AUTONOMY LEVELS FOR UNMANNED SYSTEMS (ALFUS)

Hui-Min Huang/NIST
ALFUS Working Group
SAE AS4D Committee
ALFUS OBJECTIVES

Framework to facilitate characterizing and articulating autonomy for unmanned systems:

- Standard terms and definitions for requirements analysis and specification
- Metrics, processes, and tools for evaluation/measurement
ALFUS SCOPE

• Generic framework covering all UMSs.
• From remote control through full and intelligent autonomy.
• From single UMS subsystem level operational behavior through multi-level, joint missions.
HISTORY

- Stage I: Started in 2003 as Cross-Government Ad Hoc Workgroup. Published Terminology.
- Stage II: Collaboration with FCS. Published Framework.
- Stage III: January 2008, joined SAE as AS4-D Unmanned Systems Performance Measures Committee
ALFUS CHARACTERISTICS

• Metrics based—measurable levels with smooth transitions

• Multiple layers of abstraction for autonomy requirements and capabilities

• Basis for a general performance metrics framework for unmanned systems
AUTONOMY
Focusing on Context

A UMS’s own ability of sensing, perceiving, analyzing, communicating, planning, decision-making, and acting/executing, to achieve its goals as assigned by its human operator(s) through designed HRI.
ALFUS FRAMEWORK

Human Independence

Mission Complexity

Environmental Complexity
ALFUS METRICS

Mission Complexity
- Subtasks, decision
- Organization, collaboration
- Performance
- Situation awareness, knowledge requirements

Environmental Complexity
Solution ratios on:
- Terrain variation
- Object frequency, density, intent
- Climate
- Mobility constraints
- Communication dependencies

Human Independence
- Frequency, duration, robot initiated interactions
- Workload, skill levels
- Operator to UMS ratio

UMS team Alpha
UGV-1
LAYERS OF DETAIL

Contextual Autonomous Capability:
- Mission/Task/UMS Autonomy
- Mission Complexity
- Environmental Complexity

Metric Decomposition
- Metrics Groups
- Root Autonomous Capability
  Autonomy

CAC
MC metric score
HI metric score
EC metric score

MC tactical behaviormetric groupscore

taskstructure metricscore

subtasking metricscore
## CONTEXTUAL AUTONOMY

### Evaluation Form

<table>
<thead>
<tr>
<th>Autonomy Levels</th>
<th>MC</th>
<th>ED</th>
<th>HRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MC: mission complexity,  
ED: environmental difficulty  
HRI: human-robot interaction
ALFUS FRAMEWORK
Illustrative Application
ALFUS EVALUATION PROCESS

- MC individual metric
- task metric score
- task complexity
- task weight
- higher level task or mission complexity
- * metric weights
- * inter-metric dependency
- * axis performance issues
- mission ALFUS scores
- option 1?
- option 2?
Remote control Full, intelligent autonomy

100%

HRI

• approaching 0 HRI
• highest complexity, all missions
• extreme environment

Single actuator

Single function

Single UMS

UMS team

SOS

Autonomy Level

• mid level HRI
• mid complexity, multi-functional missions
• moderate environment

• low level HRI
• collaborative, high complexity missions
• difficult environment

• high level HRI
• low level tactical behavior
• simple environment

• low level HRI
• collaborative, high complexity missions
• difficult environment

Single actuator/subfunction

Single function

Single UMS

team

ALFUS ILLUSTRATION

Single actuator

Single function

Single UMS

UMS team

SOS

NIST Homeland Security
ALFUS MODEL
Simplified by Combined Mission and Environment Axes

Mission Complexity: Tasks / Environments

Human Independence

Level of autonomy (global, comprehensive)
Level of autonomy (operational domain specified)

fully autonomous
remote control
ALFUS FRAMEWORK APPLICATION

Missions Complexity:
Tasks: countermine, RSTA, ...
Coordination: joint operations, ...
Planning: real-time
Performance: 90% success
Perception: onboard LADAR, ...

HRI:
Intervention freq: 20%
Workload: mid pressure
Skill level: 6 month training
UMS ratio: 1:1

Environmental Complexity:
Terrain: field, sparse forest, ...
Soil: grass, gravel, ...
Obstacle density: N/sq-km, ...
Comm dropout: 20 sec max
Traffic: ...

