An Application of Agent Based Modeling in the Analysis of Communication Links in Network Centric Operations

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Background

- These models were conducted as part of a case study for SAS-050, an international group established by NATO's Research and Technology Organization's Studies Analyses and Simulation Panel in 2003 for the purpose of exploring new Command and Control concepts

- The objective of these experiments is to
  - Identify advantages and limitations of the Conceptual Model of Command and Control being developed by SAS-050
  - Generate NCO/C2 related studies within the Project Albert Modeling community

Project Albert

www.projectalbert.org

Project Albert is the research and development effort whose goal is to develop the process and capabilities of Data Farming, a method to address decision-maker's questions that applies high performance computing to modeling in order to examine and understand the landscape of potential simulated outcomes, enhance intuition, find surprises and outliers, and identify potential options.

Modeling Efforts

- Simple comparison of C2 information network arrangements – no terrain, no complex behaviors, no doctrinal specifications.

  Test insights and compare network arrangements across a variety of mission objectives.

- Investigate social and cognitive impacts of organizational structure within the context of a simple cognitive task
  - Comparison of Two organization structures:
    - Command and Control Organization (Hierarchical Network)
    - Edge Organization (Complete Network)

Modeling Tools

MANA, Map-Aware Non-Uniform Automata (New Zealand)

- Detailed communications for various levels of networked forces
- Behavior state changes for coordinated movement of forces

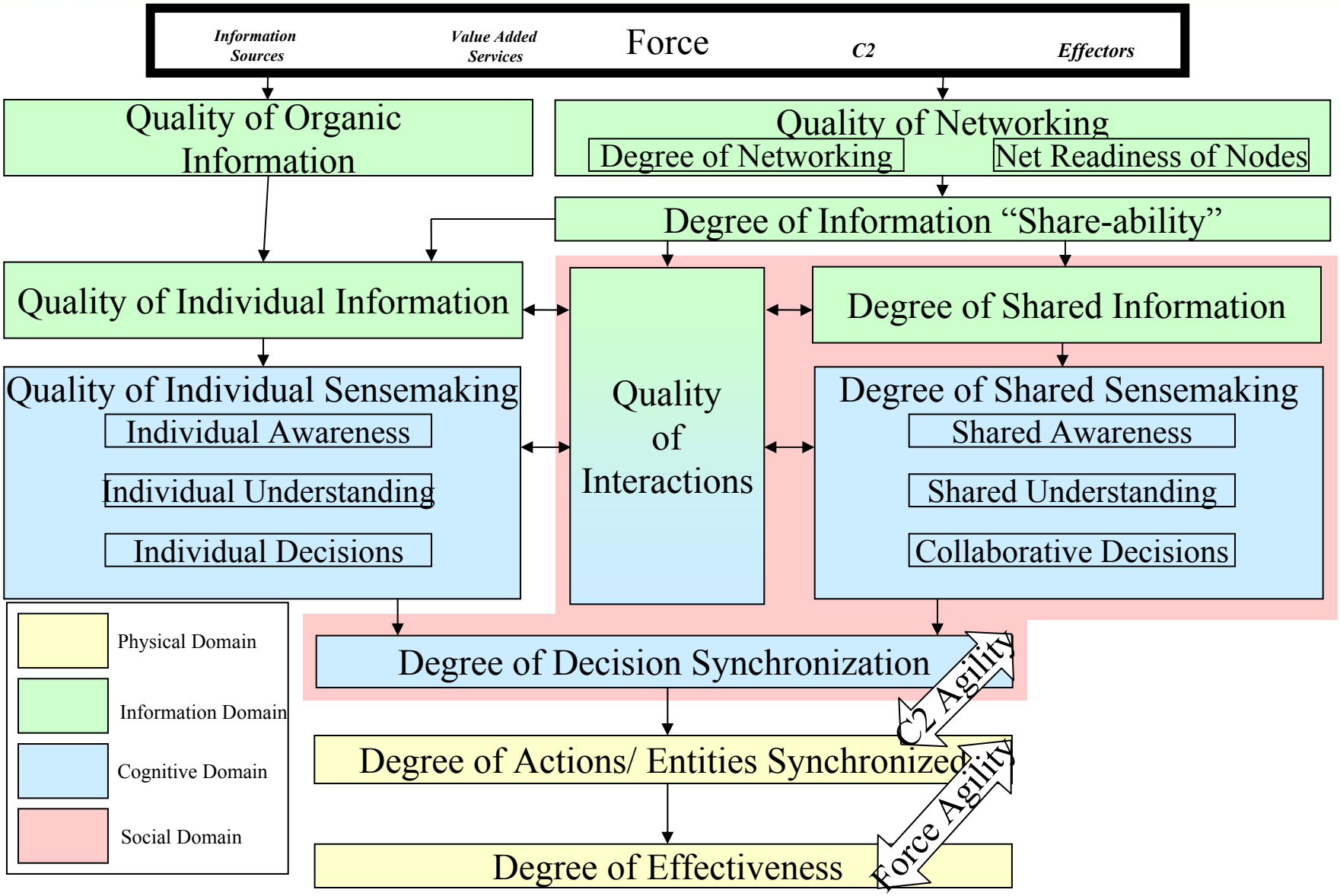
- NetLogo (Northwestern University)
  - Fully Programmable
  - Modeling complex systems developing over time
  - Can give instructions to hundreds or thousands of independent "agents" all operating concurrently and observe behavior patterns

- Project Albert Data Farming Environment (International)
  - Leveraging High Performance Computing
  - Question based collaboration

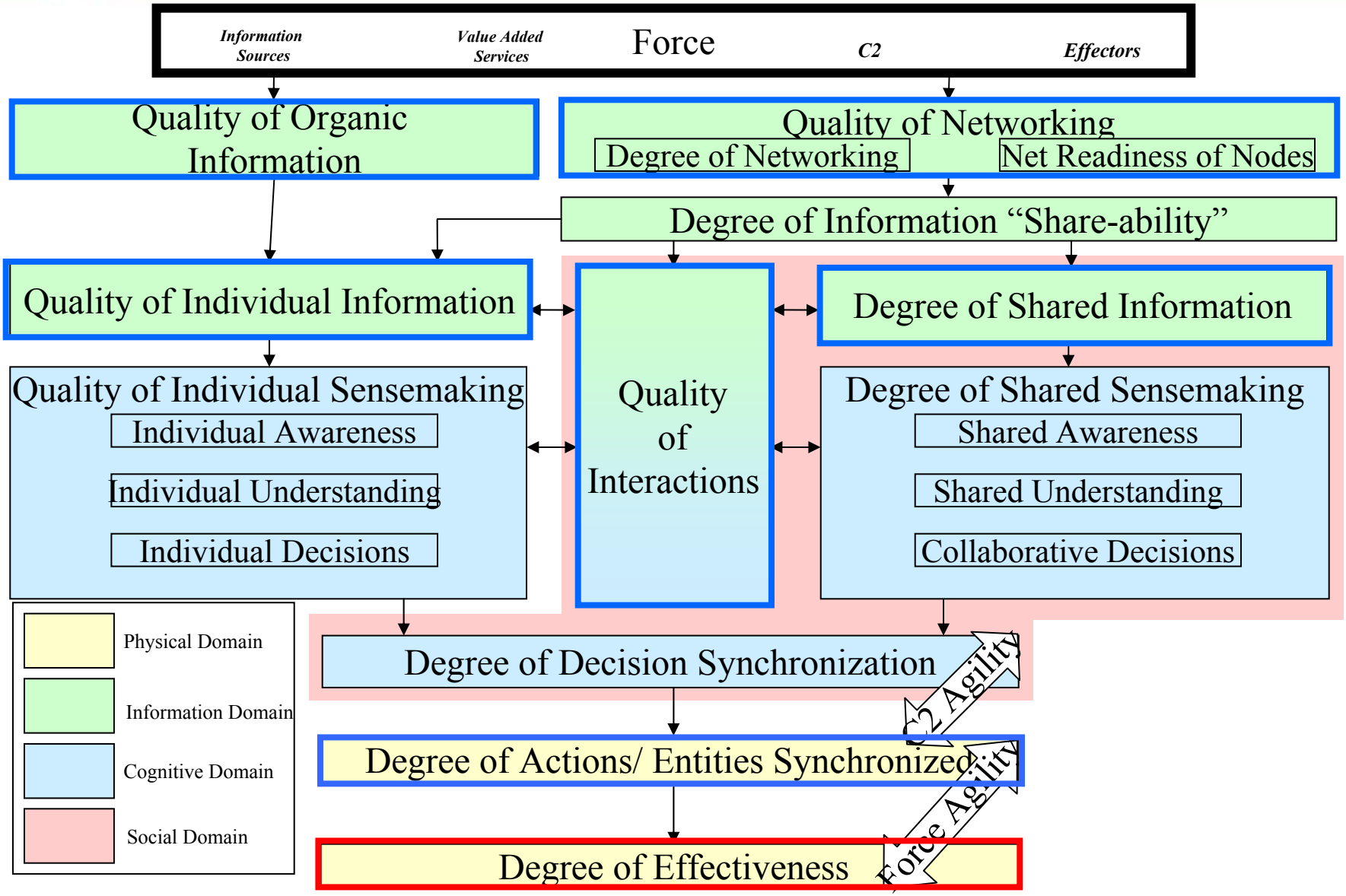
Distillation Advantages/Disadvantages

- Advantages:
  - Ease of use for quick scenario modeling
  - Quick turnaround cycle for data farming
  - Ability to conduct visual analysis of scenario in addition to data analysis – intermediate behaviors visually present via playback but may be overlooked or summarized via data examination
- Disadvantages:
  - Ability to model both communication aspects combined with leadership aspects not present in a single model
  - Artifacts in model difficult to trace without direct contact with developers
  - Too much data and too little time

Network Centric Operations Conceptual Framework

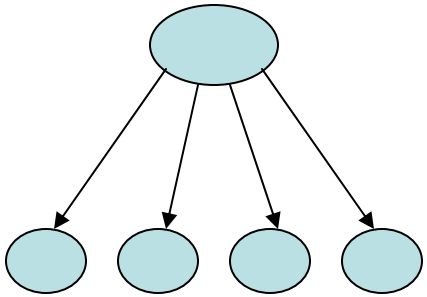


Network Centric Operations Conceptual Framework



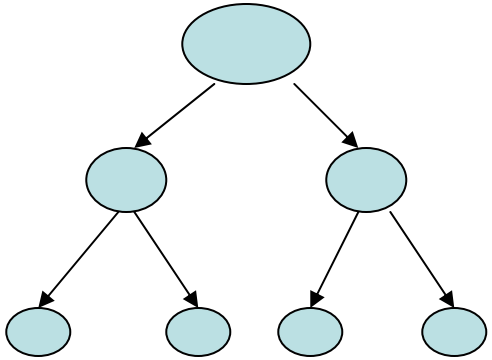
Information Networks

Flat Hierarchy

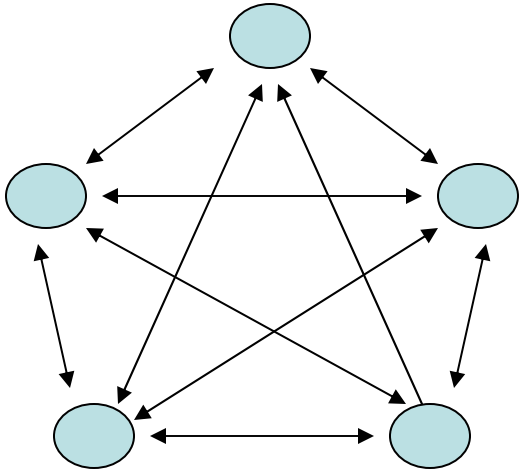


Centralized

Traditional Hierarchy

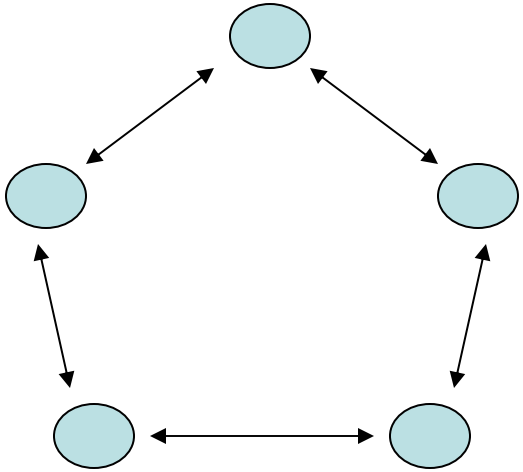


Web – Fully Networked



Decentralized

Circular Network



Four Network Topologies

Reference ***Power to the Edge*** (pg. 182)

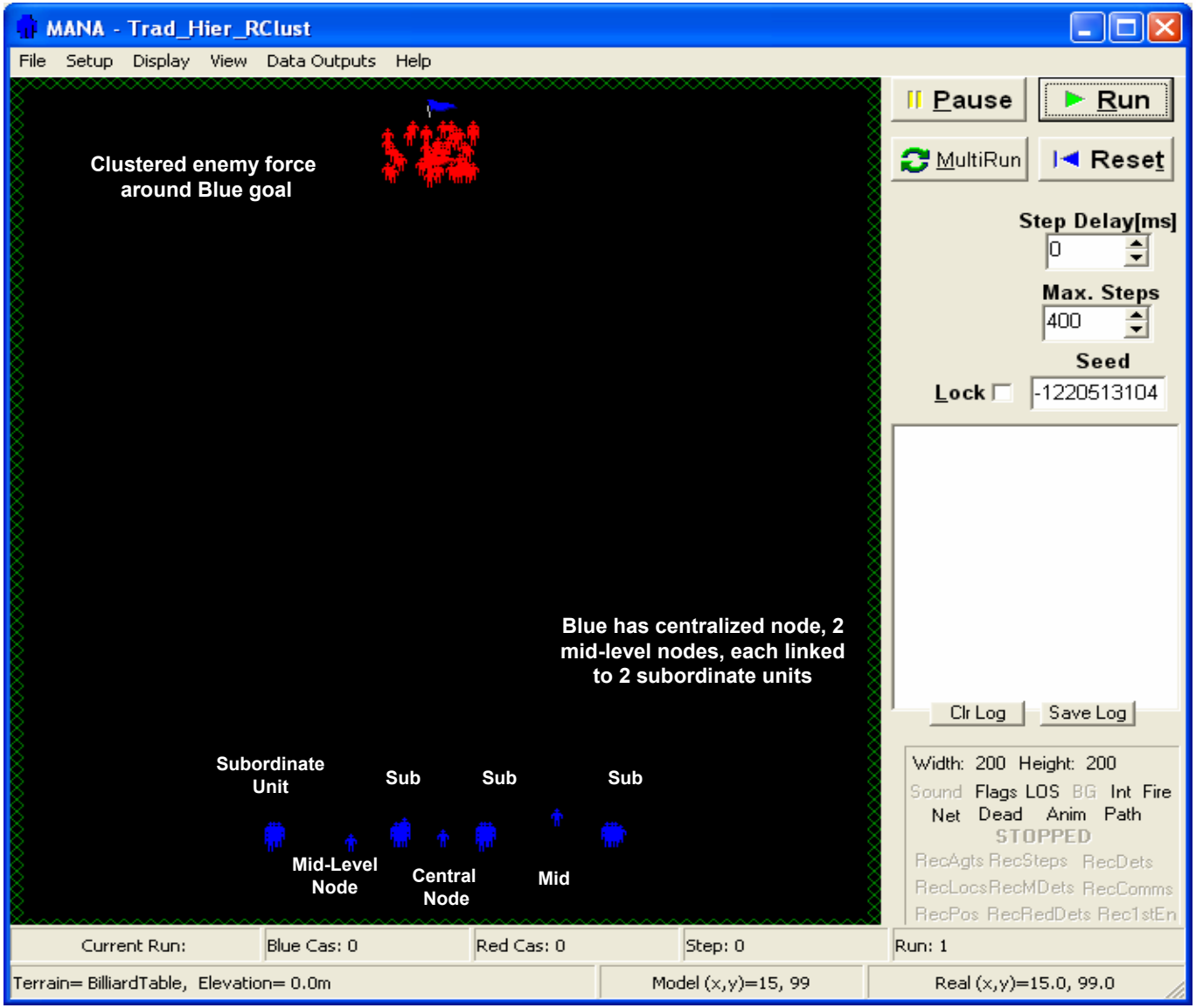
Hypotheses

- Shared information leads to better performance
- Broader or earlier information sharing leads to better performance as individuals have common picture of enemy contacts before getting caught up in battle
- Full connectivity leads to better performance
- Perfect is preferable to degraded communications

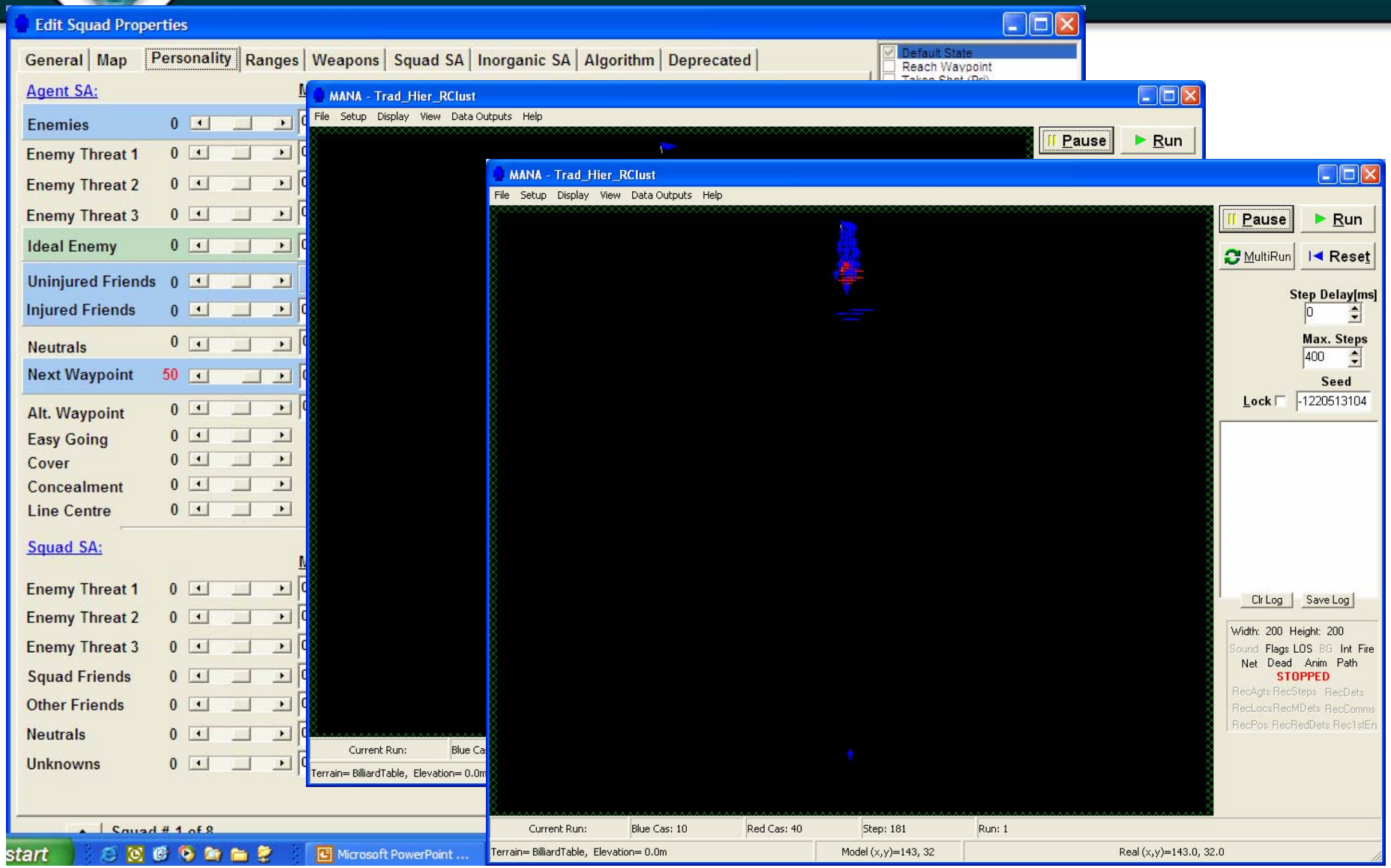
Overview of Experiment I

- Experimental objective:
  - Scenario A: Get to goal at whatever cost (optimal path at shortest time, no consideration for losses; no maneuvering behaviors)
  - Scenario B: Get to goal with minimal losses (maneuvering behaviors with consideration of friendly losses; time to complete mission not a major factor)
  - Scenario C: Deplete enemy forces (from USMC Tactical Decision Game - execute major enemy losses; no established physical goal; no consideration for friendly losses except to have initial advantage in the fight)
- Organization structures
  - Traditional Hierarchy
  - Fully Connected/Web Network
- Scenario
  - Agents receive both organic and inorganic information
  - Information sharing and receiving is constrained by the network structure
  - Each time step an agent will share all of the information it has about the 200x200 map
  - The user has the ability to alter the communication parameters for each agent
- ABM environment: MANA
- Key Questions
  - How does the performance of the Traditional Hierarchical organization compare with that of the fully connected organization under various conditions?
  - How are the performance and situational understanding achieved by each affected by various factors, such as the communication accuracy, reliability, range, etc.?
  - Do these factors affect the organizations differently?

