  - Force Multiplying Effects: Significant performance improvements to the force
    - Better sensing & shaping technologies ⇒ increase detection of enemies ⇒ decrease the # of attacks ⇒ reduce casualties ⇒ improve throughput and troop efficiency
    - Improve (in 4 out of 6 measures) over regular SASO with a full force, at 50%-reduced force with SPEYES
  - SPEYES Component Technology Benefits
    - Throughput improvements: Sensing 11% – SA/C2 49% – Shaping 12%
    - Casualty reduction: Sensing 29% – SA/C2 62% – Shaping 2%
- **Future: DARPA is planning to build a physical SPEYES System**

SPEYES Technologies

Class	Technology	Performance Profile	Application Example
Sensing	Video	360 degree rotation. Auto-focus up to 600 m	Place a grid of 3 cameras in position on watch tower for persistent surveillance instead of 6 soldiers.
	Acoustic	Locate source of weapon discharge from a distance of 100s meters.	Faster neutralization of snipers; decrease in casualties
	Explosive sniffers grid	Grid detecting IEDs, VBIEDs at 10-20 meters	Increased throughput at checkpoints; decreased casualties & asset damage decrease
SA/C2	Sensor placement	Optimized grid-based placement every 100 m	Faster hot-spot detection and increased throughput
	Distributed planning & resource mgnt	High-bandwidth one-to-one communication	Reduce manning for patrol due to mutual support
	Data fusion	Predictive threat dynamics models	Acoustic and video data fusion estimates crowd size, hostility, and predicts dynamics
Shaping	NL-foam	Non-toxic. Hard to remove. Easily transportable. Short curing time.	Use foam to secure buildings (e.g. weapons cache) instead of leaving 5-10 soldiers
	REOD	Clear IEDs remotely from a distance of up to 600 meters.	Send REOD to neutralize IEDs instead of human EOD squad; reduce casualties, increase throughput
	Non-lethal High-power Micro Wave	Disrupts electronics at range in 10s of meters.	Stop suspect vehicles to search; reduce friendly and civilian casualties; reduce manning at checkpoint
	Smart patrols	Threat prediction & optimal path planning for 1000 km^2	Decreased response time Threat avoidance reduces casualties

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HELO: helicopter

SPEYES Technologies

HSMAP: sensor placement, hot-spot mapping
DPLAN: distributed planning & resource management
SFUSE: sensor and data fusion models
CAM: camera/sensor cluster
UAVS: SPEYES UAV
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