PRODUCT LIFECYCLE

requirements

specification
design, development, simulation
T & E, V & V
operation
upgrade

level N Mission levelM HRI level L Environment
ALFUS GENERALIZATION
Performance Test Methods
Framework to facilitate characterizing/articulating autonomy levels for unmanned systems:

- Generic framework covering all UMSs.
- From remote control through full autonomy.
- From single UMS to team to joint missions.

http://www.nist.gov/mel/isd/ks/autonomy_levels.cfm
BACKUPS
<table>
<thead>
<tr>
<th>Level and Descriptor</th>
<th>Metrics and Definition</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 – Full, intelligent autonomy</td>
<td>Collaborative in team of teams, real-time planning to complete all required missions with highest complexity; understands, adapts to, and maximizes benefit/value/efficiency while minimizes costs/risks on the broadest scope environmental and operational changes; approaching total independence on information and from operator input.</td>
<td>Any mission assigned to the team of teams in its native environment</td>
</tr>
</tbody>
</table>

**HRI Metrics:**
Requiring approaching zero human interaction after assigning mission.

**Mission Complexity Metrics:**
- All required missions for SoS, highest level of subtasking and collaboration throughout organization.
- Full, self, efficient, real-time planning and execution, highest precision and success rate, maximizes/minimizes on values/cost, benefit/risk.
- Self-sufficient SA and KB, highest fusion/perception levels.

**Environmental Difficulty Metrics:**
- Generate and assimilate highest fidelity map for mission, infer highest res info from low res
- Adaptable to extreme terrain and climate variations and obstacle density and frequency.
- Independence to comm. link with operator.
PARTICIPATION (partial)

DOD – AATD*, AFRL, AMRDEC*, ARL*, MANCEN*, CERDEC*, DARPA, NAVAIR, NSWC, OSD/JPO, TARDEC*, TRADOC*, ...

DOC – NIST

DOE – HQ, INEEL

DOT – FHWA

Industry

Collaborations with AIAA, JAUS WG, NASA, PerMIS, ...

*U.S. Army
The following, in alphabetical order, contributed to the ALFUS Framework effort: **Air Force:** Bruce Clough, Robert Smith, Jeff Wit. **Army (inc. AATD, AMRDEC, ARL, CERDEC, MENCEN, TARDEC, TSM FCS, UAMBL):** Curt Adams, Keith Arthur, Robert Barnhill, Bruce Brendle, Marsha Cagle-West, Jeff Cerny, Sanjiv Dungrani, Mike Dzugan, Woody English, Bill Fedak, Ray Higgins, Susan Hill, Julie Hertz, Kelley Hodge, Jeffrey Jaczkowski, Robert Kania, David Knichel, Brian Majala, Peter Melick, Brian Novak, Kerry Pavek, Richard Pena, Jason Pusey, John Rovegno, Kent Schvaneveldt, Charles Shoemaker, Stephen Swan, David Thomas, Terrance Tierney, Robert Wade. **DARPA:** LTC Gerrie Gage, Doug Gage, Dennis Overstreet. **DOE:** David Bruemer, Tom Weber. **DOT FHWA:** Robert Ferlis, Peter Huang. **Industry (inc. FCS):** Thomas Adams, Thomas Altshuler, John Bergman, Charles Bishop, Dale Fleck, William Klarquist, Mark Peot, Dan Rodgers, Chiraq Tasker. **IDA:** Julianna Connelly, David Sparrow. **NASA:** Jeremy Hart, Ryan Proud. **Navy:** Darryl Brayman, Eric Hansen, Caesar Mamplata, Marc Steinburg. **NIST:** James Albus, Brian Antonishek, Tony Barbera, Maris Juberts, Elena Messina, Jean Scholtz, Harry Scott, Albert Waivering. **OSD:** Richard Abraham, Keith Anderson, Jeffrey Kotora. **Project Funding:** DHS and NIST
Each Level of Autonomy Scale is broken into 8 levels. The levels for the Decide functions are shown.

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>The computer performs ranking tasks. The computer performs final ranking, but does not display results to the human.</td>
</tr>
<tr>
<td>7</td>
<td>The computer performs ranking tasks. The computer performs final ranking and displays a reduced set of ranked options without displaying &quot;why&quot; decisions were made to the human.</td>
</tr>
<tr>
<td>6</td>
<td>The computer performs ranking tasks and displays a reduced set of ranked options while displaying &quot;why&quot; decisions were made to the human.</td>
</tr>
<tr>
<td>5</td>
<td>The computer performs ranking tasks. All results, including &quot;why&quot; decisions were made, are displayed to the human.</td>
</tr>
<tr>
<td>4</td>
<td>Both human and computer perform ranking tasks, the results from the computer are considered prime.</td>
</tr>
<tr>
<td>3</td>
<td>Both human and computer perform ranking tasks, the results from the human are considered prime.</td>
</tr>
<tr>
<td>2</td>
<td>The human performs all ranking tasks, but the computer can be used as a tool for assistance.</td>
</tr>
<tr>
<td>1</td>
<td>The computer does not assist in or perform ranking tasks. Human must do it all.</td>
</tr>
</tbody>
</table>
EXISTENT WORK
Essential Foundations

• OODA -- Observe, Orient, Decide, Act.