MANA Traditional Network Example



MANA Traditional Network Example
Optimal Path at Shortest Time

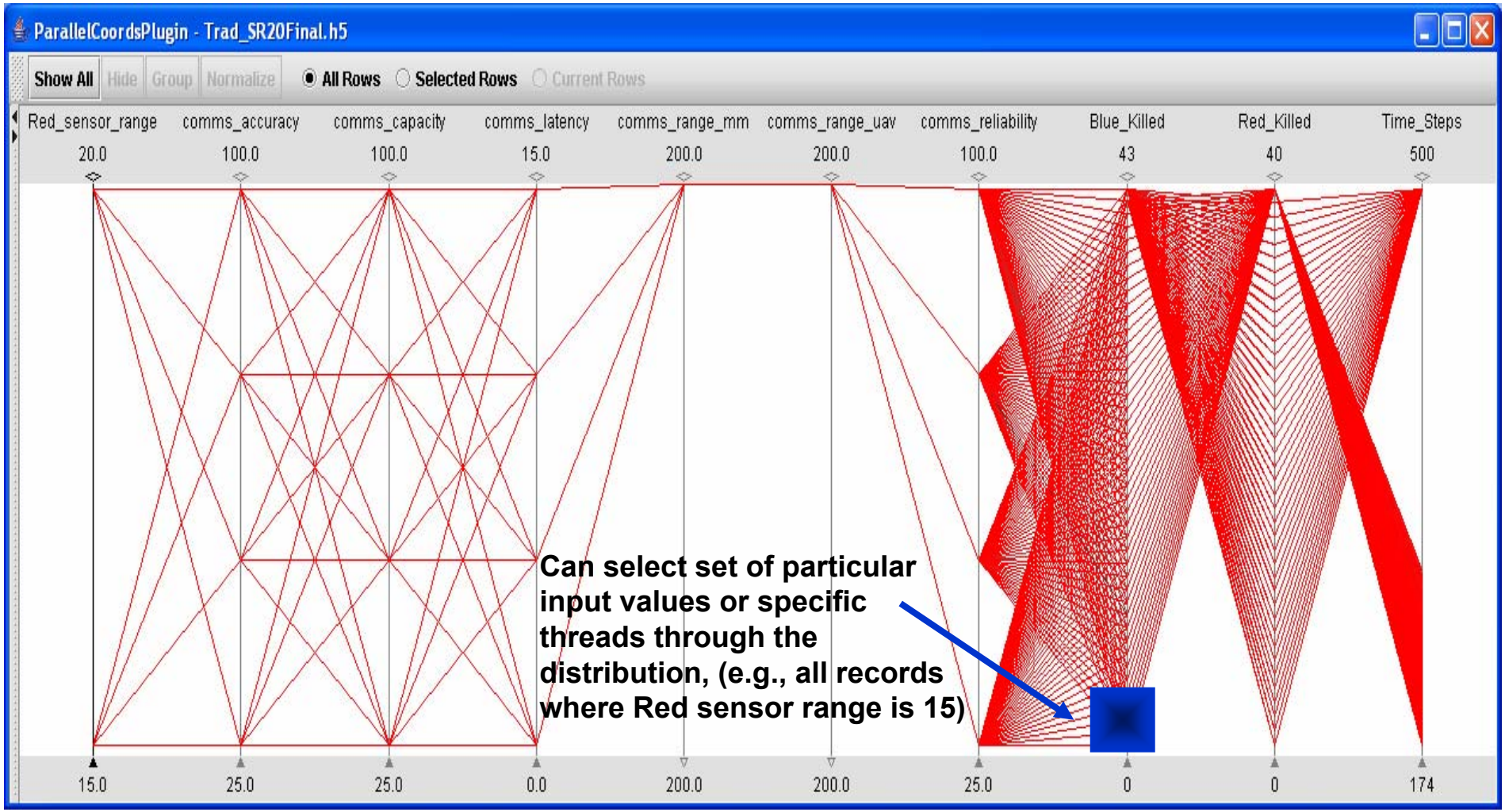


End of Run

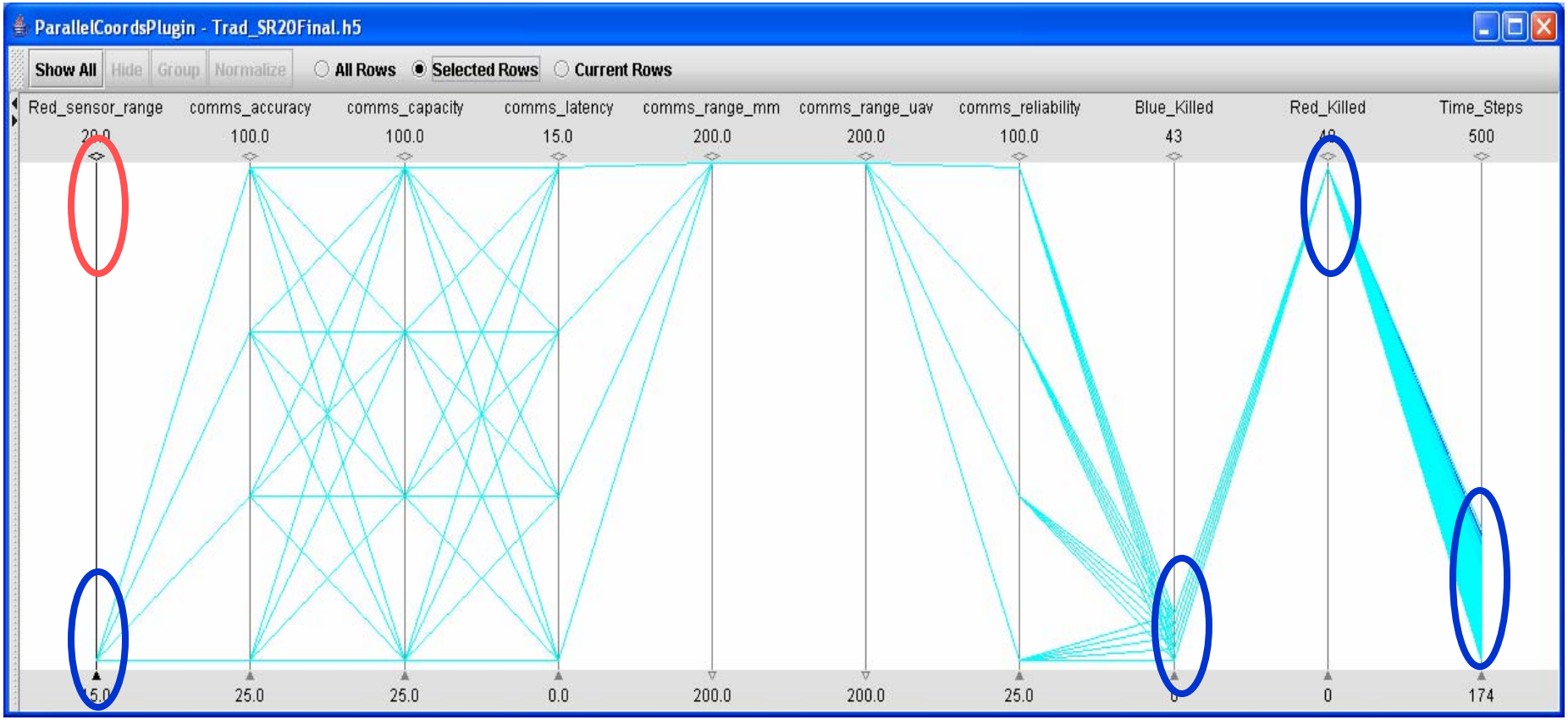
Data Farming Parameters

- Comms Range (100-200 grid cells, in increments of 100 cells)
- Comms Capacity (25-100 messages passed through the comms link, in increments of 25 messages)
- Comms Latency (0-15 time step delay, in increments of 5 time steps)
- Comms Accuracy (25-100% accurate passage of information for correctly detected and classified contacts, in increments of 25%)
- Comms Reliability (25-100% reliability that messages made it through the comms link, in increments of 25%)
- Red Sensor Range (15-20 grid cells, in increments of 5 cells)

Traditional Network
Full Distribution of Data Across All Variable Settings
For Fixed Comms Range = 200 Grid Cells

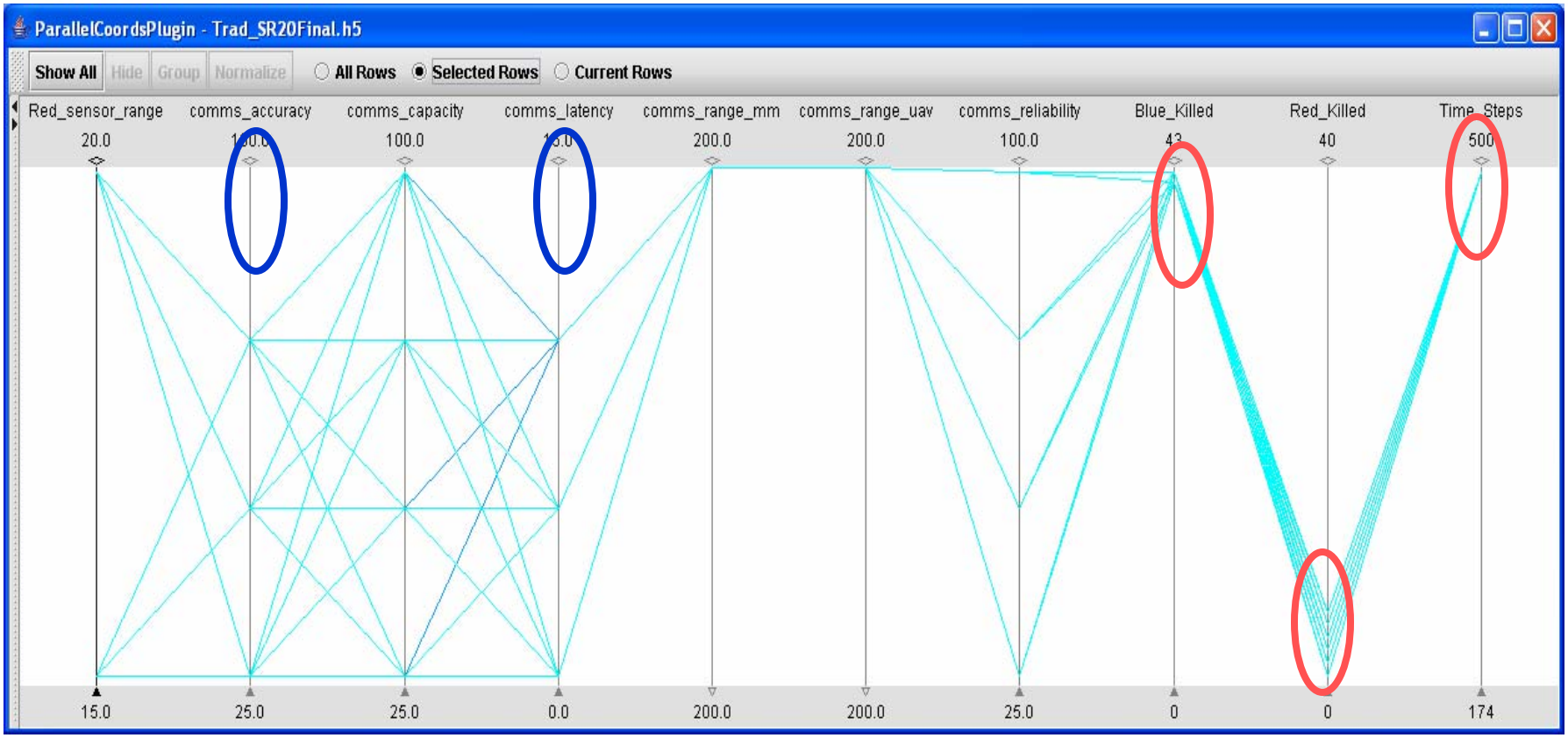


Traditional Network
Low Blue Casualties
Comms Range at 200 Grid Cells (Full View)



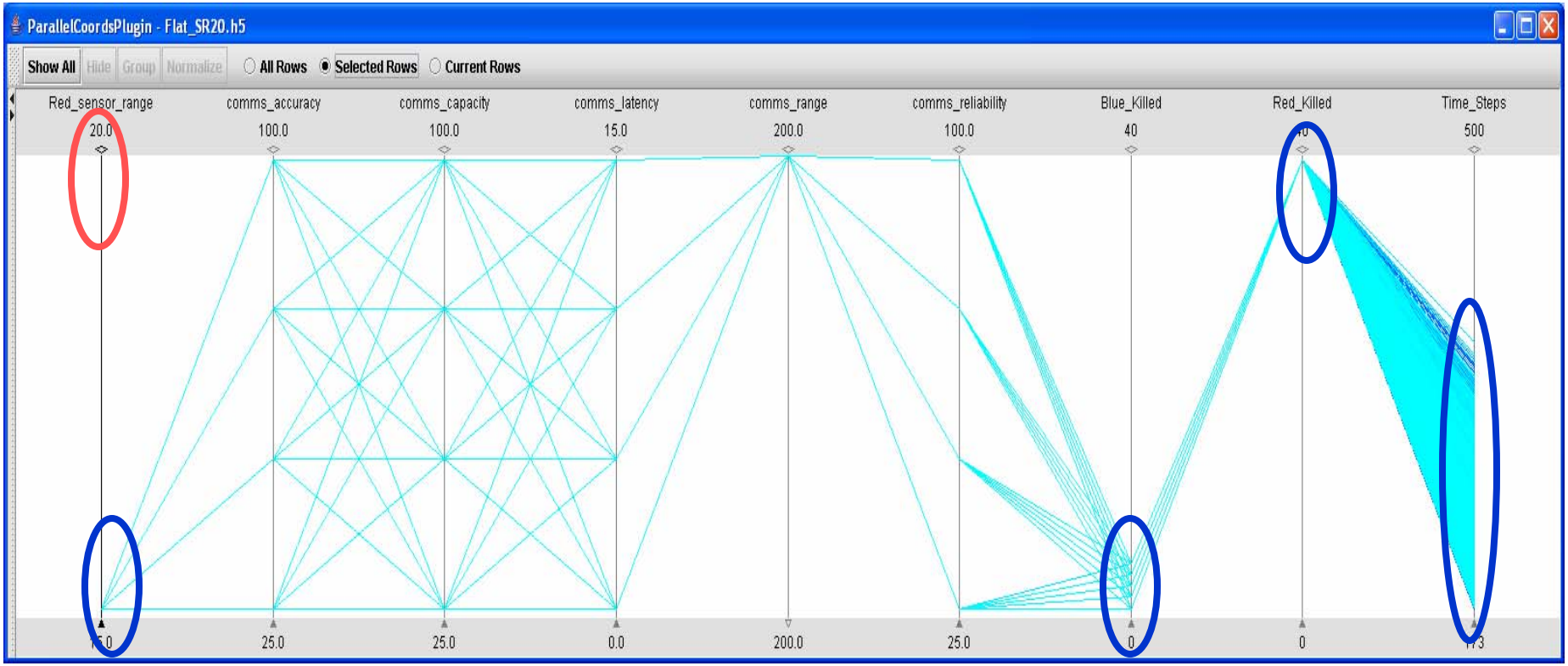
Low Blue killed linked to high Red Killed and lower time to get to goal. In this case Blue always gets to goal. Low Blue killed happens only when Red sensor range is 15 grid cells (which is less than Blue sensor range of 20).

Traditional Network
Low Red Casualties
Comms Range at 200 Cells (Full View)



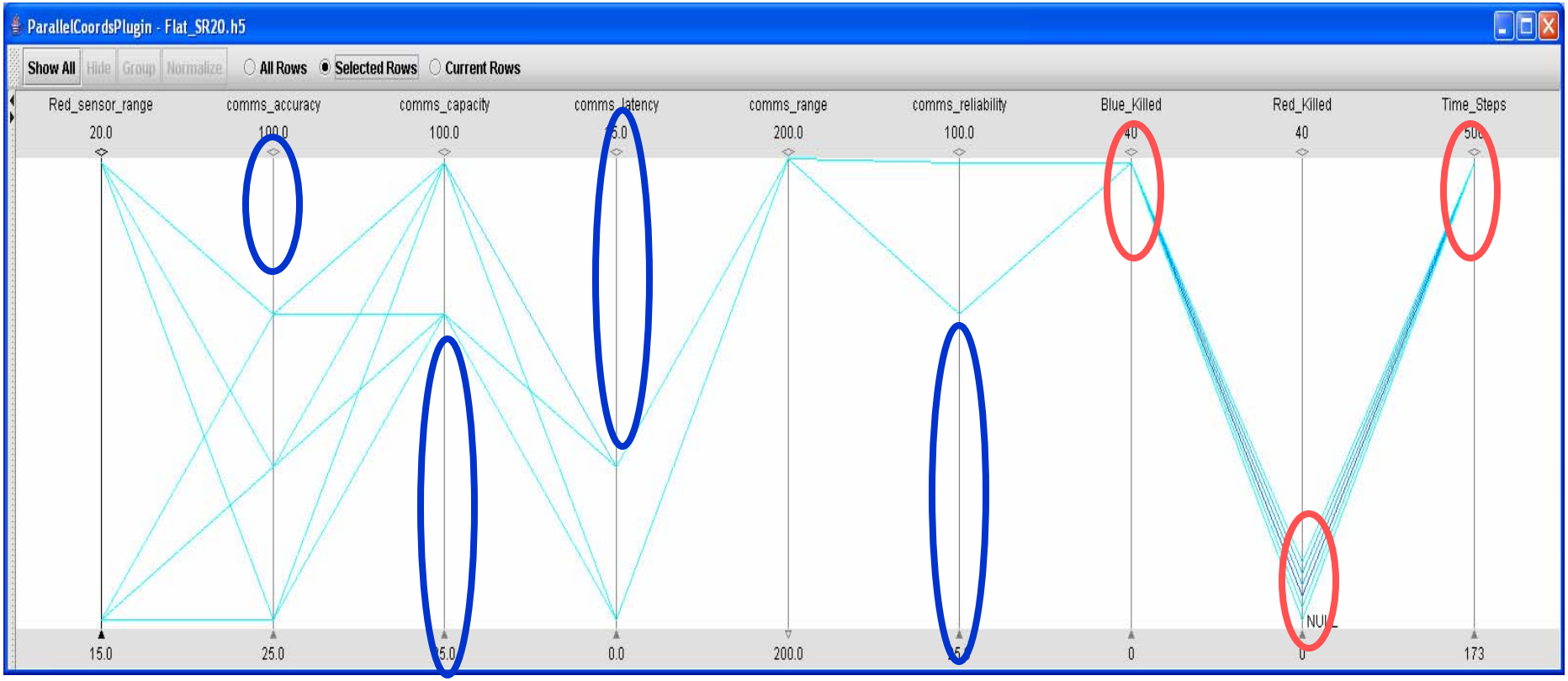
Low Red casualties occur for all parameters except for comms accuracy of 100% and comms latency of 15 time step. Low Red casualties prevents Blue from getting to goal and causes heavy losses for Blue.

Flat Network
Low Blue Casualties
Comms Range at 200 Cells (Full View)



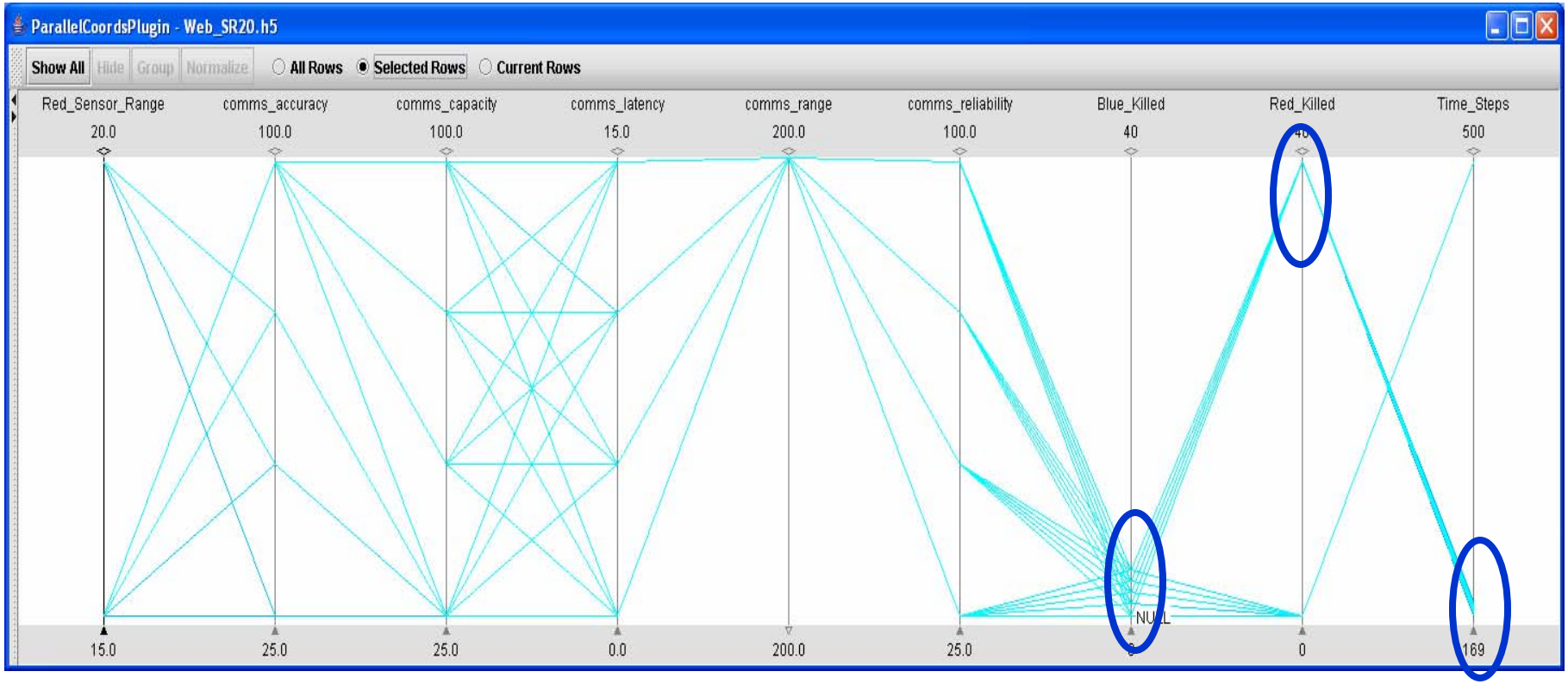
Low Blue killed is linked to high Red Killed. Blue always gets to goal, although on a more variable time period. Low Blue killed happens only when Red sensor range is 15 grid cells.

Flat Network
Low Red Casualties
Comms Range at 200 Cells (Full View)



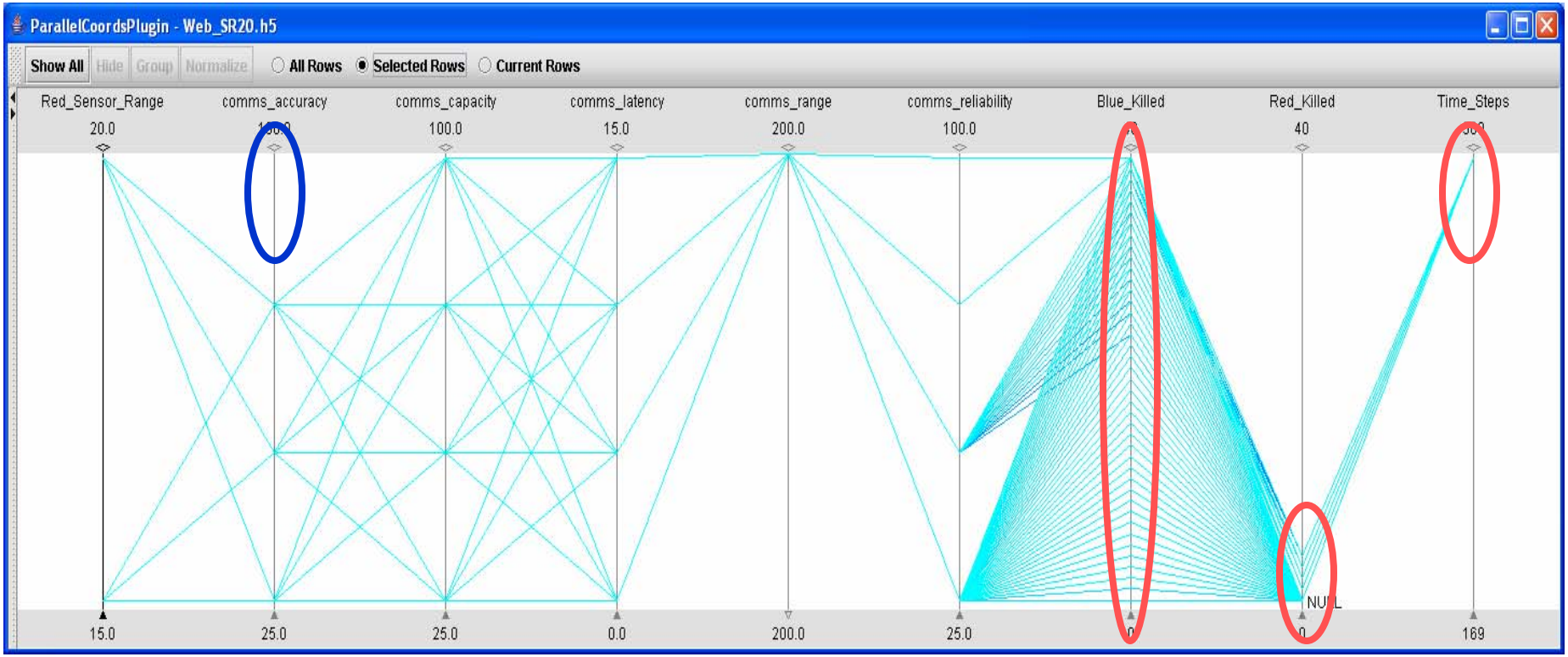
Low Red casualties occur for all parameters except for comms accuracy of 100%, comms capacity less than 75 messages per time step, comms latency greater than 10 time steps, and comms reliability less than 75%. Low Red casualties prevents Blue from getting to goal and causes heavy losses for Blue.