• 4D/RCS Reference Architecture
  – Generic Node consistent with OODA
  – System Hierarchy harmonizes many, many OODA nodes.
  – Hierarchical Task Decomposition organizes missions of different complexity.
<table>
<thead>
<tr>
<th>Level</th>
<th>Level Description</th>
<th>Orient</th>
<th>Decide</th>
<th>Act</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Fully Autonomous</td>
<td>Cognitive of all within battle space</td>
<td>Perception/Situational Awareness</td>
<td>Capable of total independence</td>
<td>Requires little guidance to do job</td>
</tr>
<tr>
<td>9</td>
<td>Battle Space</td>
<td>Battle space inference - intent of self and others</td>
<td>Analysis/Coordination</td>
<td>Distributed tactical group planning</td>
<td>Group accomplishment of strategic goal with</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strategic group goals assigned</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battle Space (alleys and lanes)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swam</td>
<td>Complex/Intense environment - on-board tracking</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cognizance</td>
<td>Enemy strategy inferred</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Choose tactical targets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Battle Space</td>
<td>Battle space inference - intent of self and others</td>
<td>Strategic group goals assigned</td>
<td>Coordinated tactical group planning</td>
<td>Group accomplishment of strategic goal with</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strategic group goals assigned</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battle Space (alleys and lanes)</td>
<td>Individual task planning/execution</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cognizance</td>
<td>Reduced dependence upon off-board data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Choose targets of opportunity (example: go STOOG hunting)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Battle Space</td>
<td>Battle space inference - history and predictive battle</td>
<td>Tactical group goals assigned</td>
<td>Individual task planning/execution to meet goals</td>
<td>Group accomplishment of tactical goal with</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tactical group goals assigned</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battle Space (alleys and lanes)</td>
<td>Individual task planning/execution to meet goals</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cognizance</td>
<td>Limited inference supplemented by off-board data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minimal supervision assistance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Real Time</td>
<td>Real Time</td>
<td>Tactical group goals assigned</td>
<td>Coordinated trajectory planning and execution to meet goals</td>
<td>Group accomplishment of tactical goal with</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Vehicle</td>
<td>Ranged awareness - on-board sensing for long range</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooperation</td>
<td>Enemy location sensed/estimated</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Group supervision assistance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Possible close air space separation (1-100 yds)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Real Time</td>
<td>Real Time</td>
<td>Tactical group goals assigned</td>
<td>On-board trajectory replanning - optimizes for</td>
<td>Group accomplishment of tactical plan as externally</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Vehicle</td>
<td>Sensed awareness - local sensors to detect others</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coordination</td>
<td>Tactical group plan assigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>On-board trajectory replanning - optimizes for</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>current and predictable conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Collision avoidance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Air collision avoidance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Possible close air space separation (1-100 yds) for</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AAR formation in non-threat conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Real Time</td>
<td>Real Time</td>
<td>Tactical plan assigned</td>
<td>On-board trajectory replanning - event driven</td>
<td>Self accomplishment of tactical plan as externally</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fault/Event</td>
<td>Deliberate awareness - allies communicate data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vehicle</td>
<td>Tactical plan assigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>On-board trajectory replanning - event driven</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Self accomplishment of tactical plan as externally</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>assigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Self resource management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Robust Response</td>
<td>Robust Response</td>
<td>Tactical plan assigned</td>
<td>Evaluate status vs required mission capabilities</td>
<td>Self accomplishment of tactical plan as externally</td>
</tr>
<tr>
<td></td>
<td>in Real Time</td>
<td>Fault/Events</td>
<td>Tactical plan assigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Health/status history &amp; models</td>
<td>Tactical plan assigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Evaluate status vs required mission capabilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Self accomplishment of tactical plan as externally</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>assigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Abort/K/T if insufficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Abort/K/T if insufficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Changeable</td>
<td>Changeable</td>
<td>RT Health diagnosis (Do I have problems?)</td>
<td>Execute preprogrammed or uploaded plans</td>
<td>Self accomplishment of tactical plan as externally</td>
</tr>
<tr>
<td></td>
<td>Mission</td>
<td>Mission</td>
<td>RT Health diagnosis (Do I have problems?)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Health/status sensors</td>
<td>Off-board replan (as required)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Execute preprogrammed or uploaded plans</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>in response to mission and health conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Execute</td>
<td>Execute</td>
<td>Preplanned mission data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preplanned</td>
<td>Preplanned</td>
<td>Flight Control and Navigation Sensing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mission</td>
<td>Mission</td>
<td>Preflight Flight Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Preflight Flight Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Report status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Remotely</td>
<td>Remotely</td>
<td>Flight Control (attitude, rates) sensing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Piloted Vehicle</td>
<td>Vehicle</td>
<td>Telemetered data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td>Control by remote pilot</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Final ACL Chart
EXISTENT WORK