Web Network
Low Blue Casualties
Comms Range at 200 Cells (Full View)



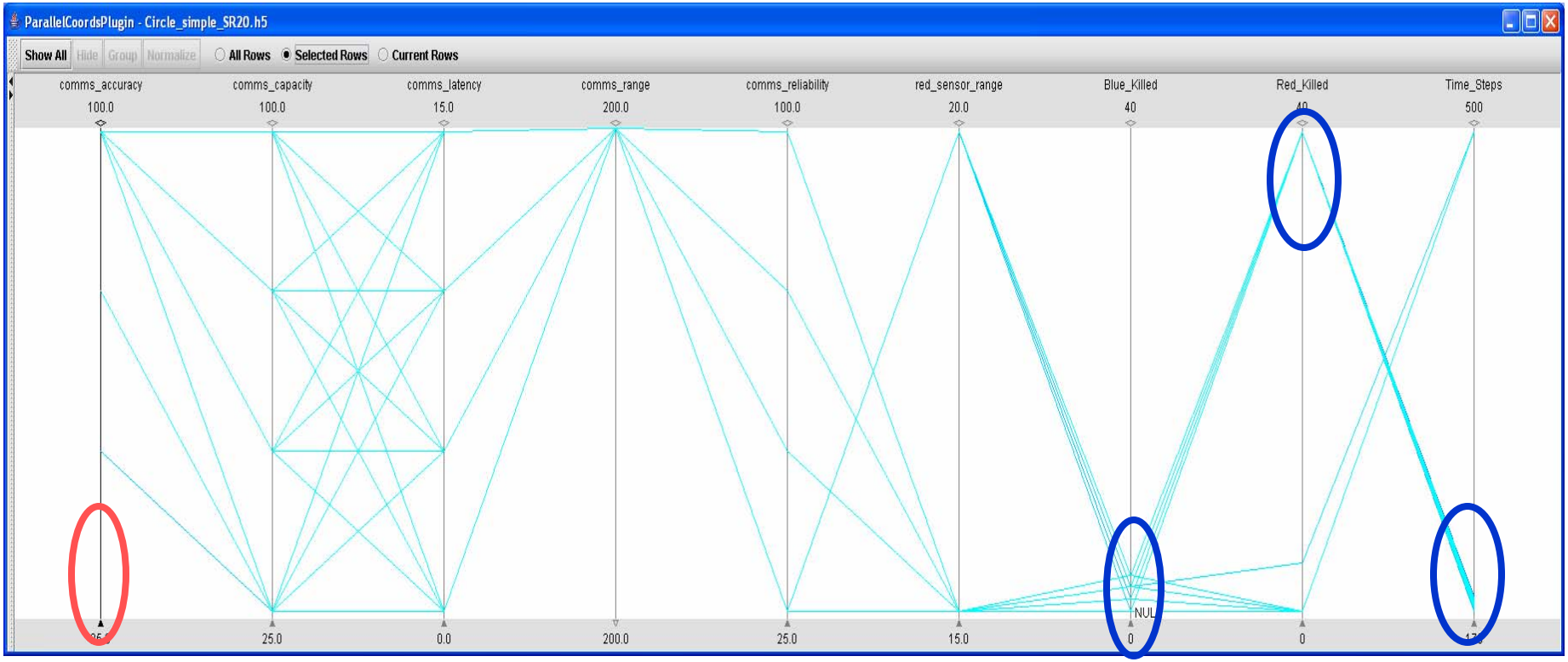
Low Blue killed linked to mix of low and high Red Killed and lower time to get to goal. In this case Blue does not always get to goal and no distinguishing input parameter identified as possible driver of outcomes.

Web Network
Low Red Casualties
Comms Range at 200 Cells (Full View)



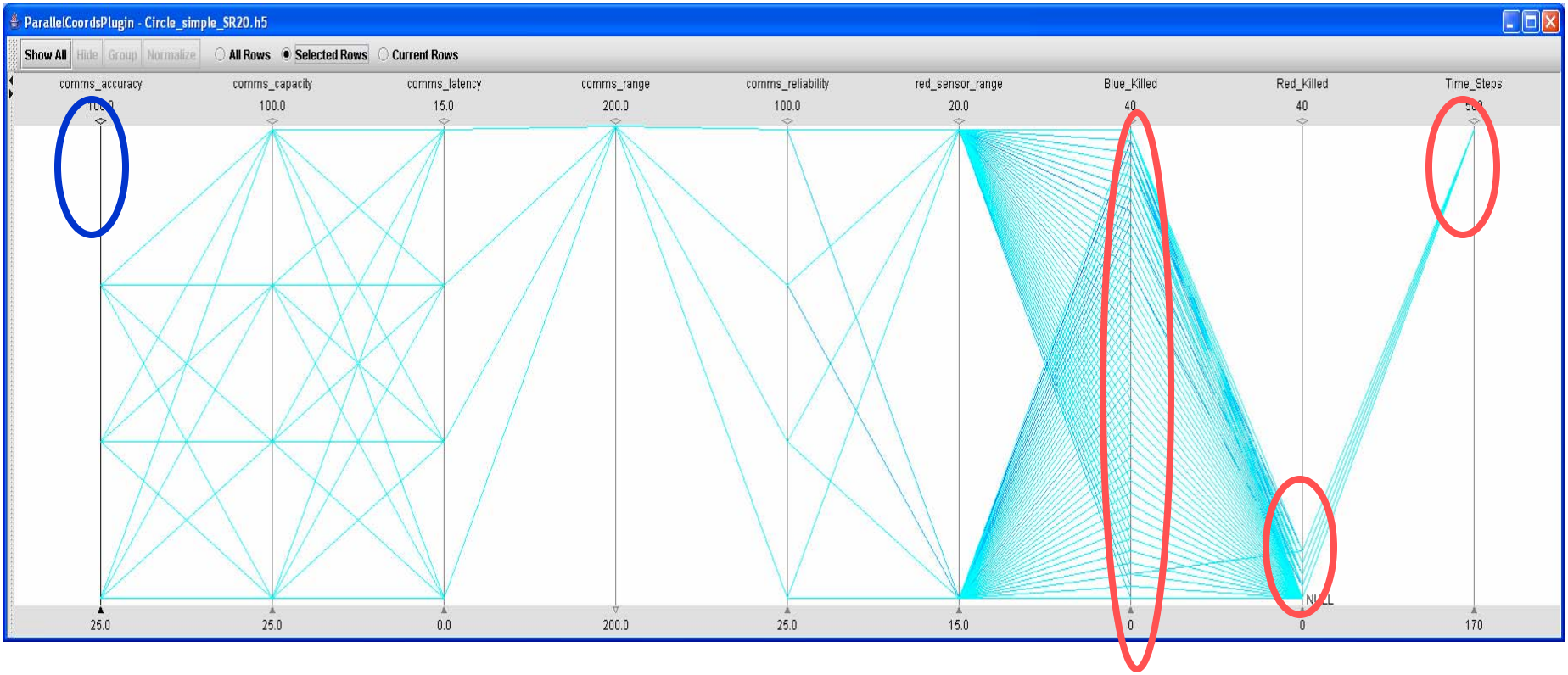
Low Red casualties occur for all parameters except for comms accuracy of 100%. Low Red casualties prevents Blue from getting to goal and causes range of losses for Blue from min of 0 to max possible of 40.

Circle Network
Low Blue Casualties
Comms Range at 200 Cells (Full View)



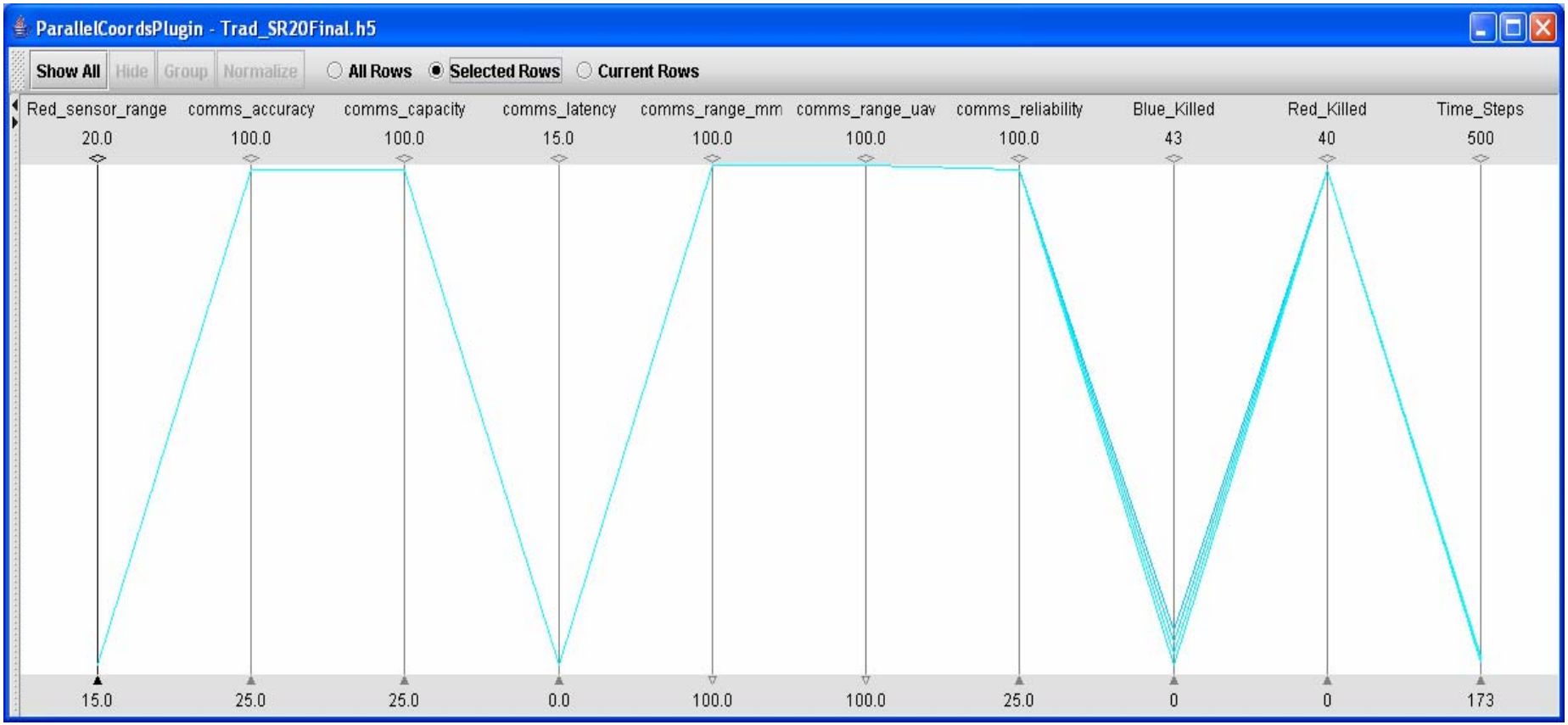
Low Blue killed linked to mix of low and high Red Killed and lower time to get to goal. In this case Blue does not always get to goal and Red sensor range is not the main indicator of outcomes. Low Blue casualties happen for all parameters except for comms accuracy of 25%.

Circle Network
Low Red Casualties
Comms Range at 200 Cells (Full View)



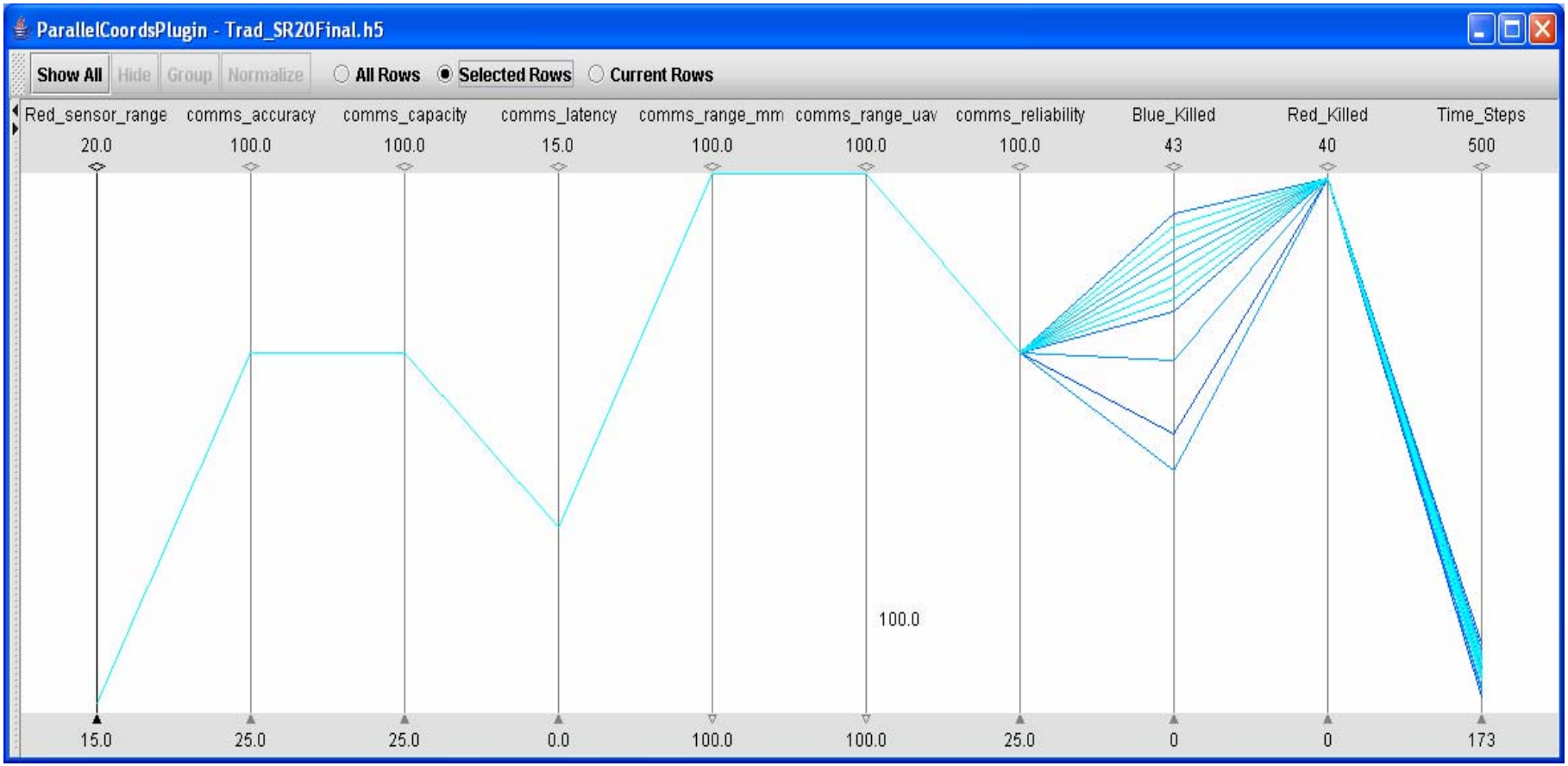
Low Red casualties occur for all parameters except for comms accuracy of 100%. Low Red casualties prevents Blue from getting to goal and causes range of losses for Blue from min to max.

Traditional Network
Perfect Comms Thread
Comms Range = 100, Red Sensor Range = 15



Looking at the thread for perfect comms under our variable settings, we see that Blue suffers minimal casualties, inflicts maximum casualties on Red, and gets to the goal in a very short period of time.

Traditional Network
Slightly Degraded Comms Thread
Comms Range = 100, Red Sensor Range = 15

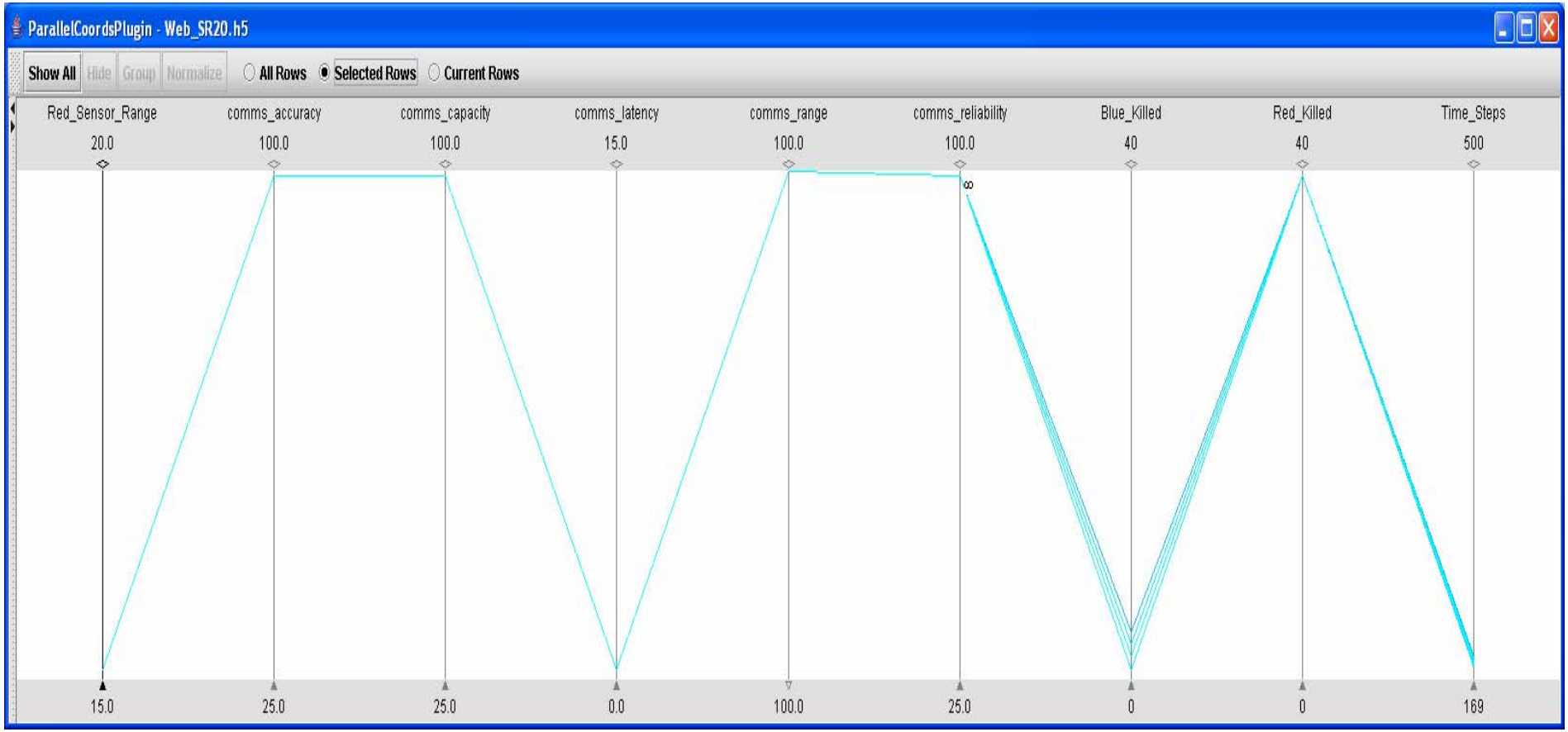


When comms have been degraded by about 25%, we see that Blue suffers heavy casualties, although not the maximum number possible. Blue is able to inflict maximum casualties on Red and still get to the goal in a shorter period of time.

Traditional Network
Fully Degraded Comms Thread
Comms Range = 100, Red Sensor Range = 15

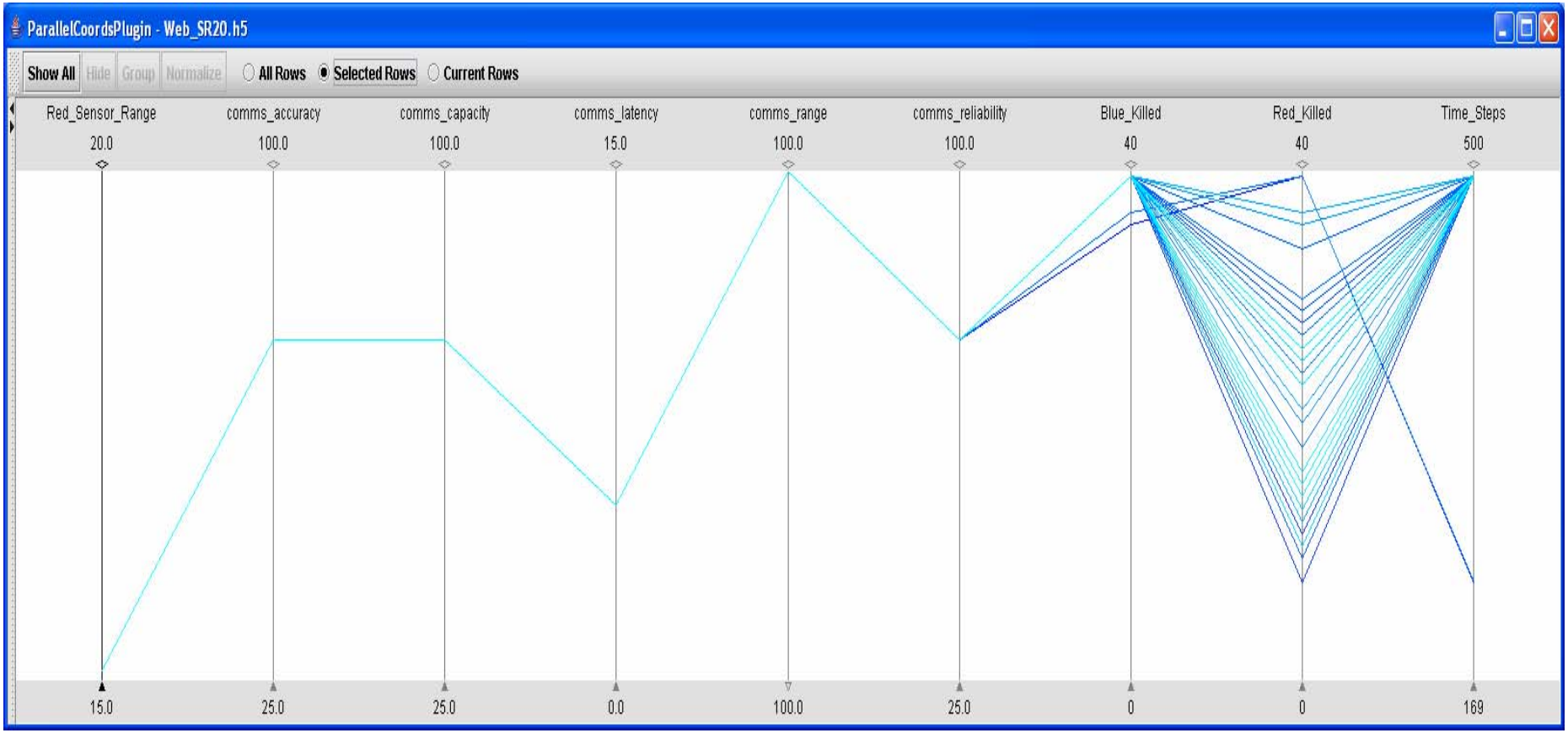
In the case of fully degraded comms, we see that Blue suffers minimal casualties, inflicts maximum casualties on Red, and gets to the goal in a short period of time. This is an interesting anomaly, that contradicts the logical hypothesis that fully degraded comms lead to the inverse outcome for Blue than indicated in this chart. Cannot say with certainty that this is not an artifact of the model, however, if not an artifact, could indicate behaviors that we were not expecting.

Web Network
Perfect Comms Thread
Comms Range = 100, Red Sensor Range = 15



In the case of the web network for perfect comms, we see the same pattern that occurred for the traditional network. Blue suffers minimal casualties, inflicts maximum casualties on Red, and gets to the goal in a very short period of time.

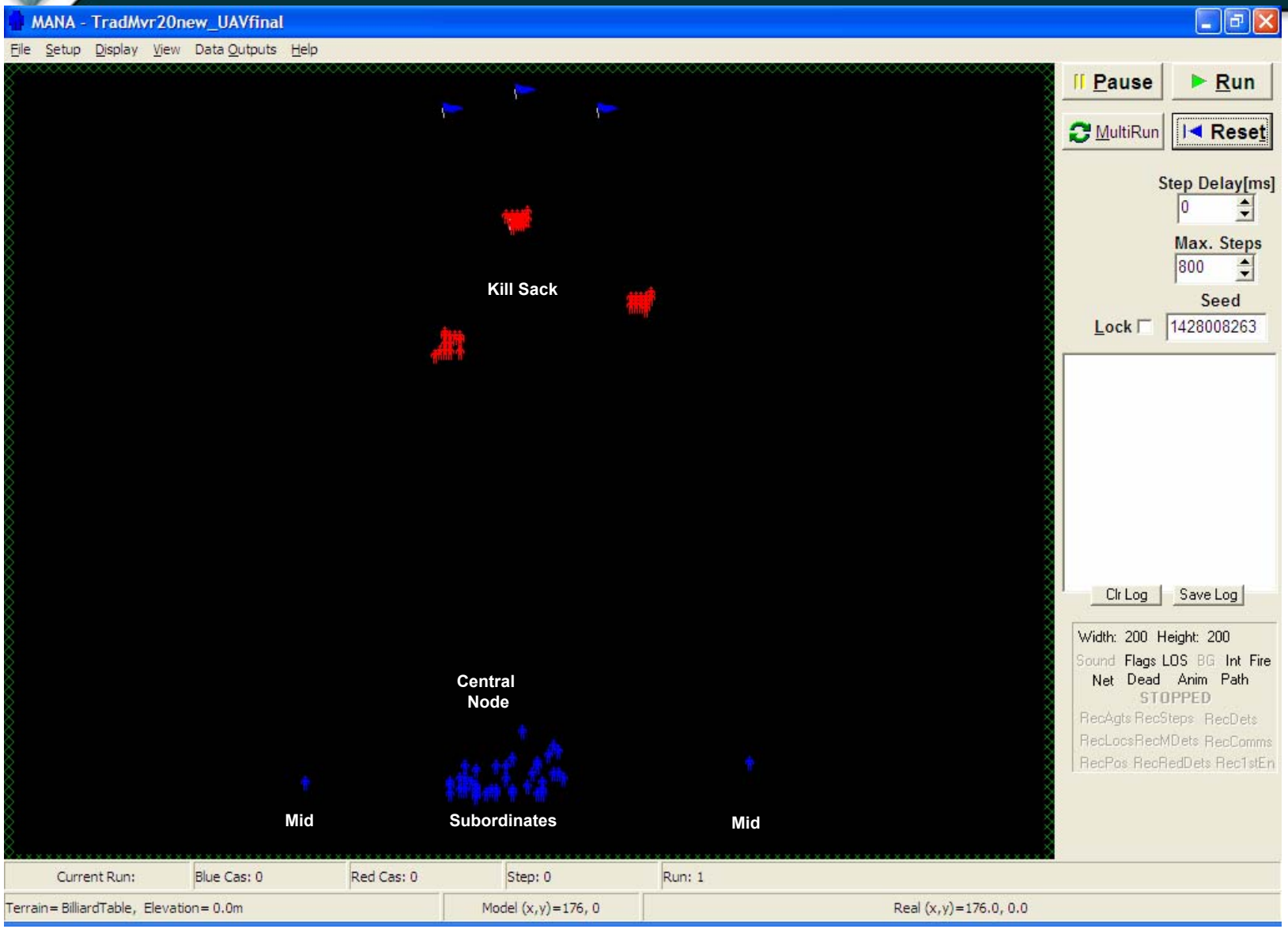
Web Network
Slightly Degraded Comms Thread
Comms Range = 100, Red Sensor Range = 15



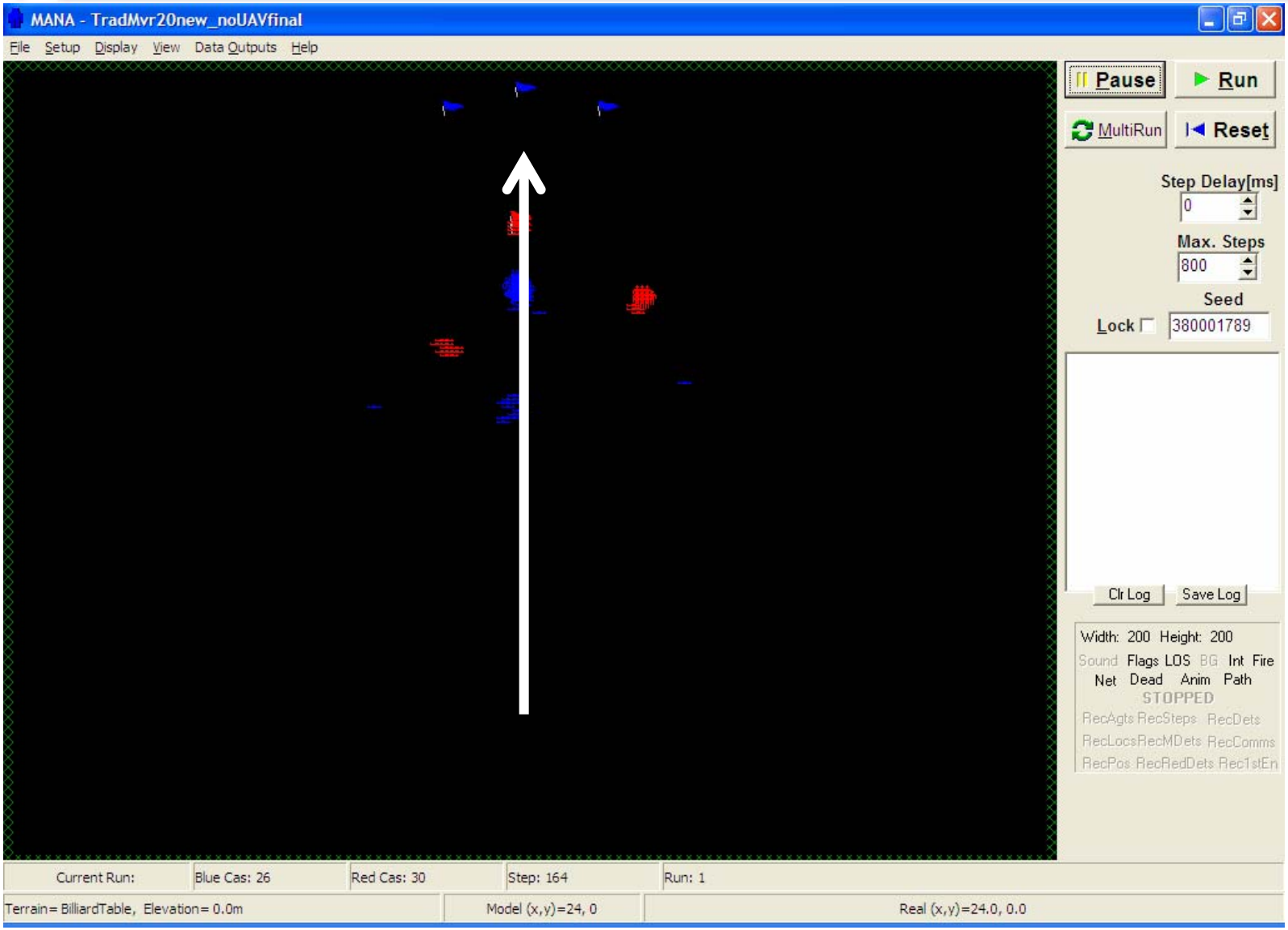
When comms have been degraded by about 25%, we see that Blue suffers close to maximum casualties, and inflicts a range of casualties on Red, however less than with perfect comms. In this case, slightly degraded comms prevent Blue from getting to the goal in almost every case.

Patterns of Movement

Maneuvering Behaviors with Consideration of Friendly Losses

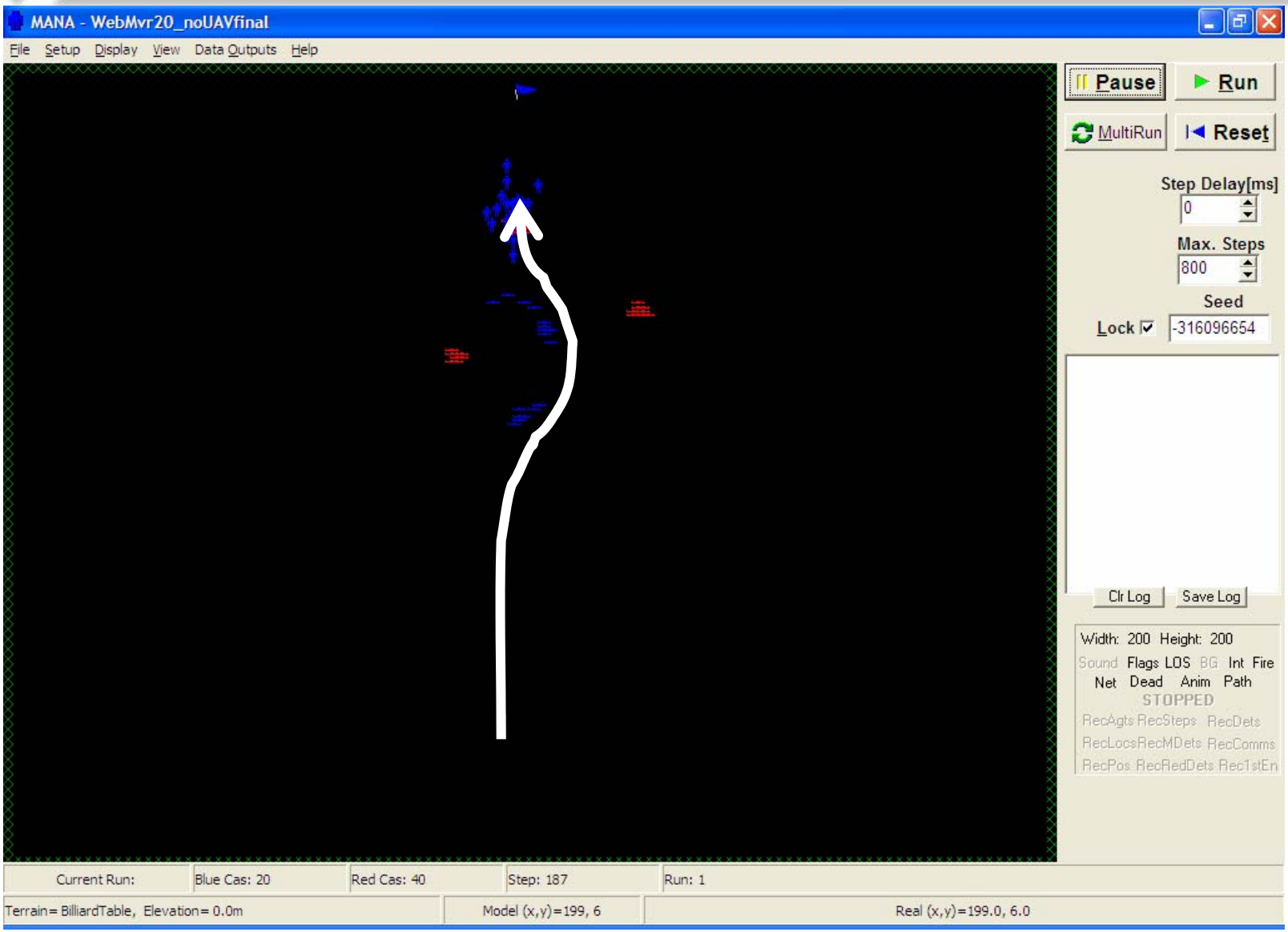


Traditional Network without UAV



Traditional Network with UAV

Web Network without UAV



Web Network with UAV

Visual Analysis Summary

Traditional

Without UAV:

- All Blue agents head straight up the middle of the battlefield, without maneuvering to avoid enemy
- The Subordinates receive no Inorganic SA until the Mid-Level Nodes encounter Red, within their sensor range of 20
- Mid-Level Nodes are often killed before any other agents
- Blue suffers great loss (more than half)
- Successful in reaching the goal and require little time

With UAV:

- All Blue subordinates initially move in the opposite direction of the goal, away from enemy
- The Mid-Level Nodes often lose communication with their respective squad, the distance between them is greater than the comms range of 100
- Blue travels in squads as opposed to one large group
- Upon close contact with the enemy, the Blue squads move away from Red so much that they go far out of their way, in turn taking a long time to reach the goal
- Blue suffers great loss (more than half)
- Successful in reaching the goal, requires a lot of time

Web

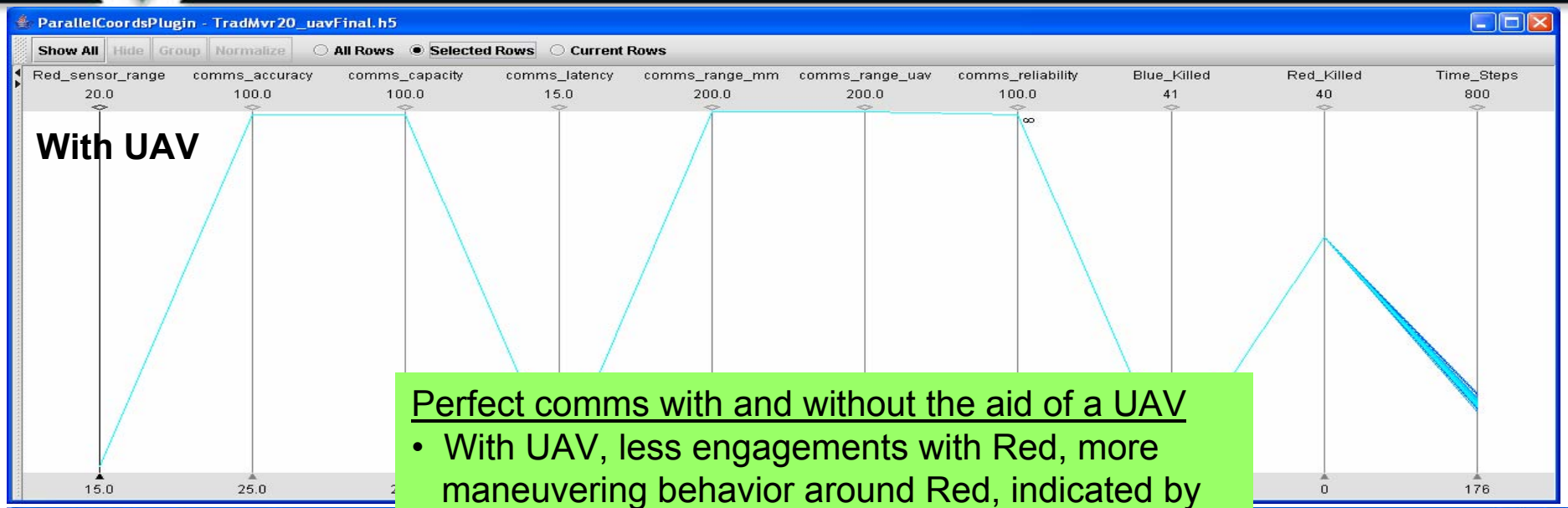
Without UAV:

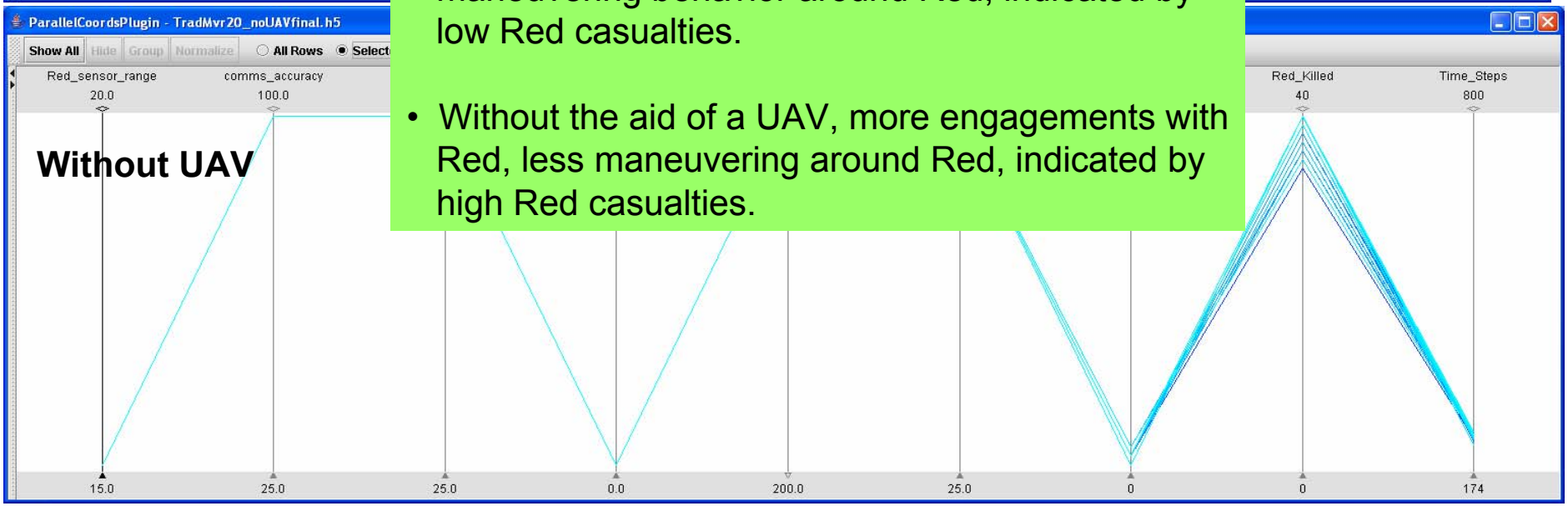
- All Blue agents head straight up the middle of the battlefield, however upon enemy contact, squads maneuver to avoid enemy
- Each squad supplies the others with Inorganic SA once Red is within their sensor range of 20
- Even though the squads try to avoid the enemy, they are caught in the kill sack since the information was not received prior to Red contact
- Blue suffers loss
- Successful in reaching goal for majority of trials

With UAV:

- All Blue subordinates initially move toward the goal
- Each squad maneuvers to the right or left of the enemy, splitting the force across the battlefield
- The split in maneuvers is unique to this scenario
- The mission is accomplished fairly quickly with minor losses to both Blue and Red

Traditional Network
Comms Range =200 for UAV and Mid-Level Node Red
Sensor Range = 15

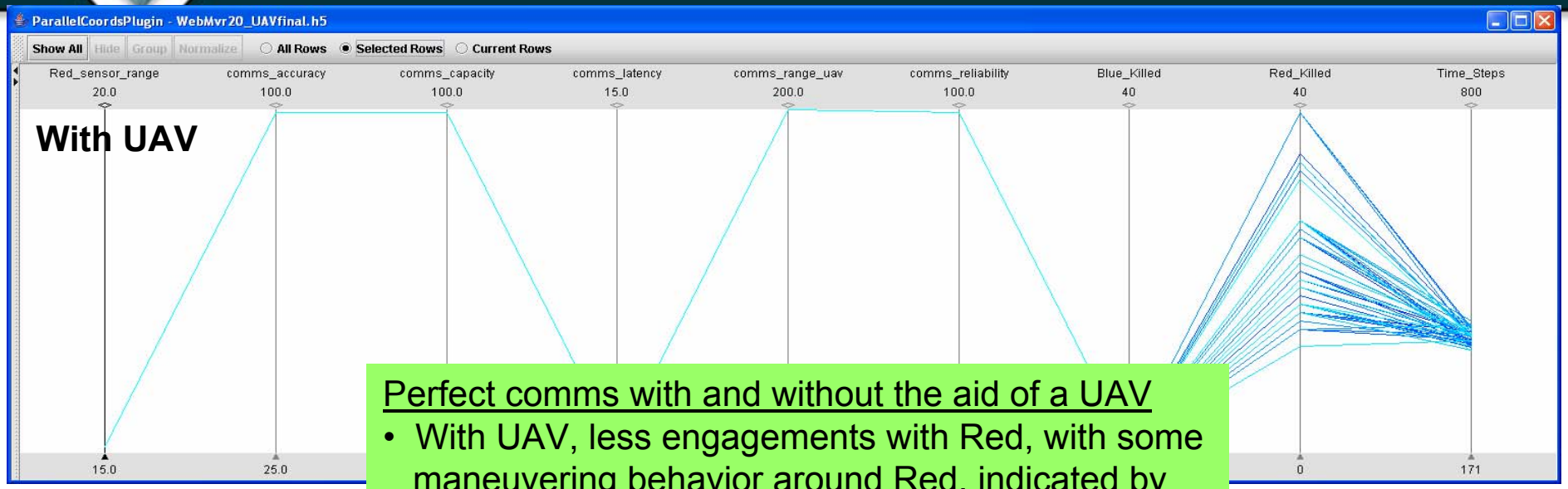


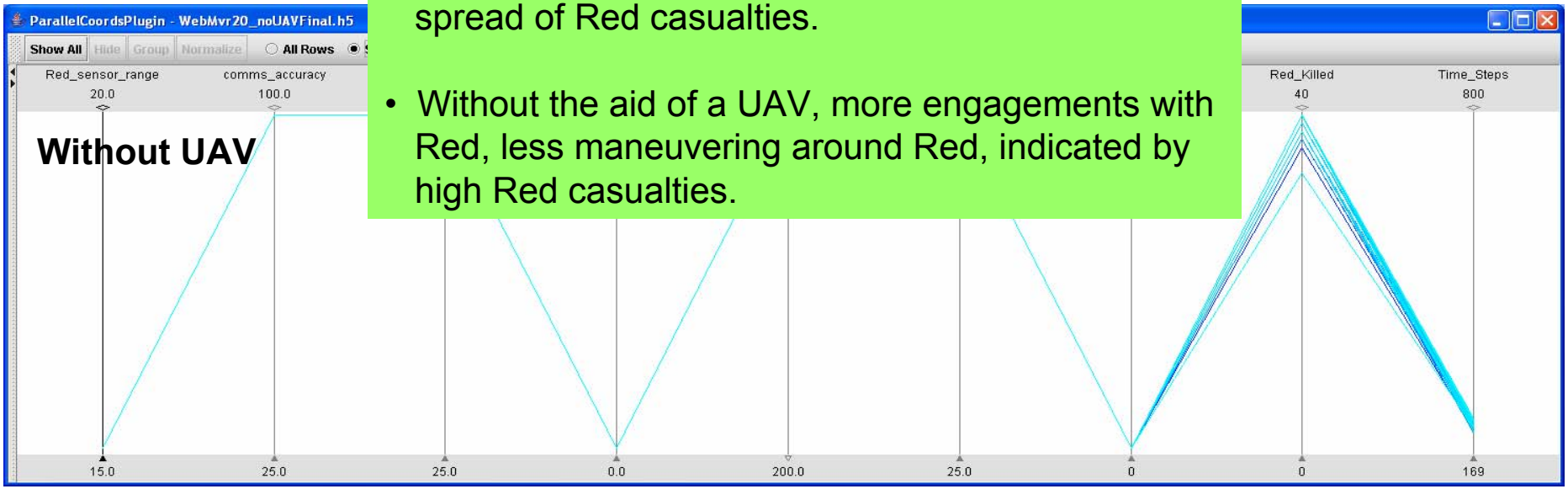


Perfect comms with and without the aid of a UAV

- With UAV, less engagements with Red, more maneuvering behavior around Red, indicated by low Red casualties.
- Without the aid of a UAV, more engagements with Red, less maneuvering around Red, indicated by high Red casualties.

Web Network
Comms Range =200 for UAV
Red Sensor Range = 15





<u>Perfect comms with and without the aid of a UAV</u>

- With UAV, less engagements with Red, with some maneuvering behavior around Red, indicated by spread of Red casualties.
- Without the aid of a UAV, more engagements with Red, less maneuvering around Red, indicated by high Red casualties.

Marine Corps Gazette Tactical Decision Game Deplete Enemy Forces

Tactical Decision Game #97-3

Meeting at 'The Mounds'

by Maj John F. Schmitt, USMCR

This TDG should look familiar. Its scenario is essentially the same as the one encountered in TDG #97-1 for which three solutions are given on the preceding pages. There is one major difference however—this time you are the enemy. How does having read pages 83-85—having looked at three alternate ways your opponent might see the situation—influence your decision? Does it help you to have "worn your opponent's shoes" for a few minutes? Is "wearing his shoes" part of what is meant by orienting on the enemy?

Situation

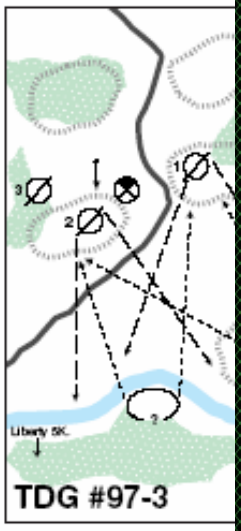
You are a squad leader in Company K, 3d Battalion, 4th Marines. The company is making a movement to contact, moving south toward Liberty. The company's mission is to locate and destroy any sizable enemy forces en route. The company commander has made it clear that the march objective is merely a reference point for the direction of movement; the true objective is the enemy. You are fighting an aggressive infantry force that when assembled usually either pushes rapidly ahead to bypass your positions or calls in supporting fires and attacks them.

Your platoon is the advance guard, and your squad has the point. Your lieutenant has given you the following instructions:

> I'm relying on you to develop the situation to the best of your ability whenever you make contact. If you can overpower the enemy yourself, fine. If it's a sizable enemy force, my intent is for you to develop the situation advantageously for the rest of the company. Try to maneuver to fix the enemy so they can't escape and so the CO can bring the rest of the company to bear. I'll support you with the other two squads.

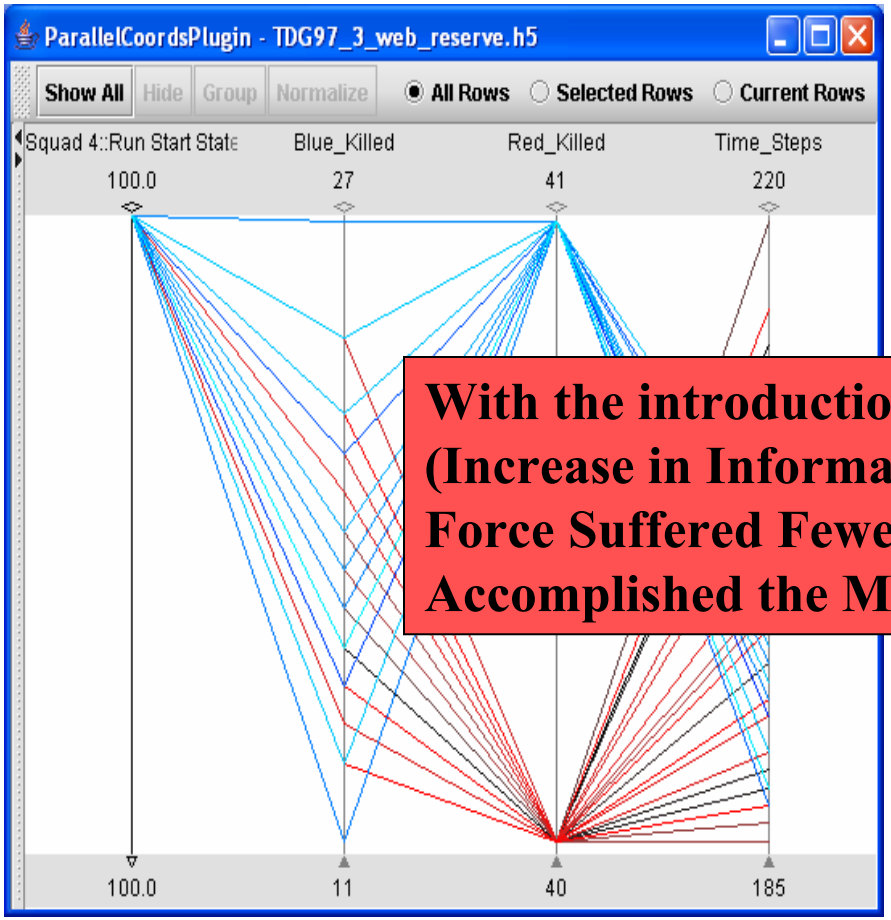
Your squad is in a wedge formation with 1st Fire Team on the left, 2d Fire Team in the center leadi and 3d Fire Team on the right. attached machinegun squad is loc ed with you behind 2d Fire Tea The platoon commander is ab 200 meters behind you, and the m of the platoon is about 300-400 m ters back.

Your squad is moving through area known as The Mounds, gen ally following a road that winds way toward Liberty. The terrain unusual and you have Marines both sides of the road alert for p sible contact. As 2d Fire Team cre one of the mounds, you see Marines drop quickly to the pro position and begin firing. You cra forward to the crest and can see enemy force firing from a sure bed about 500 meters south. Another position soon opens up from a mound to the left front. You esti-

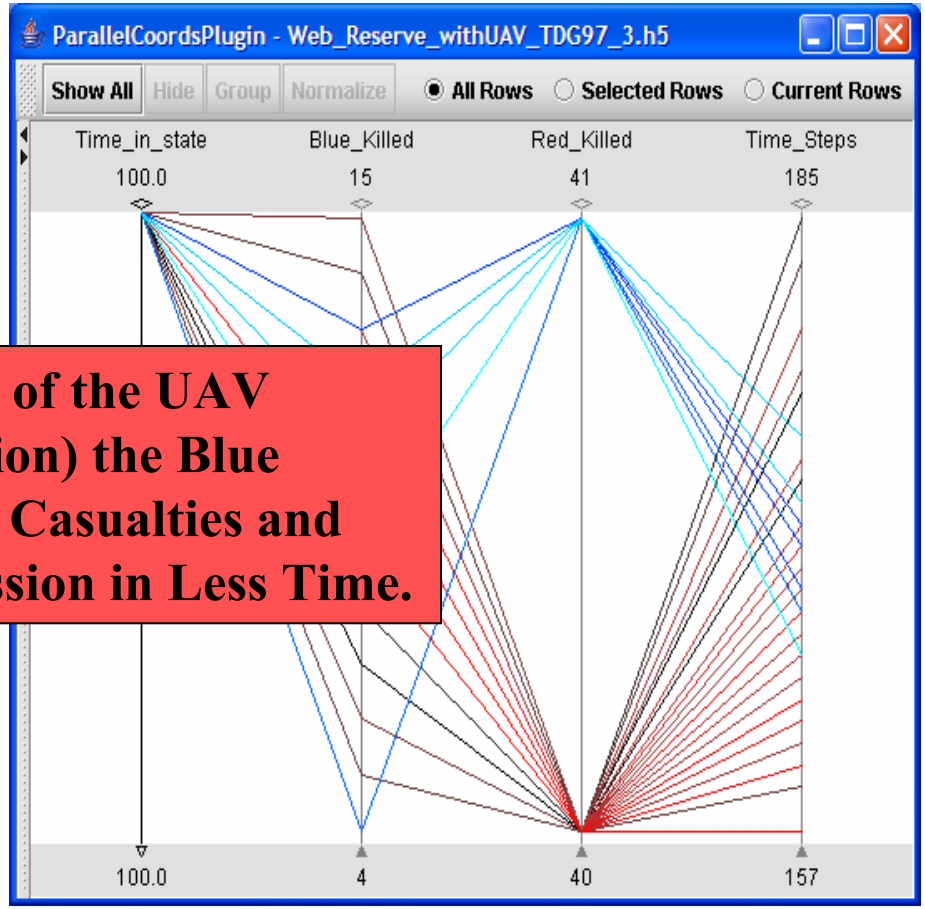


TDG 97-3 Web Network
Reserve Delay 100 time steps

Without UAV



With UAV



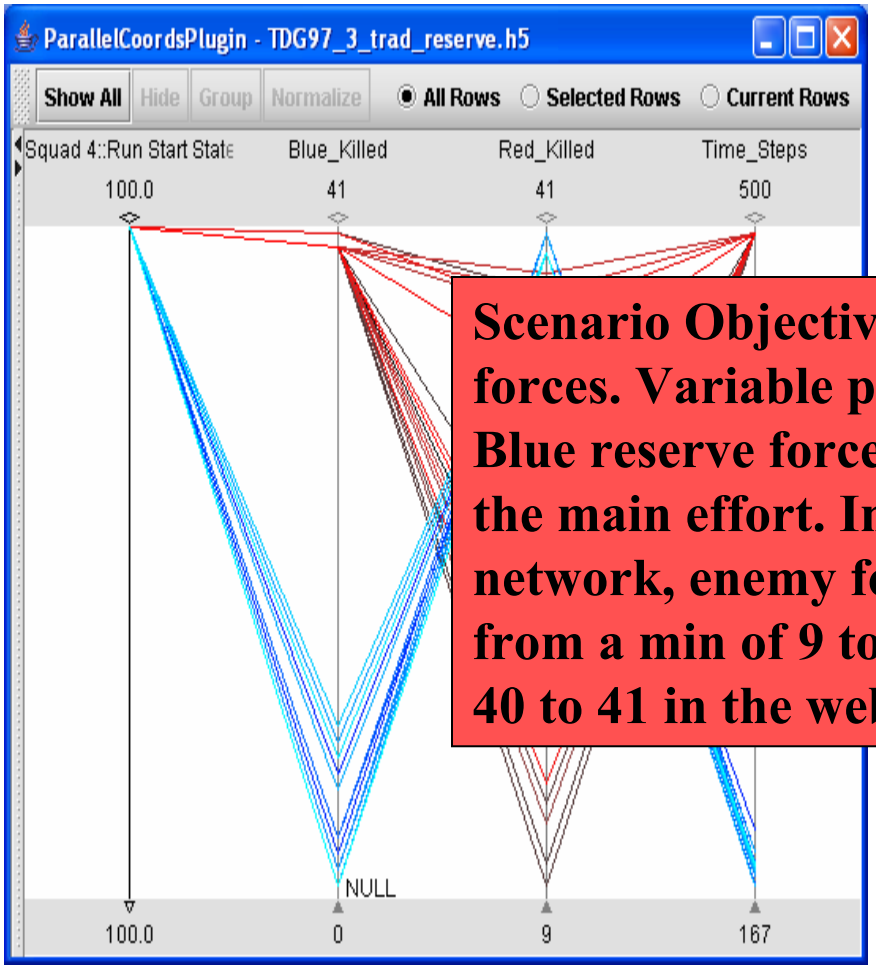
With the introduction of the UAV (Increase in Information) the Blue Force Suffered Fewer Casualties and Accomplished the Mission in Less Time.

Blue Casualties: 11-25

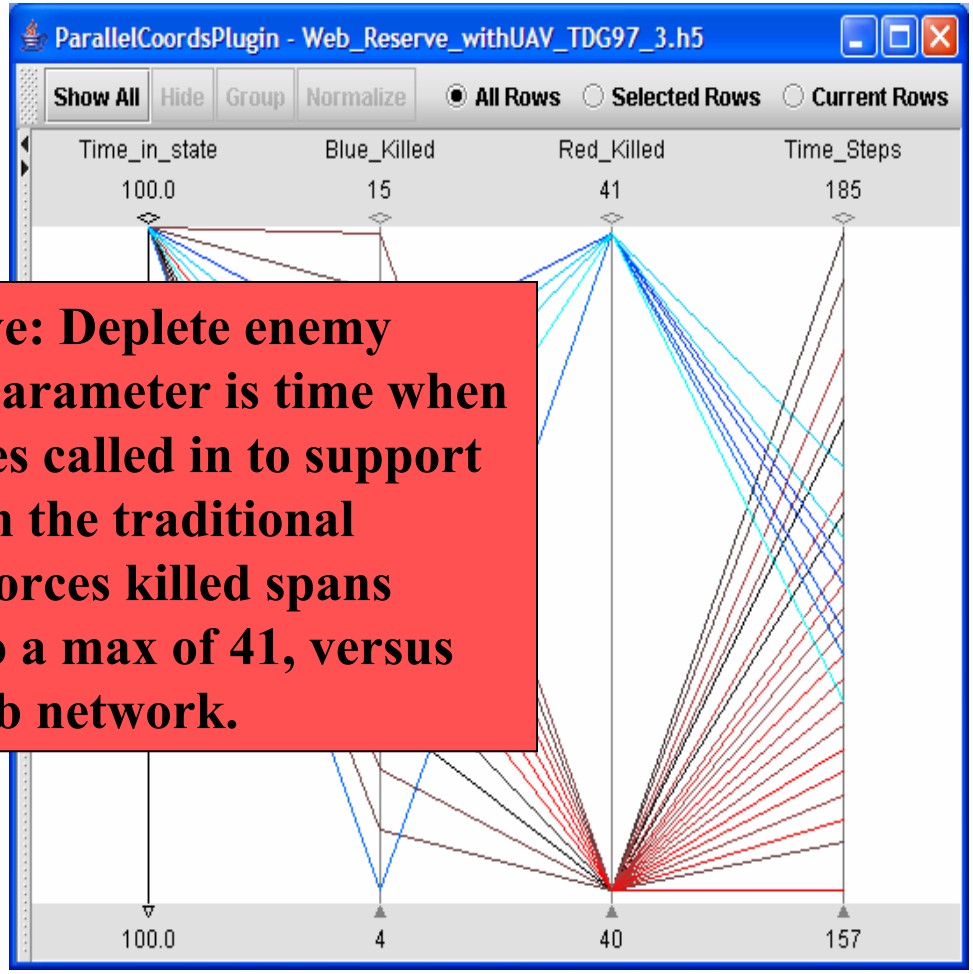
Blue Casualties: 4-15

TDG 97-3 Traditional vs. Web Network Reserve Delay 100 time steps

Traditional - With UAV

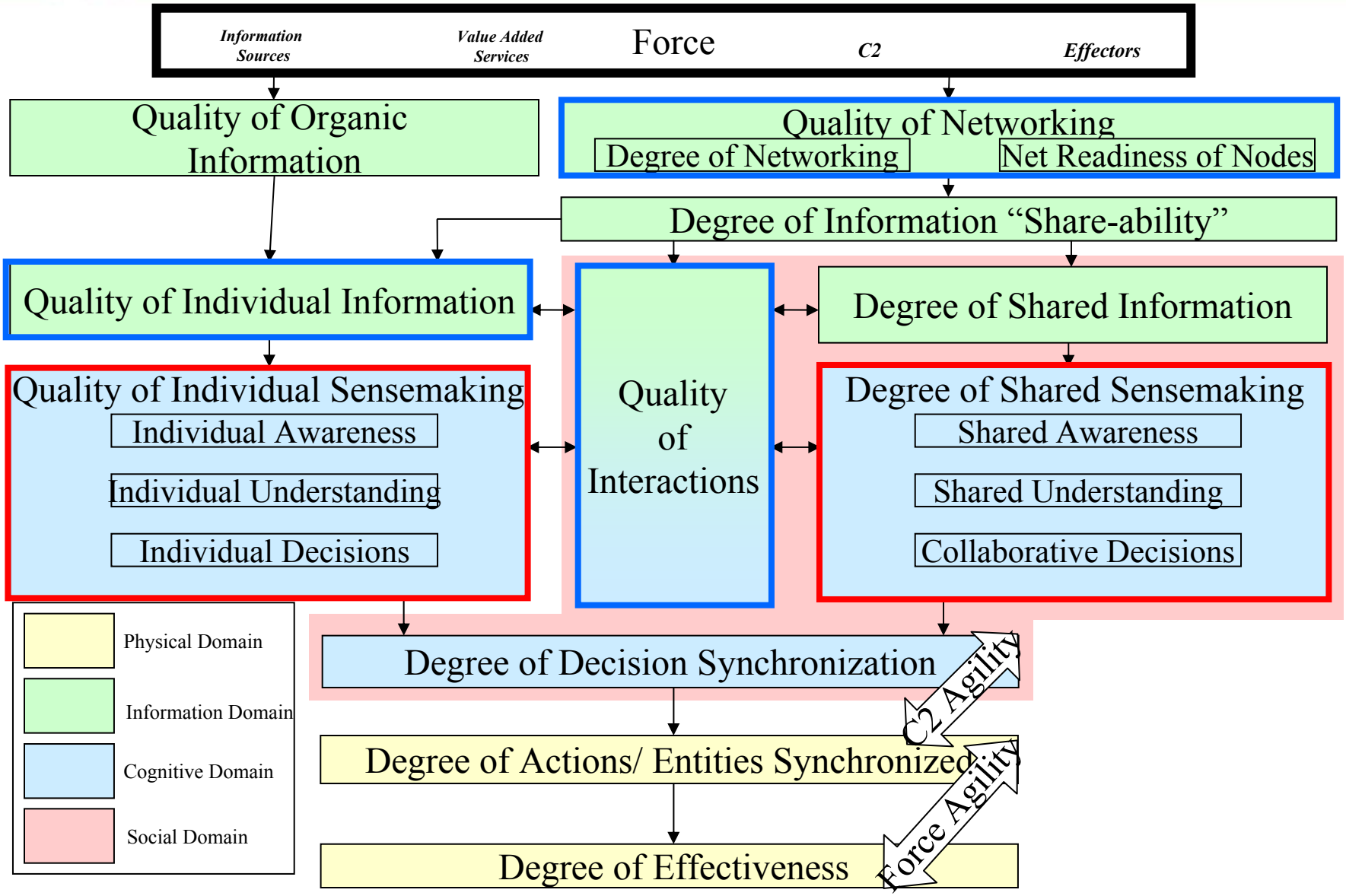


Web - With UAV



Scenario Objective: Deplete enemy forces. Variable parameter is time when Blue reserve forces called in to support the main effort. In the traditional network, enemy forces killed spans from a min of 9 to a max of 41, versus 40 to 41 in the web network.

Network Centric Operations Conceptual Framework

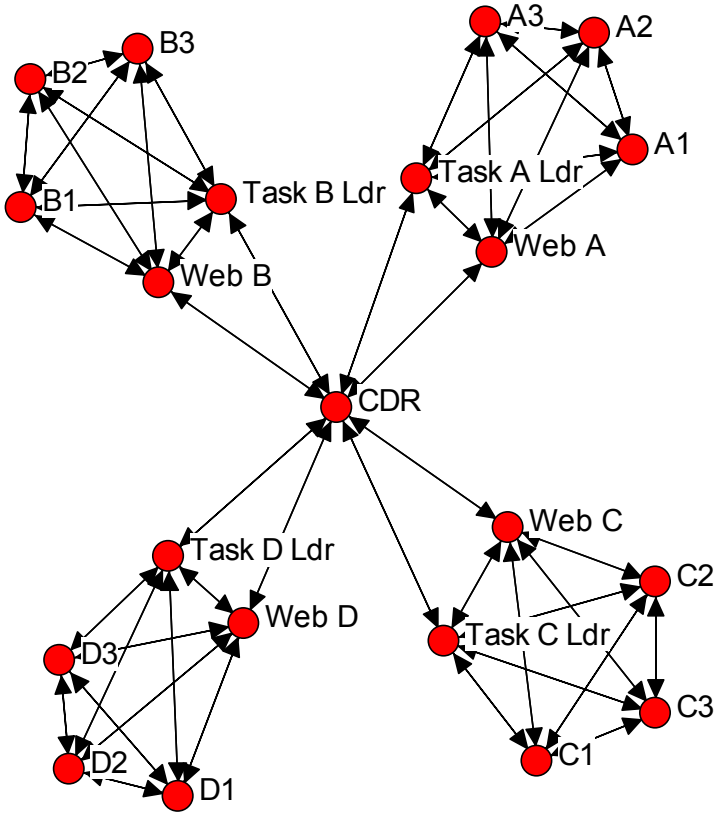


Overview of Experiment II

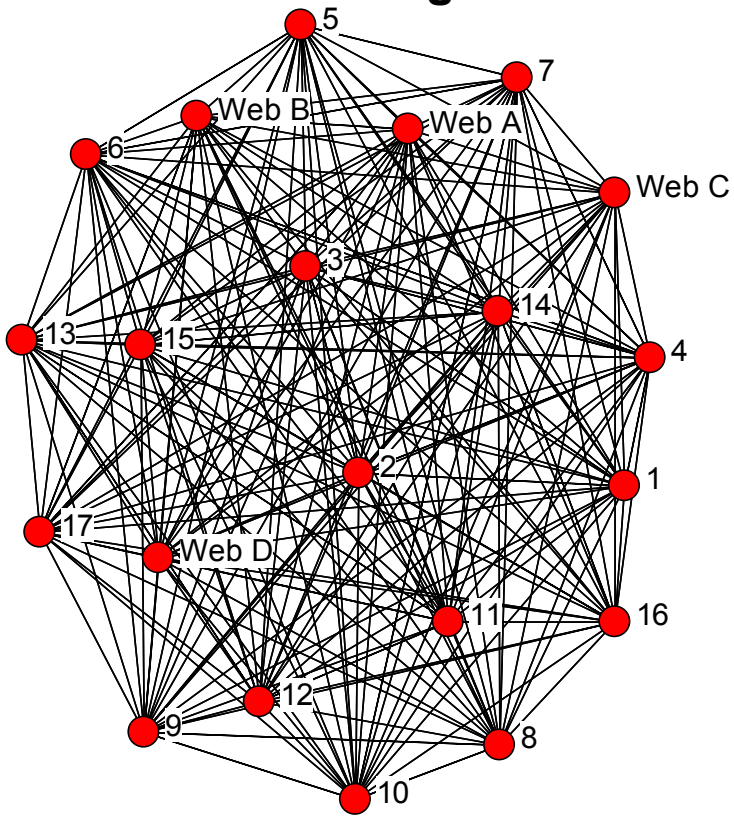
- Experimental objective:
  - Investigate social and cognitive impacts of organizational structure within the context of a simple cognitive task
- Two organization structures
  - Command and Control Organization (hierarchical network, fixed-task)
  - Edge Organization (complete network, simple task adaptation)
- Scenario
  - Agents receive information about a future attack
    - The information facts have been separated into four task categories, notionally: who, what, when, and where
    - Facts are periodically distributed among the agents
  - The goal of each organization is to build awareness in each knowledge area
  - Agents transmit known facts to other agents or websites
  - Agents build awareness by interacting with agents, websites
  - The receiving, sharing, and posting of facts is constrained by the network structure
- ABM environment: NetLogo
- Key Questions
  - How does the performance of the CC organization compare with that of the edge organization under various conditions?
  - How are the performance and situational understanding achieved by each affected by various factors, such as the rate and form of data distribution, the propensity to interact via 1-to-many websites, etc.?
  - Do these factors affect the organizations differently?

Organizational Types Considered

Hierarchical



Edge



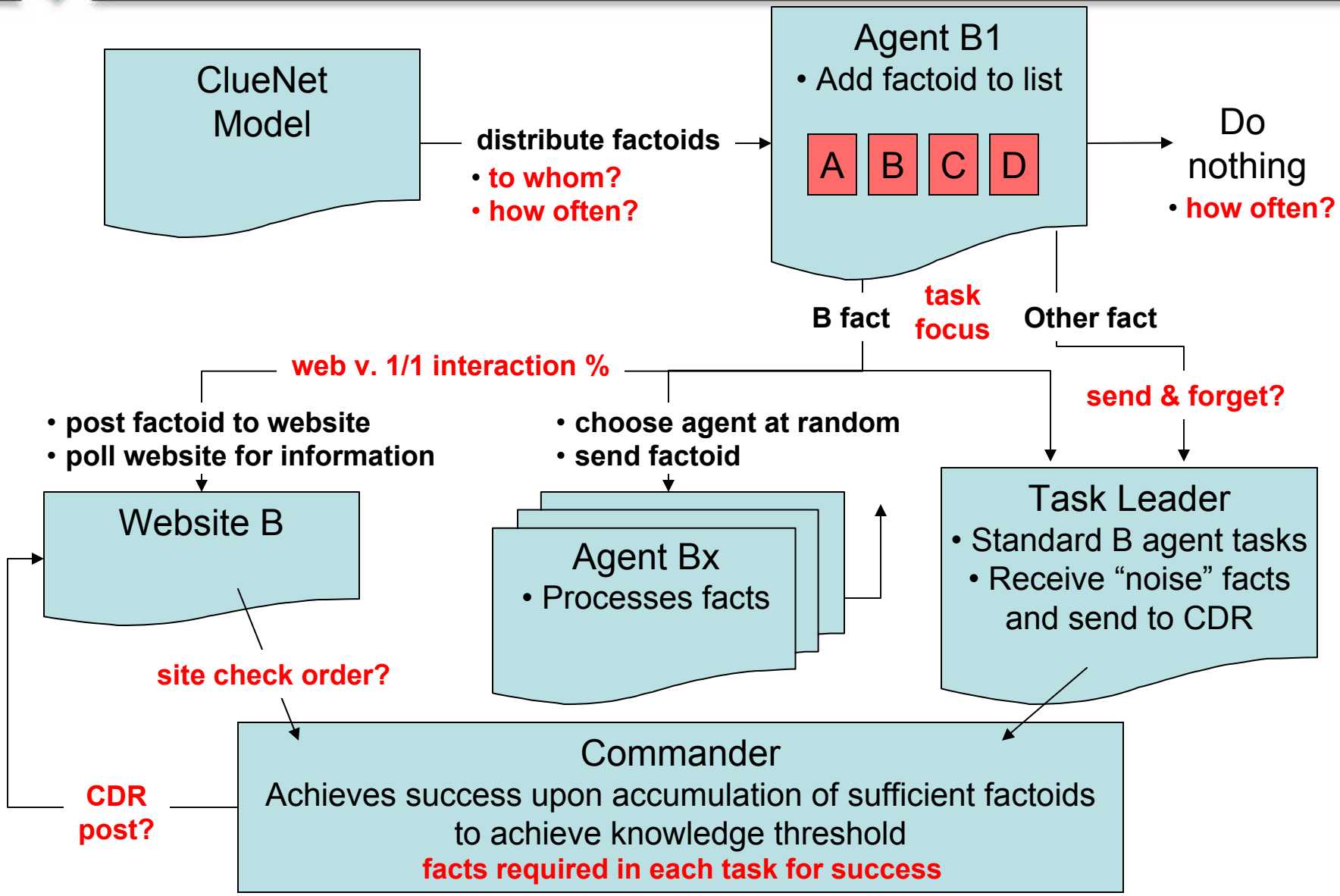
- Groups can only work on designated tasks
- Success achieved when CDR gains required level of situational awareness

- Each agent decides which task to work on based on knowledge level
- Success achieve when any agent gains required SA awareness

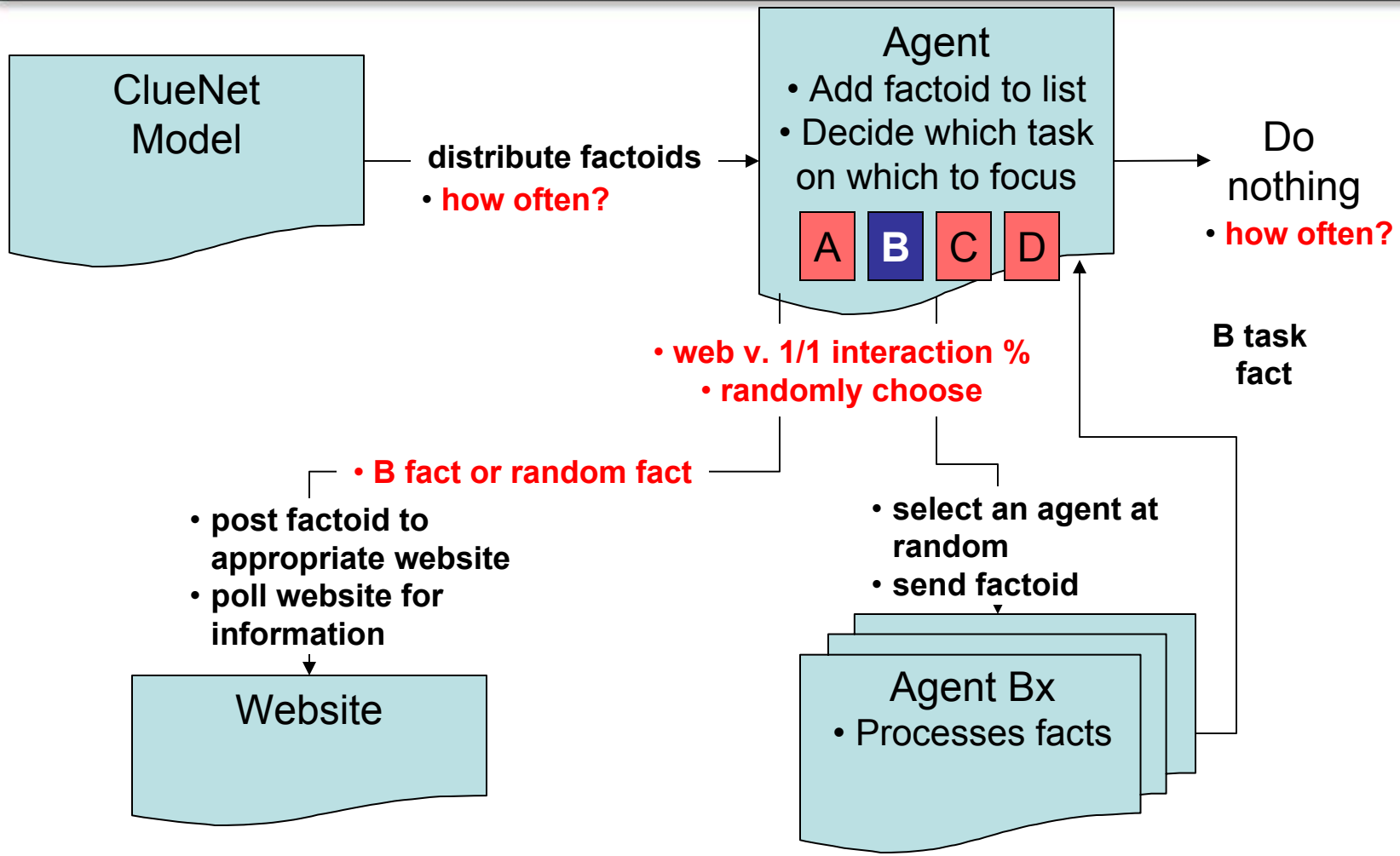
Parameters of Interest

- Currently farmable
  - Use of websites
  - Task difficulty
  - Frequency of fact distribution
  - Alignment of fact distribution with organizational structure
  - Propensity to share superfluous information
- Effects to be considered this week
  - Reliability of communications
  - Reliability of information internalization
  - Information overload
  - Information misclassification
  - Fidelity of message direction
  - Organizational/task scale
    - Number of facts, agents
    - Number of hierarchical layers

Agent Tasks and Task Execution (Hierarchical)



Agent Tasks and Task Execution (Edge)



Success achieved upon any agent's accumulation of sufficient factoids to achieve knowledge threshold

• facts required in each task for success

NetLogo: EBR_CC_Thur_nothing

File Edit Tools Zoom Tabs Help

Interface | Information | Procedures | Errors

Edit Delete Button Slider Switch Chooser Monitor Plot Output Text

setup

factoids_every 3

time_counter 0

info_counter 42.0

go

step

webpost_probability 0.50

level_understanding 8

task_focus 0.87

Color Key
where = red
when = green
who = yellow
what = blue

On Off track_info

wheres 0

wheres_left 13

whens 0

whens_left 12

whos 0

whos_left 10

whats 0

whats_left 12

cdr_check
in_order

On Off cdr_post

setup_type
0

distribute

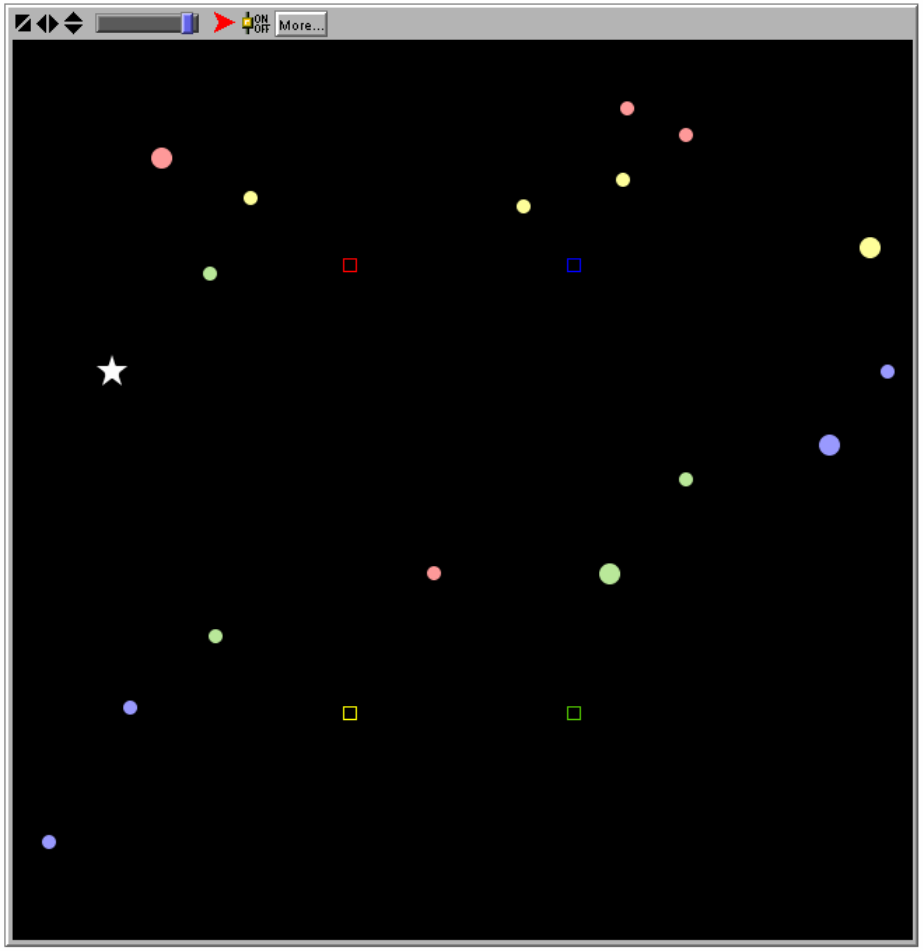
distribute

tabulate

share_info

On Off delete_noise

where_level-of turtle 4	when_level-	who_level-	what_level-	actions_
0	1	0	0	0.0
where_level-of turtle 5	when_level-	who_level-	what_level-	actions_
0	0	1	0	0.0
where_level-of turtle 6	when_level-	who_level-	what_level-	actions_
1	0	0	0	0.0
where_level-of turtle 7	when_level-	who_level-	what_level-	actions_
0	0	1	1	0.0
where_level-of turtle 8	when_level-	who_level-	what_level-	actions_
0	1	0	0	0.0
where_level-of turtle 9	when_level-	who_level-	what_level-	actions_
1	0	0	0	0.0
where_level-of turtle 10	when_level-	who_level-	what_level-	actions_
1	0	0	0	0.0
where_level-of turtle 11	when_level-	who_level-	what_level-	actions_
0	1	1	0	0.0
where_level-of turtle 12	when_level-	who_level-	what_level-	actions_
0	1	0	0	0.0
where_level-of turtle 13	when_level-	who_level-	what_level-	actions_
0	1	0	0	0.0
where_level-of turtle 14	when_level-	who_level-	what_level-	actions_
0	0	1	0	0.0
where_level-of turtle 15	when_level-	who_level-	what_level-	actions_
0	0	1	1	0.0
where_level-of turtle 16	when_level-	who_level-	what_level-	actions_
1	0	0	0	0.0
where_level-of turtle 17	when_level-	who_level-	what_level-	actions_
0	0	1	0	0.0
where_level-of turtle 18	when_level-	who_level-	what_level-	actions_
0	0	0	1	0.0
where_level-of turtle 19	when_level-	who_level-	what_level-	actions_
0	0	1	1	0.0
where_level-of turtle 20	when_level-	who_level-	what_level-	actions_
0	0	0	1	0.0



clock 0

ave_understand 15.353

level of where website 0

level of when website 0

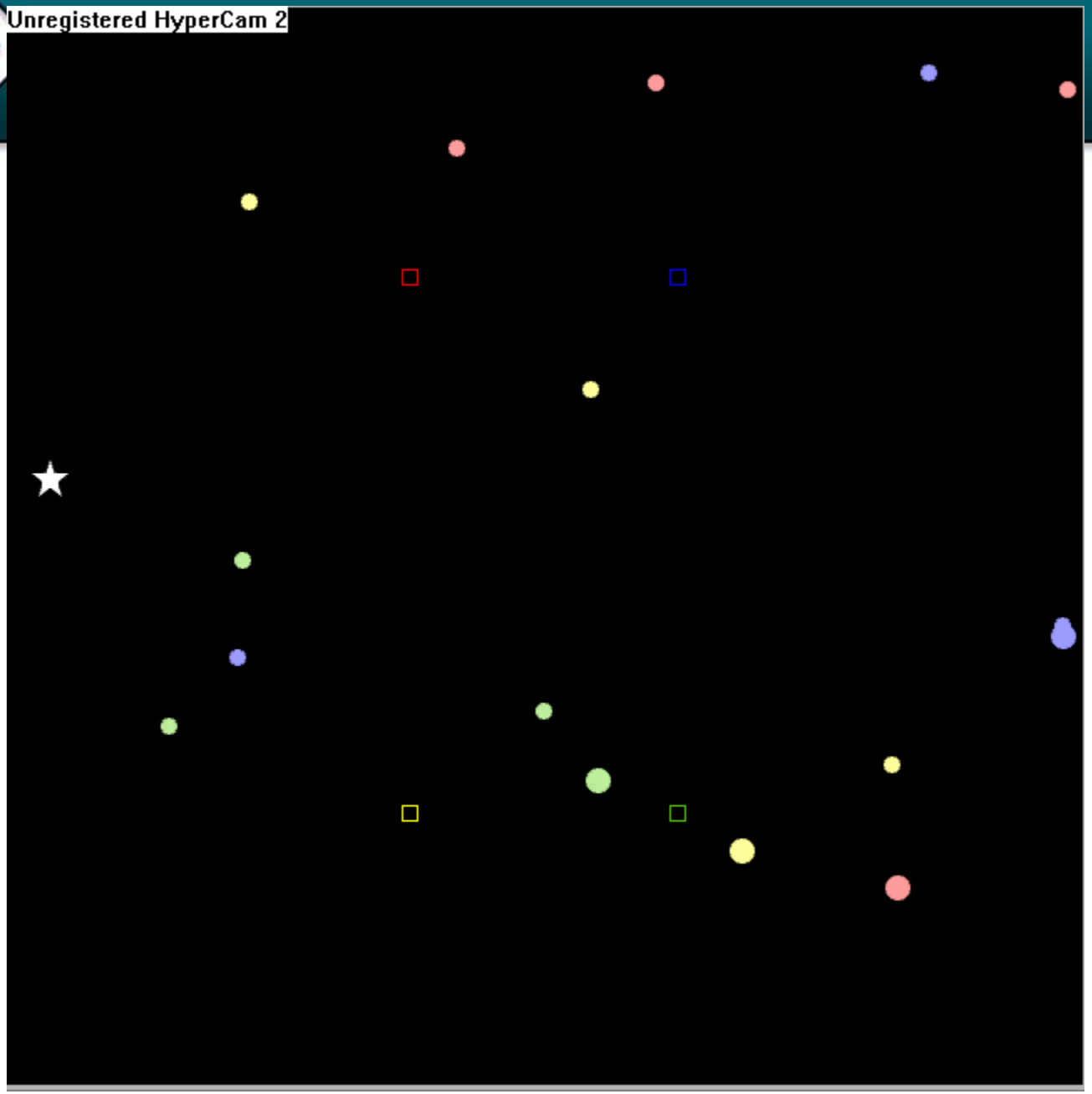
level of who website 0

level of what website 0

do-nothing-prob 0.00

Command Center

O>


Unregistered HyperCam 2

NetLogo: EBR_CC_Thur_nothing

File Edit Tools Zoom Tabs Help

Interface | Information | Procedures | Errors

Edit | Delete | Button | Slider | Switch | Chooser | Monitor | Plot | Output | Text

setup

factoids_every 3

time_counter 29

info_counter 42.0

go | step

webpost_probability 0.50

level_understanding 8

task_focus 0.87

Color Key
where = red
when = green
who = yellow
what = blue

On Off track_info

wheres 0	wheres_left 0
whens 0	whens_left 0
whos 1	whos_left 0
whats 2	whats_left 0

cdr_check: in_order

On Off cdr_post

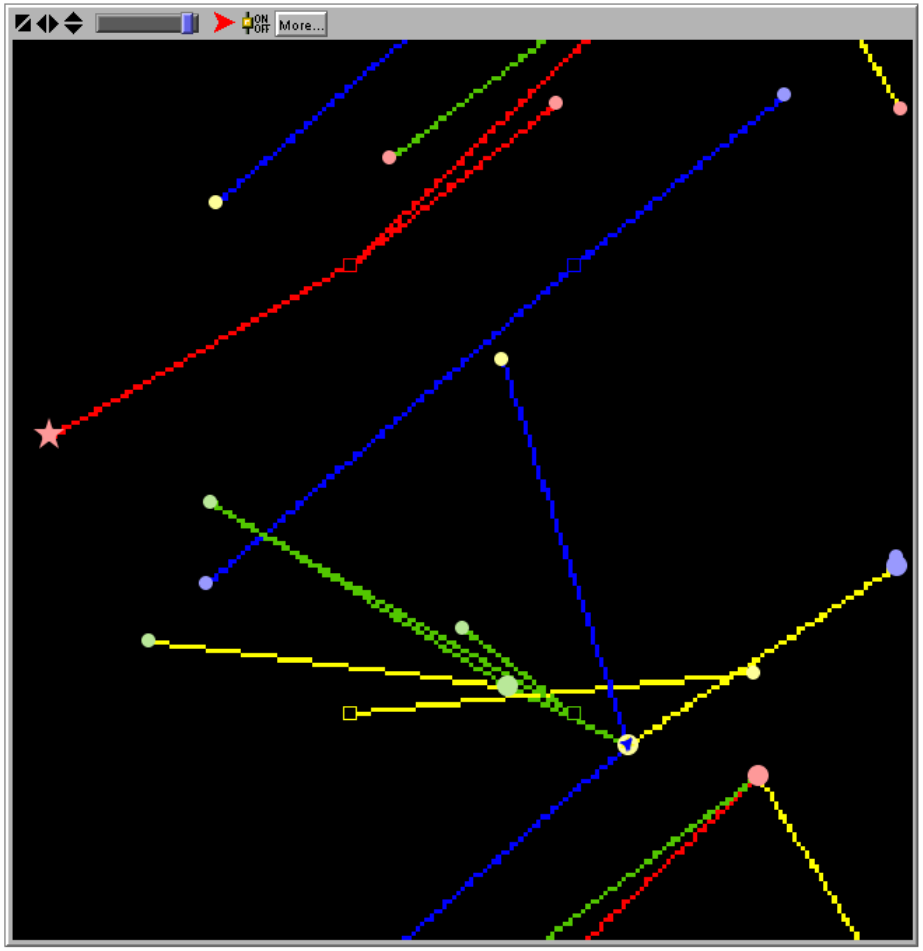
setup_type: 0

distribute | distribute

tabulate | share_info

On Off delete_noise

where_level-of turtle	when_level-	who_level-	what_level-	actions_
where_level-of turtle 4: 0	when_level- 8	who_level- 0	what_level- 2	actions_ 27.0
where_level-of turtle 5: 1	when_level- 8	who_level- 1	what_level- 0	actions_ 27.0
where_level-of turtle 6: 2	when_level- 8	who_level- 1	what_level- 1	actions_ 27.0
where_level-of turtle 7: 4	when_level- 12	who_level- 2	what_level- 4	actions_ 29.0
where_level-of turtle 8: 2	when_level- 1	who_level- 1	what_level- 7	actions_ 28.0
where_level-of turtle 9: 1	when_level- 1	who_level- 0	what_level- 7	actions_ 27.0
where_level-of turtle 10: 0	when_level- 1	who_level- 2	what_level- 7	actions_ 27.0
where_level-of turtle 11: 4	when_level- 3	who_level- 3	what_level- 11	actions_ 29.0
where_level-of turtle 12: 8	when_level- 0	who_level- 1	what_level- 1	actions_ 26.0
where_level-of turtle 13: 8	when_level- 1	who_level- 1	what_level- 0	actions_ 28.0
where_level-of turtle 14: 8	when_level- 2	who_level- 0	what_level- 0	actions_ 30.0
where_level-of turtle 15: 14	when_level- 4	who_level- 2	what_level- 2	actions_ 28.0
where_level-of turtle 16: 0	when_level- 0	who_level- 11	what_level- 3	actions_ 28.0
where_level-of turtle 17: 2	when_level- 1	who_level- 11	what_level- 2	actions_ 27.0
where_level-of turtle 18: 2	when_level- 2	who_level- 10	what_level- 2	actions_ 30.0
where_level-of turtle 19: 4	when_level- 5	who_level- 11	what_level- 6	actions_ 28.0
where_level-of turtle 20: 8	when_level- 9	who_level- 9	what_level- 8	actions_ 26.0



clock 6280

ave_understand 15.353

level of where website 8

level of when website 8

level of who website 10

level of what website 7

do-nothing-prob 0.00

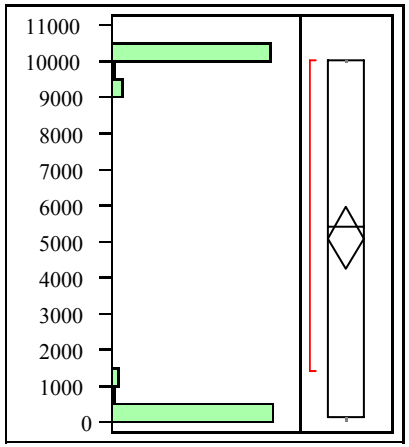
Command Center

O>

Summaries (over replications)

Distributions

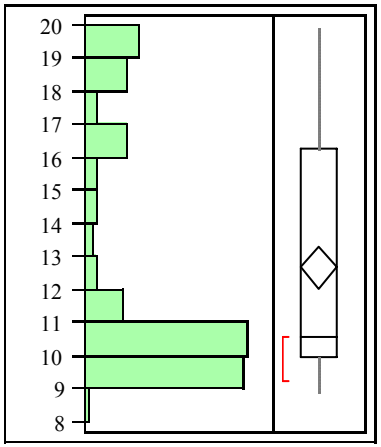
Mean(solution_time)



Moments

Mean	5078.6096
Std Dev	4901.4291
Std Err Mean	426.61464
upper 95% Mean	5922.5551
lower 95% Mean	4234.6641
N	132

Mean(avg_understanding)



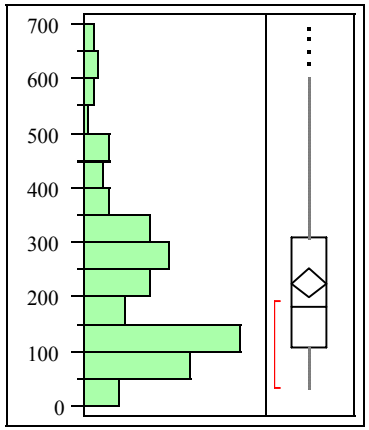
Moments

Mean	12.656491
Std Dev	3.6572761
Std Err Mean	0.318325
upper 95% Mean	13.286214
lower 95% Mean	12.026769
N	132

CC

Distributions

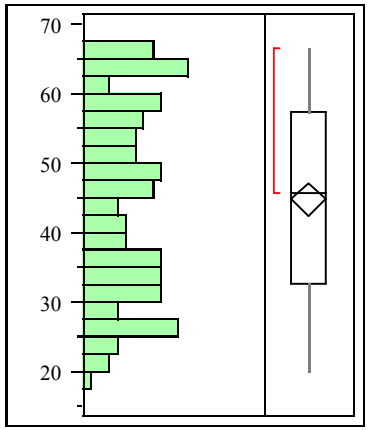
Mean(solution_time)



Moments

Mean	224.25784
Std Dev	151.08901
Std Err Mean	13.15061
upper 95% Mean	250.27288
lower 95% Mean	198.24279
N	132

Mean(avg_understanding)



Moments

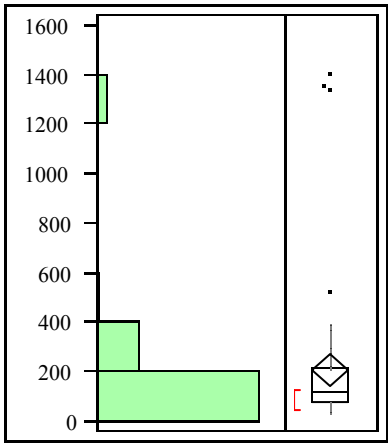
Mean	44.699342
Std Dev	13.681463
Std Err Mean	1.1908185
upper 95% Mean	47.055065
lower 95% Mean	42.343619
N	132

edge

Summaries: a closer look

Distributions

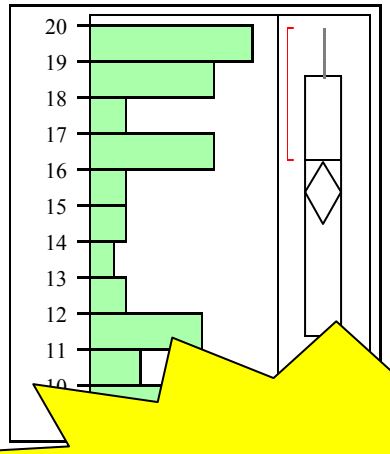
Mean(solution_time)



Moments

Mean	200.88737
Std Dev	274.14974
Std Err Mean	33.7455
upper 95% Mean	268.28179
lower 95% Mean	133.49296
N	66

Mean(avg_understanding)

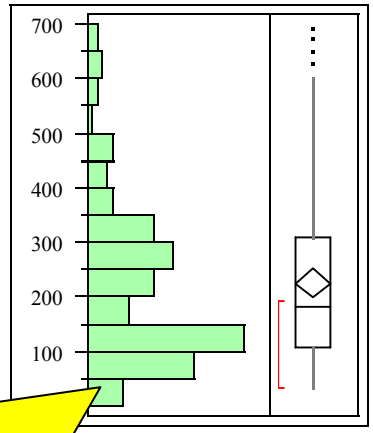


low

N

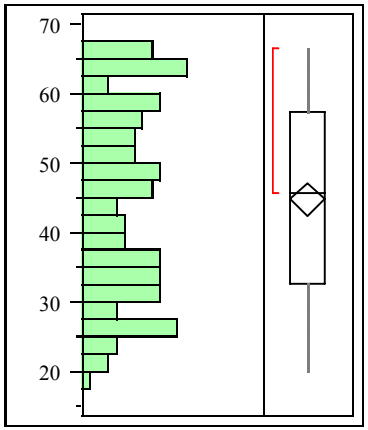
Distributions

Mean(solution_time)



	224.25784
	151.08901
	13.15061
Mean	250.27288
	198.24279
	132

Mean(avg_understanding)



Moments

Mean	44.699342
Std Dev	13.681463
Std Err Mean	1.1908185
upper 95% Mean	47.055065
lower 95% Mean	42.343619
N	132

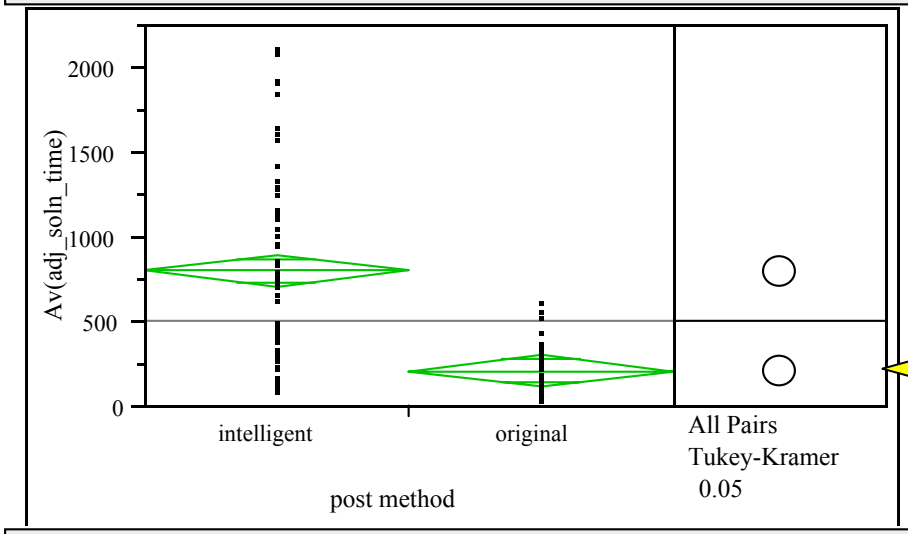
surprise!

CC (ordered)

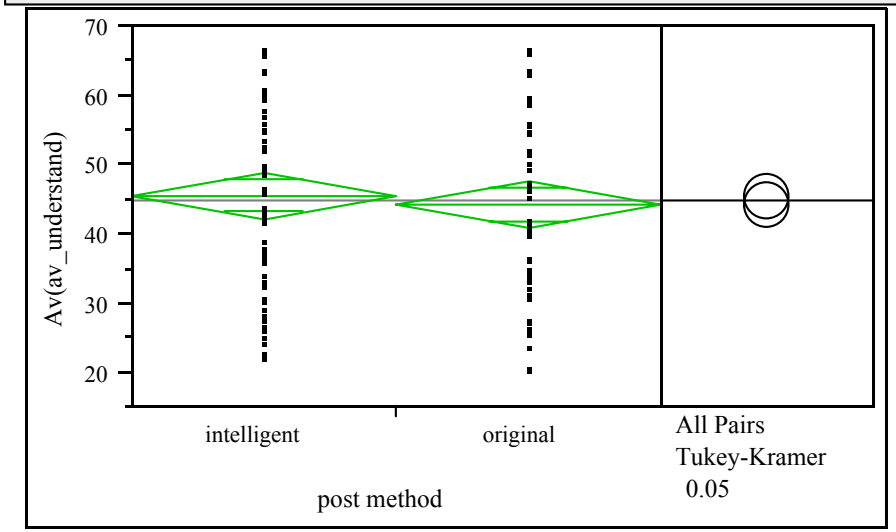
edge

Edge

Oneway Analysis of Av(adj_soln_time) By post method



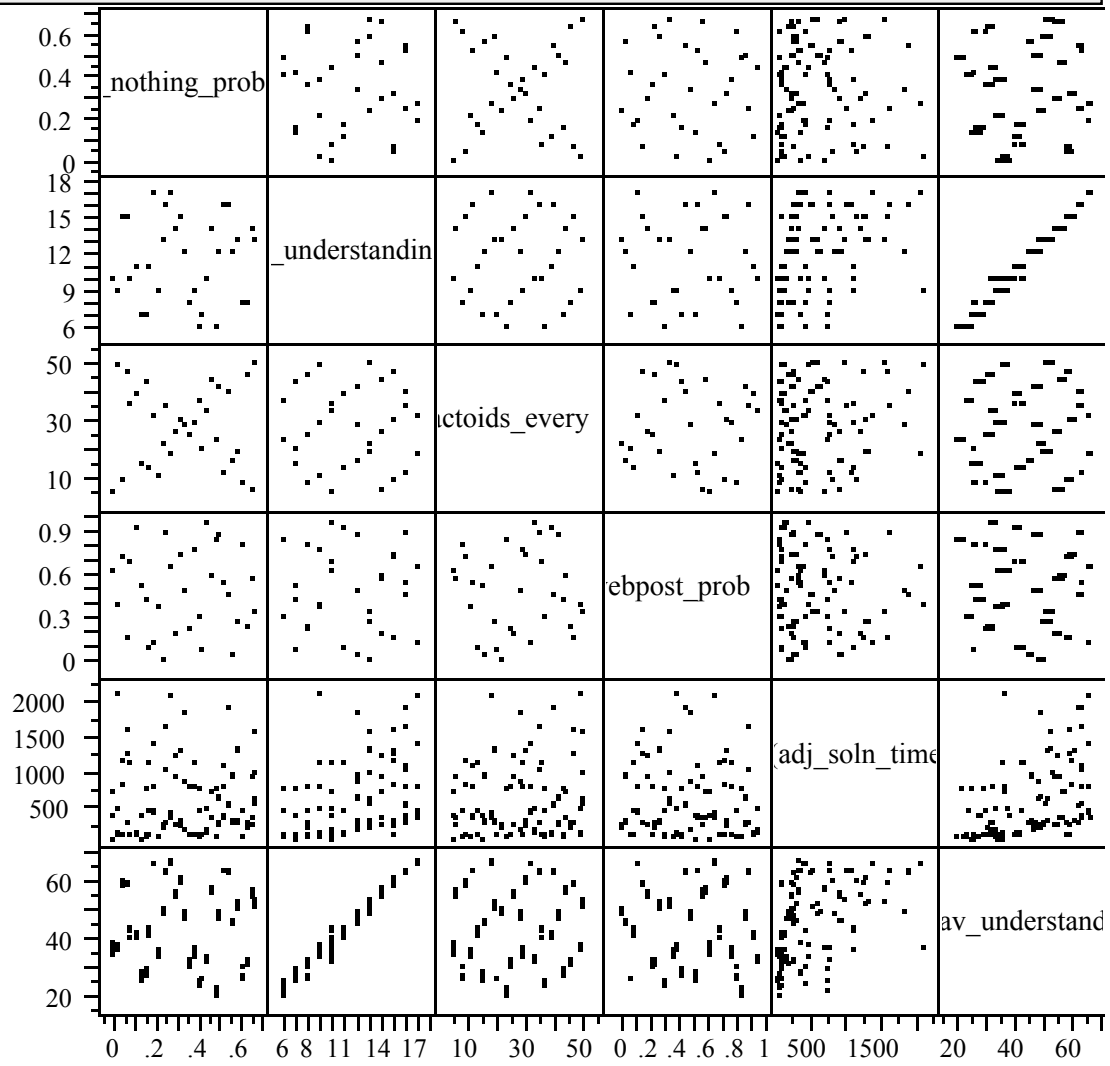
Oneway Analysis of Av(av_understand) By post method



Edge

Multivariate

Scatterplot Matrix

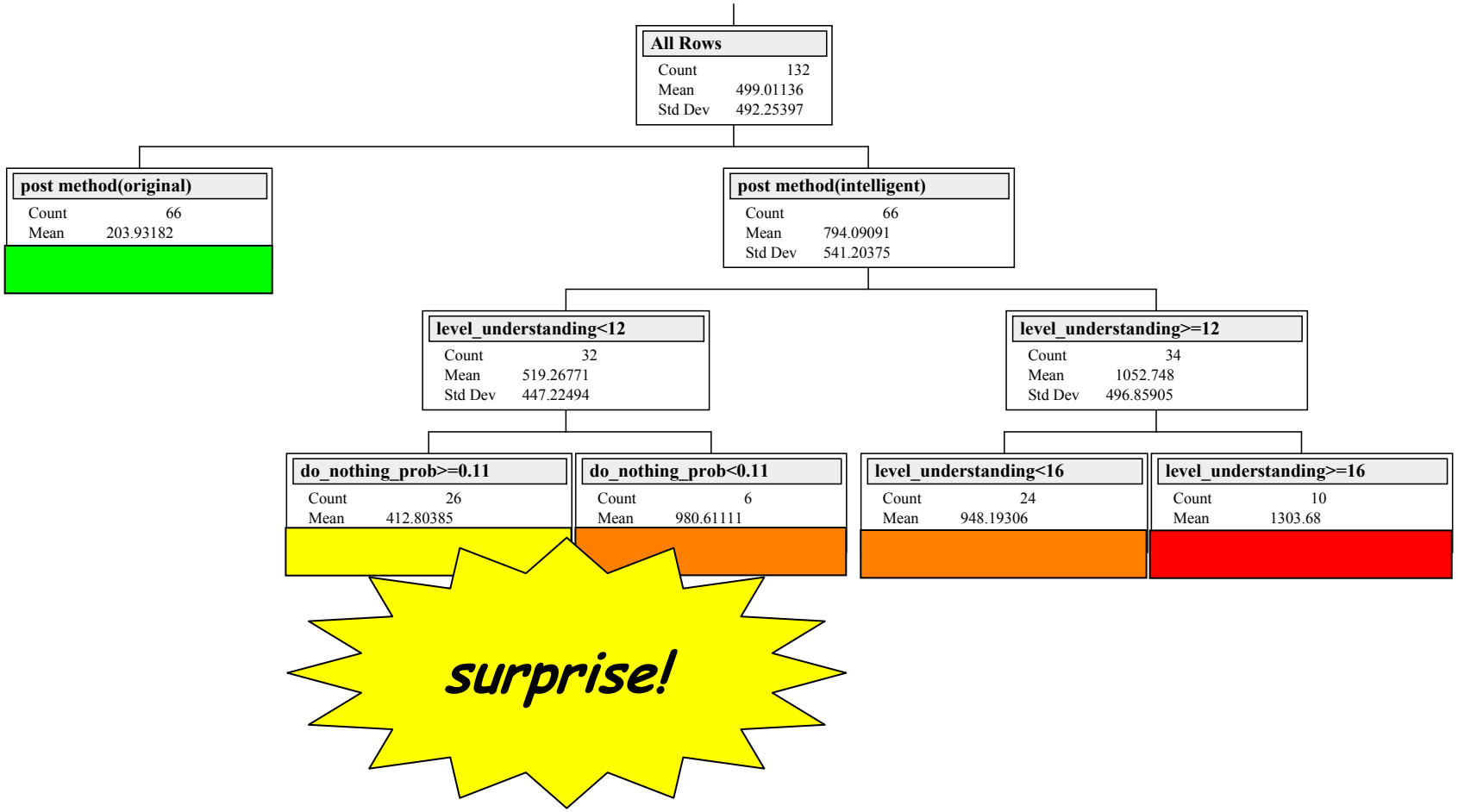


Edge: Av Solution Time (Regression Tree)

RSquare
0.587

N
132

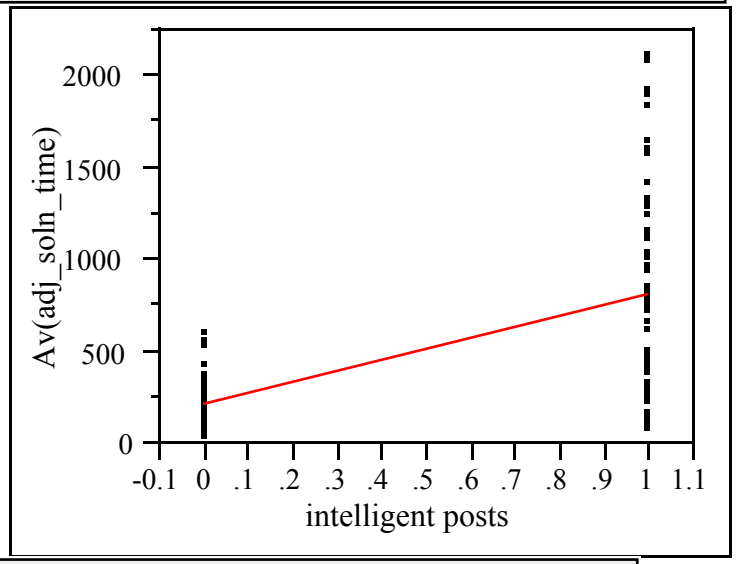
Imputes
0



Edge decision factors: Av Solution Time (Regression line)

Response Av(adj_soln_time)

Regression Plot



Summary of Fit

RSquare	0.362078
RSquare Adj	0.357171
Root Mean Square Error	394.6725
Mean of Response	499.0114
Observations (or Sum Wgts)	132

Parameter Estimates

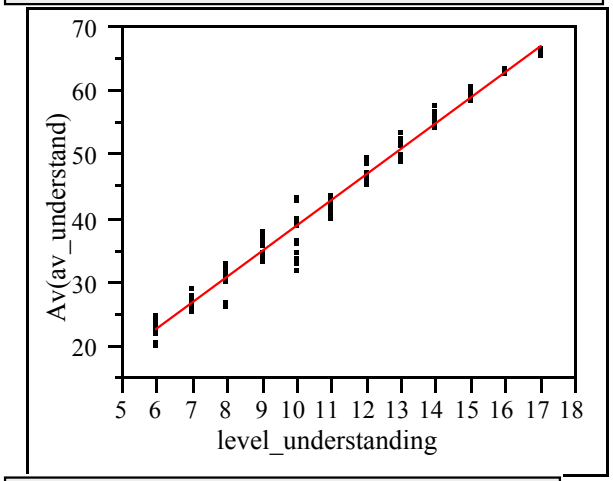
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	203.93182	48.58083	4.20	<.0001
intelligent posts	590.15909	68.70367	8.59	<.0001

- little ability to affect solution time
- no model fits well

Edge: Avg Understanding (regression line)

Response Av(av_understand)

Regression Plot



Summary of Fit

RSquare	0.982621
RSquare Adj	0.982487
Root Mean Square Error	1.810539
Mean of Response	44.69934
Observations (or Sum Wgts)	132

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.873632	0.565622	-3.31	0.0012
level_understanding	4.044495	0.047175	85.73	<.0001

- high correlation with required level of understanding
- even with this out of the model, nothing else matters

Next steps: Current activity

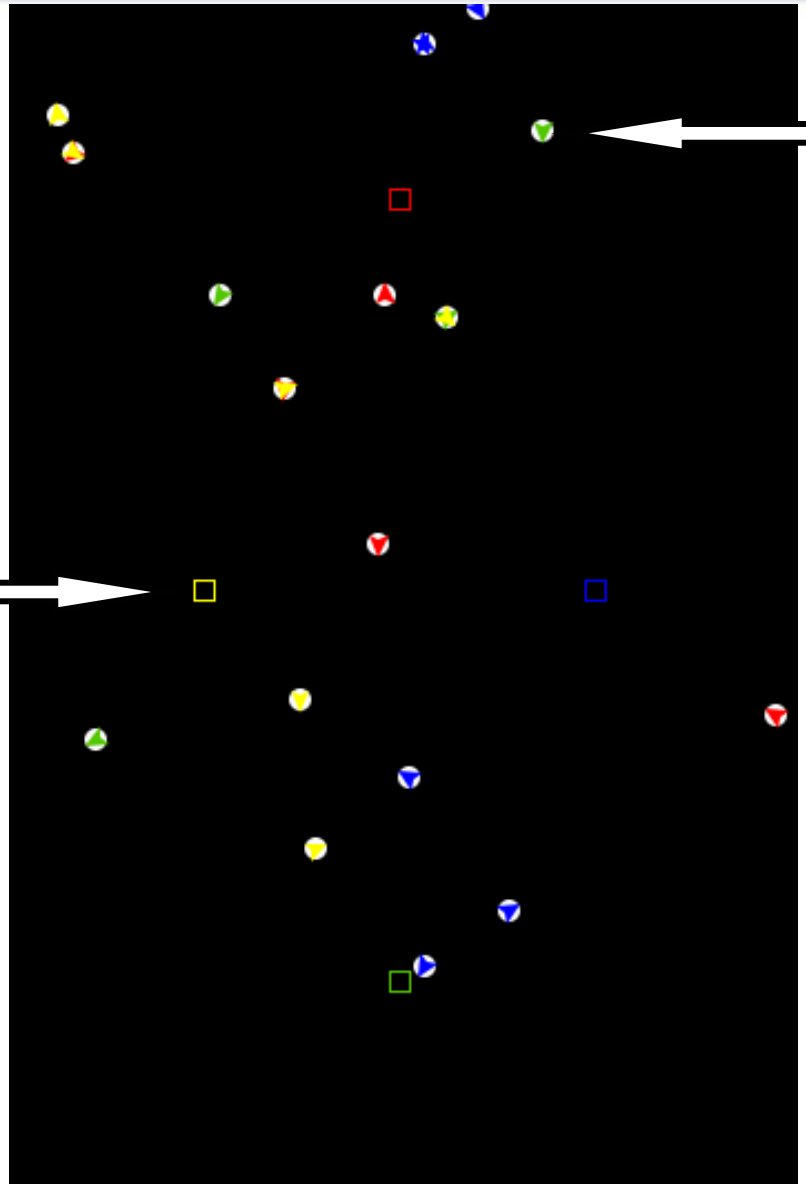
- Develop a combined Edge/CC model
- Explore space of alternate C2 structures
  - Capitalize on SAS-050 activity
    - C2 conceptual model
    - Description of key dimensions of C2
  - Examine fitness of various structures under different assumptions about task, interaction/decision rules and conditions, etc.
  - Gain insight into required capabilities for execution
    - Cognitive capabilities of individuals (task, team)
    - Potential contributions of technical enablers
- Inform development and execution of associated human experiments
  - Numerical experiments as an element of a campaign of experimentation
- This vignette is modeled after an experimental design developed by OASD/NII (US DOD)
  - A live experiment is planned for June 29, 2005

Special Thanks to:

Dr. Gary Horne, Director, Project Albert
Sarah Johnson, Mitre Corporation
Dr. Jimmie McEver, Evidence Based Research Inc.
NATO SAS-050 Members

Backups

Edge Organization Setup Screen Shot



Filter Agent with Fact

Website

Color Key

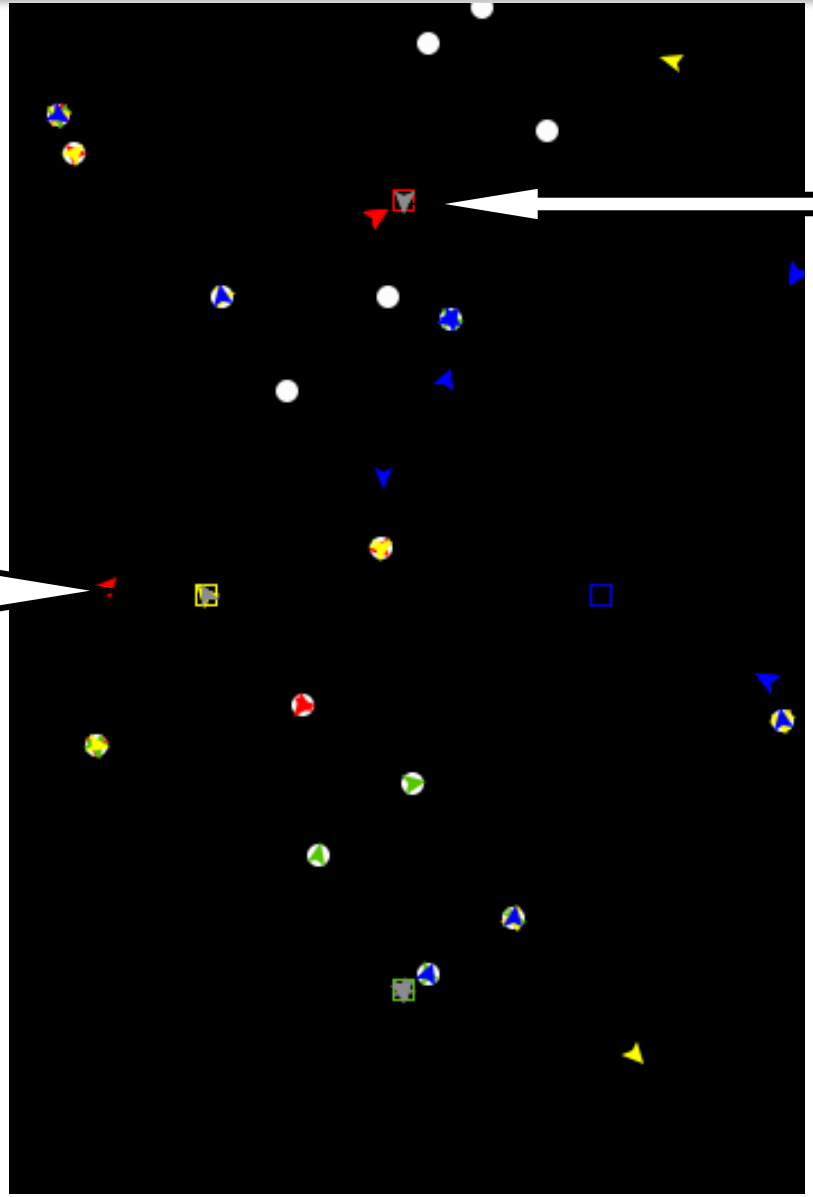
Where

When

Who

What

Edge Organization Screen Shot during run



Website with a facts posted

Fact in Transit

Color Key

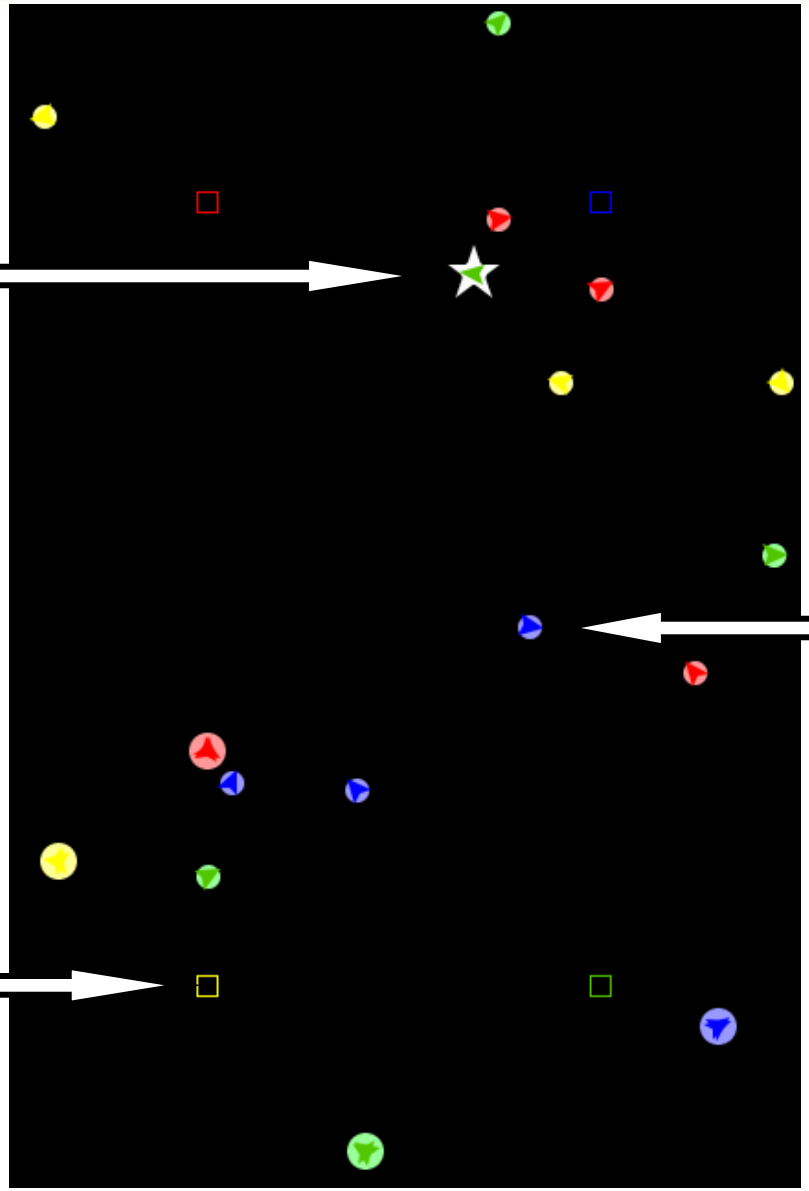
Where

When

Who

What

Hierarchical Organization Setup Screen Shot



Central Commander

Filter Agent with Fact and Designated Tasking

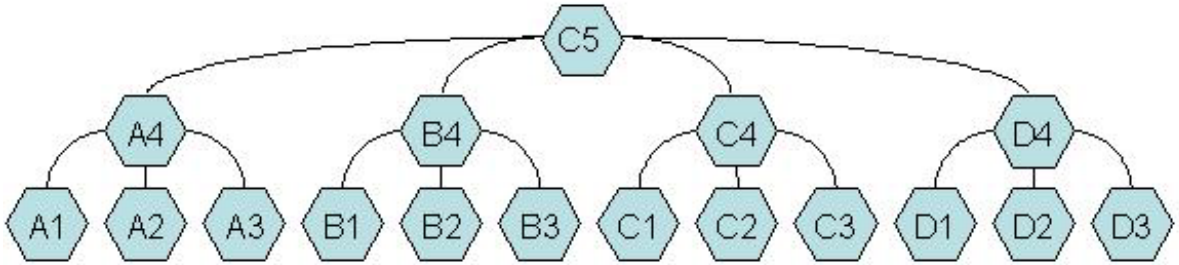
Website

Color Key
Where
When
Who
What

Hierarchical, Command and Control Organization

C2 Factors	Experimental Model
Hierarchical Decomposition	The C2 organization is divided into four separate teams of four all coordinated by a sole central coordinator (total of 17 agents)
Specialization	Each of the four teams in the C2 organization specialize in a different type of information
Team Leaders	Team leaders have "special expertise". They begin with an additional fact .
Information Hoarding	Each team's website is visible only to that team and the central coordinator, not to the other teams.
Fixed Leadership (Leadership by Position)	Subordinate agents can interact with their team members and team leader. The team leaders can communicate with the Central Coordinator.
Solution Identification	Information is passed up the network to the Central Coordinator. Only once the coordinator has achieved the appropriate knowlede level for each of the four tasks will the organization have achieved their goal.

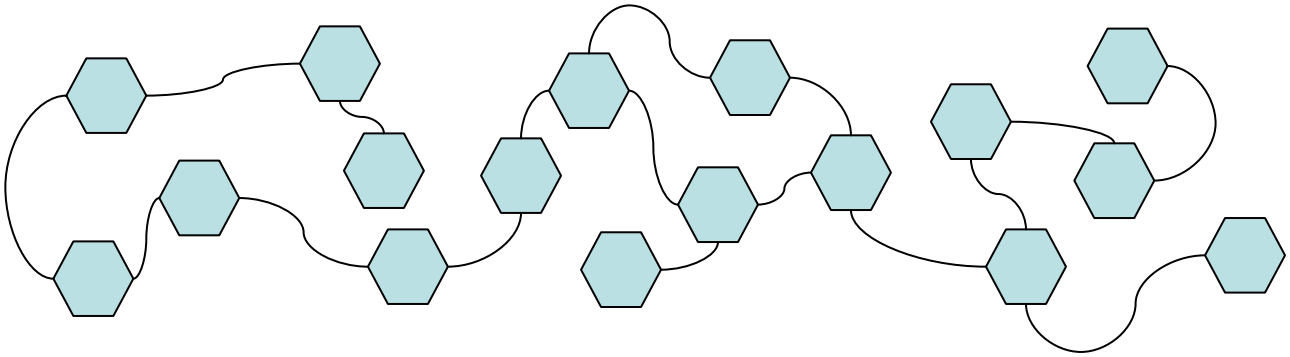
Information Network Structure



Fully Networked, Edge Organization

Edge Factors	Experimental Model
Networked Organization	Completely flat organizational structure, 17 agent peers
Information Sharing, Post/Pull	The team is visible. All four community of interest websites are shared and available to be posted to and polled by all agents. Each time step the agent must choose which of these websites to view.
Expert Agents	4 random agents begin with an additional fact .
Emergent Control	Instead of being given a designated task, agents are self-directed to work on their highest knowledge area at time t. Once an agent has solved one task he will focus on remaining tasks
Solution Identification	Information is passed any agent to any other agent in the network. Once one agent has achieved the appropriate knowlede level for each of the four tasks the organization has achieved their goal.

Information Network Structure

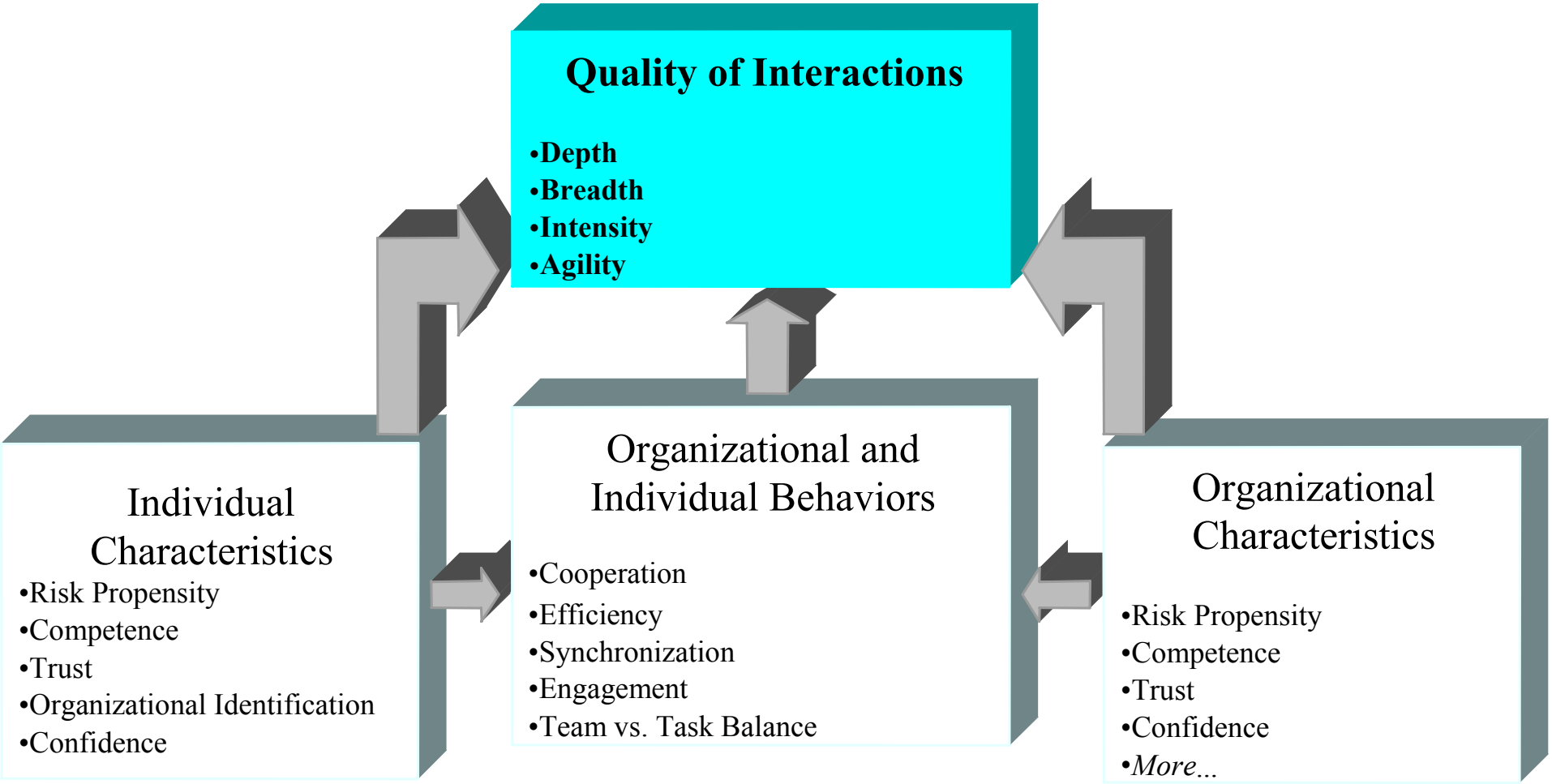


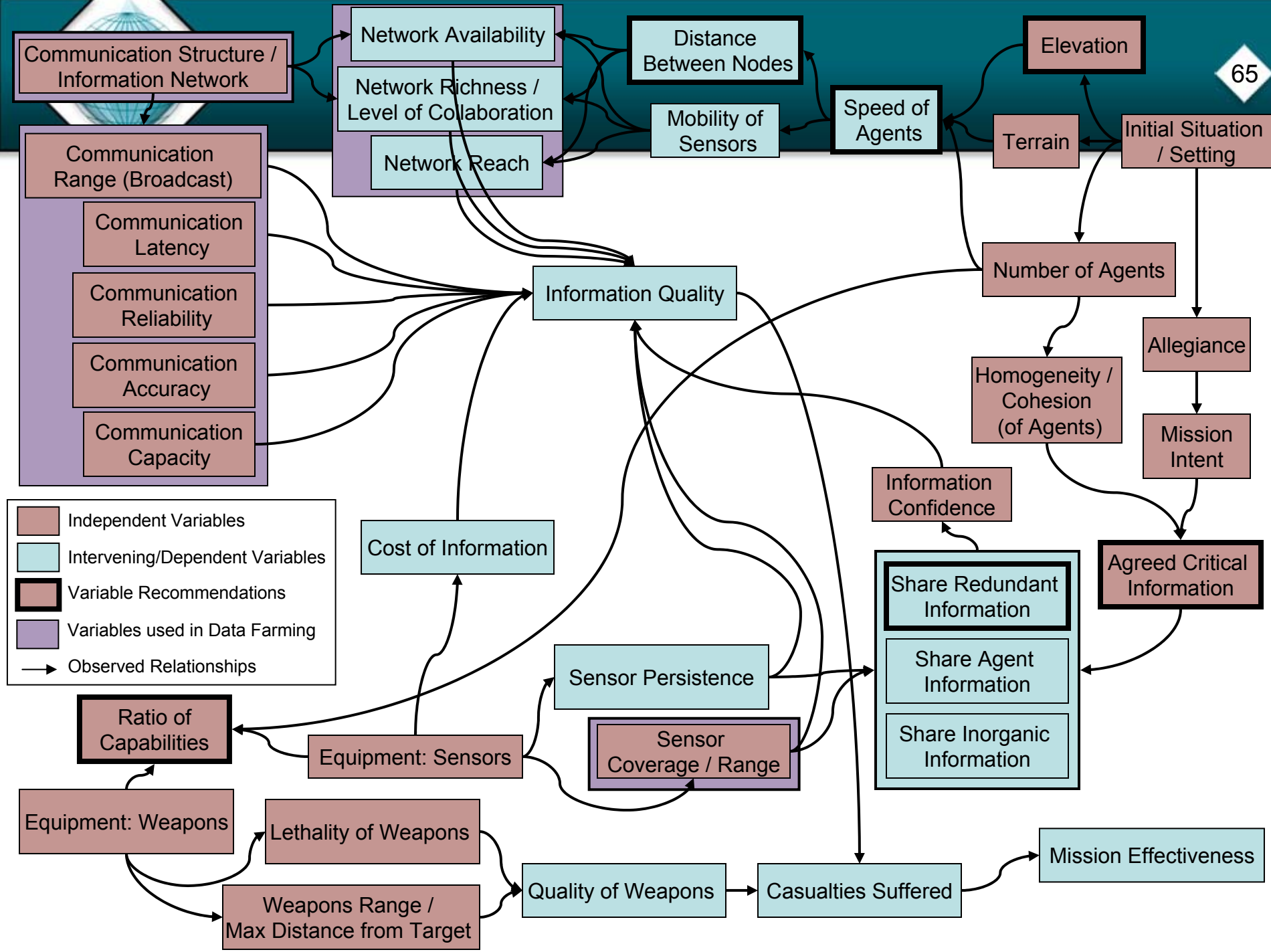
Properties Common to both Vignettes

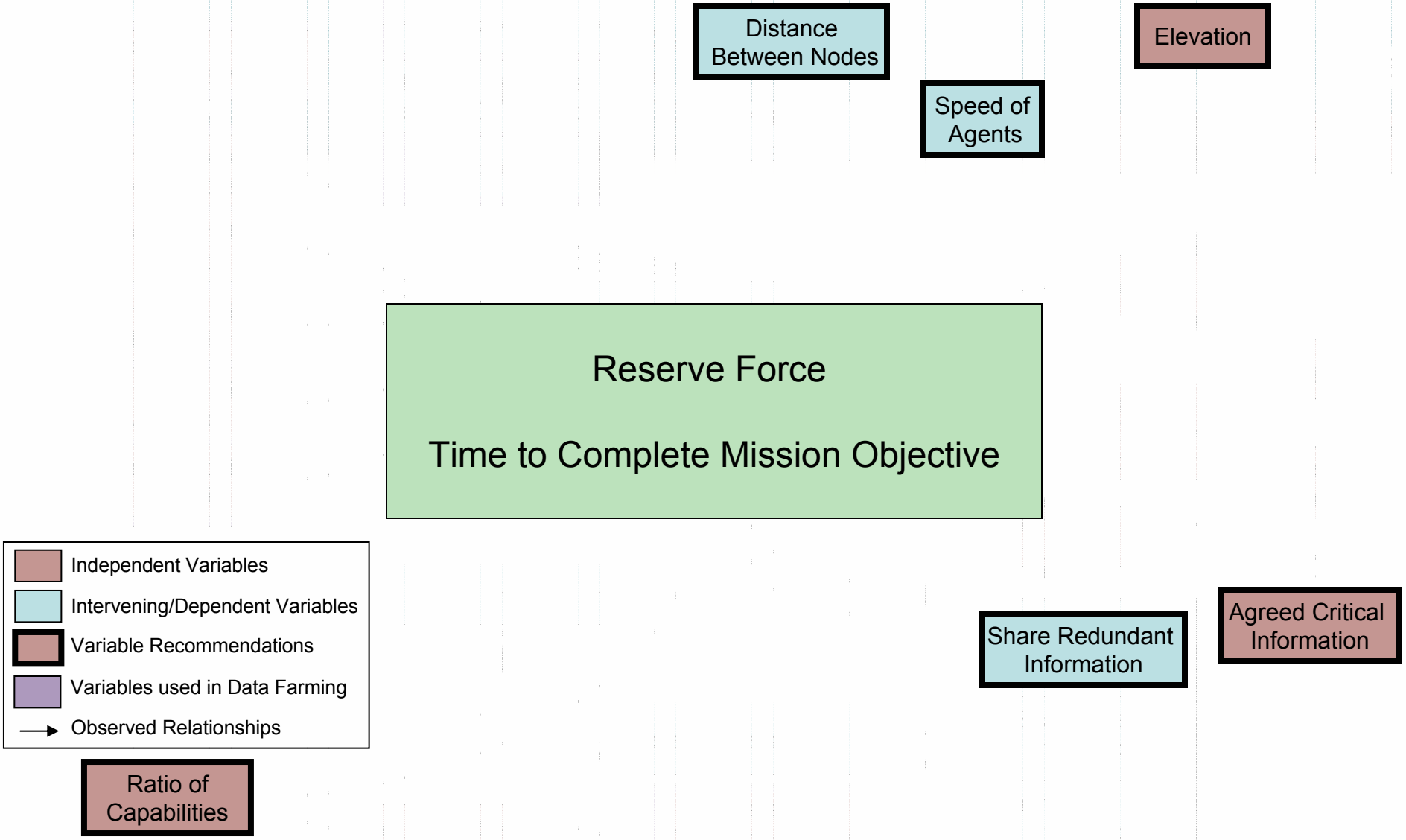
Universal Factors	Experimental Model
Multiple types of information	There are four separate dimensions of information (who, what, where and when). These information bands are color coded in the model.
Factiods	There are 68 unique information facts, 17 factoids for each information band.
Initial information	Subjects start with 1 factoid. Expert agents start with 2 factiods (expert agents are the team leaders in the C2 organization and 4 random agents in the Edge Organization). The remaining information is dispersed to the agents at time intervals dictated by the user.
Individual Work	Each timestep, agents choose between sharing a fact from their knowledge base with another agent or posting a it to the corresponding website. Only one fact may be shared per time step. Then an agent looks at a website, updating its knowledge with the list of facts posted.

NCO CF Characterization of Interactions

The focus of interaction: share information, develop and share awareness, develop and share understandings, make decisions




Communication Structure / Information Network
Network Availability
Network Richness / Level of Collaboration
Network Reach
Distance Between Nodes
Mobility of Sensors
Speed of Agents
Elevation
Terrain
Initial Situation / Setting
Communication Range (Broadcast)
Communication Latency
Communication Reliability
Communication Accuracy
Communication Capacity
Information Quality
Number of Agents
Allegiance
Homogeneity / Cohesion (of Agents)
Mission Intent
Information Confidence
Agreed Critical Information
Cost of Information
Share Redundant Information
Share Agent Information
Share Inorganic Information
Independent Variables
Intervening/Dependent Variables
Variable Recommendations
Variables used in Data Farming
Observed Relationships
Sensor Persistence
Ratio of Capabilities
Equipment: Sensors
Sensor Coverage / Range
Equipment: Weapons
Lethality of Weapons
Weapons Range / Max Distance from Target
Quality of Weapons
Casualties Suffered
Mission Effectiveness


Distance Between Nodes
Elevation
Speed of Agents
Reserve Force
Time to Complete Mission Objective
Independent Variables
Intervening/Dependent Variables
Variable Recommendations
Variables used in Data Farming
Observed Relationships
Share Redundant Information
Agreed Critical Information
Ratio of Capabilities

Study I: Scenario Objectives

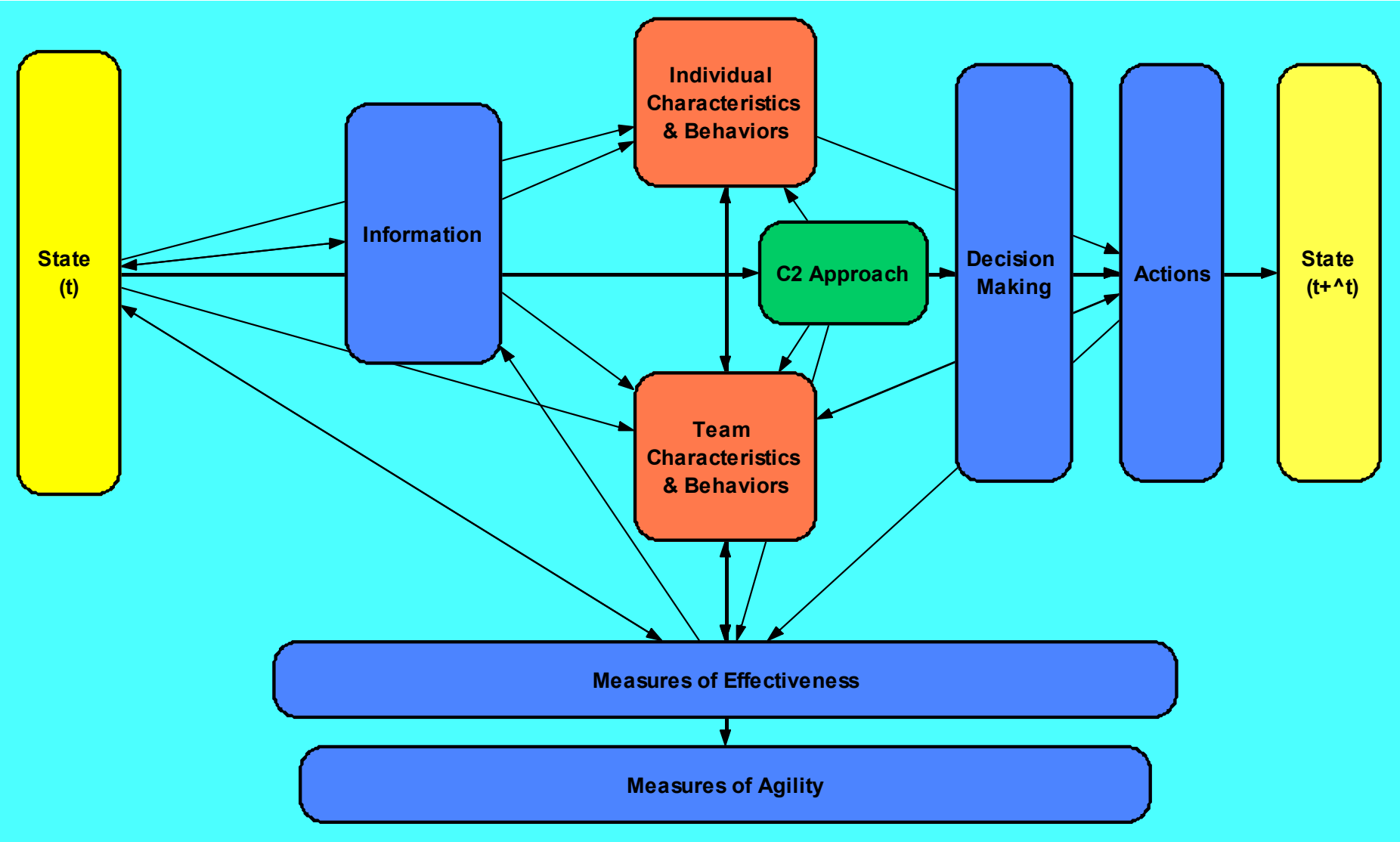
- Three objectives to scenarios modeled
  - Get to goal at whatever cost (optimal path at shortest time, no consideration for losses; no maneuvering behaviors)
  - Get to goal with minimal losses (maneuvering behaviors with consideration of friendly losses; time to complete mission not a major factor)
  - Deplete enemy forces (from USMC Tactical Decision Game - execute major enemy losses; no established physical goal; no consideration for friendly losses except to have initial advantage in the fight)

Variables Considered

Speed of movement
Allegiance
Stealth
Sensor Range
Detection Range
Weapon Range
Probability of Kill
Mission Intent
Comms Range
Comms Capacity
Comms Latency
Comms Reliability
Comms Accuracy

Threat Persistence (Age of Information)
Probability of Message Delivery
Inorganic Information
Collective Squad Information
Individual Agent Information
Line of Sight
Movement Desire
Mission Intent
Terrain
Elevation
Number of Agents

Conceptual Model



Investigating New Approaches to C2: SAS-050

- A NATO study panel
- New Approaches: *Not* “What we do” or “How we do it”
- Point of Departure: How could we accomplish the functions we associate with C2?
  - Command Functions: Intent, Roles and Responsibilities, Resource Allocation
  - Control: Recognize and Respond to Changes, within bounds established by command
- C2 Approach = point/region in a space of possibilities
  - Delegation of Decision Rights
  - Patterns of Interaction: Social domain
  - Patterns of Interaction: Information Domain

Data Characterization and Analysis

- NPS design of experiments methodology employed
  - CC: 9 parameters farmed
  - Edge: 6 parameters farmed
  - 132 parameter combinations specified with crossed Nearly Orthogonal Latin Hypercube and factorial designs
  - 30 replications per combination
  - 7920 total model runs (theoretically)