“Sheridan” Model

1) Computer offers no assistance, human must do it all.
2) Computer offers a complete set of action alternatives, and
3) narrows the selection down to a few, or
4) suggests one, and
5) executes that suggestion if the human approves, or
6) allows the human a restricted time to veto before automatic execution, or
7) executes automatically, then necessarily informs the human, or
8) informs him after execution only if he asks, or
9) informs him after execution if it, the computer, decides to.
10) Computer decides everything and acts autonomously, ignoring the human.
EXISTENT WORK
Army Science Board Study

0. Manual remote control, like a remote controlled toy
1. Simple automation
2. Automated tasks and functions, like a Hunter
3. Scripted mission, like an Shadow or Predator UAV
4. Semi-automated missions with simple decision making, like an Cruise Missile
5. Complex missions-specific reasoning
6. Dynamically mission adaptable
7. Synergistic multi-mission reasoning
8. Human-like autonomy in a mixed team
9. Autonomous teams with unmanned leader or mission manager
10. Autonomous conglomerate.
<table>
<thead>
<tr>
<th>Level</th>
<th>Level Description</th>
<th>Observation Perception/ Situation Awareness</th>
<th>Decision Making</th>
<th>Capability</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Remote Control</td>
<td>Remote camera images viewed by operator</td>
<td>None</td>
<td>Remote operation in relatively simple stationary environments</td>
<td>Basic teleoperation</td>
</tr>
<tr>
<td>2</td>
<td>Remote Control w/vehicle State Knowledge</td>
<td>Local pose, dashboard sensors, and depth image display for operator</td>
<td>Basic health and vehicle state reporting</td>
<td>Remote operation in relatively complex stationary environments</td>
<td>Teleoperate with operator knowledge of geometry of environment</td>
</tr>
<tr>
<td>3</td>
<td>Pre-Planned mission or retro-traverse</td>
<td>INS/GPS waypoints, collision avoidance</td>
<td>ANS commanded steering based on planned path</td>
<td>Basic path following with operator help</td>
<td>Pre-planned path, retro-traverse, or operator waypoint selection</td>
</tr>
<tr>
<td>4</td>
<td>On-board processing of sensory images</td>
<td>Perception of simple surfaces and shapes</td>
<td>Negotiation of simple environment</td>
<td>Robust leader follower with operator help</td>
<td>Follow foot soldiers on road march or easy cross-country</td>
</tr>
<tr>
<td>5</td>
<td>Simple obstacle detection and avoidance</td>
<td>Local perception and map database</td>
<td>Real-time path planning based on hazard estimation</td>
<td>Basic cross country semi-autonomous navigation</td>
<td>Cross country with frequent operator intervention</td>
</tr>
<tr>
<td>6</td>
<td>Complex obstacle detection and avoidance, terrain analysis</td>
<td>Perception and world model representation of local environment</td>
<td>Planning and negotiation of complex terrain and objects</td>
<td>Cross country with obstacle negotiation with some operator help</td>
<td>Cross country in complex terrain with limited intervention</td>
</tr>
<tr>
<td>7</td>
<td>Moving object detection and tracking, on-road and off-road autonomous driving</td>
<td>Local Sensor fusion with a priori maps of road network, representation of moving objects</td>
<td>Robust Planning and Negotiation of Complex Terrain, Environmental Conditions, hazards and objects</td>
<td>Cross country with obstacle avoidance with little operator help</td>
<td>Cross country in complex terrain with full mobility speed with limited intervention</td>
</tr>
<tr>
<td>8</td>
<td>Cooperative operations, convoy, intersections, oncoming traffic</td>
<td>Real-time fusion of data from external sources, broad knowledge of rules of the road</td>
<td>Advanced decisions based on shared data from other similar vehicles</td>
<td>Rapid effective execution of on-road driving tasks with minimal operator input</td>
<td>On-road operations under normal road conditions with little supervision</td>
</tr>
<tr>
<td>9</td>
<td>Collaborative operation, traffic signs and signals, near human levels of driving skill</td>
<td>Perception in bad weather and difficult environmental conditions</td>
<td>Collaborative reasoning for cooperative tactical behaviors</td>
<td>Accomplish complex collaborative missions with some operator oversight</td>
<td>Effective combat mission accomplishment with little supervision</td>
</tr>
<tr>
<td>10</td>
<td>Full autonomy with human levels of performance or better</td>
<td>Data fusion from all participating battlefield assets</td>
<td>Total independence to plan and implement to meet defined objectives</td>
<td>Accomplish complex collaborative missions with no operator intervention</td>
<td>Fully autonomous combat missions accomplished with results equal to or better than with human soldiers</td>
</tr>
</tbody>
</table>

As Autonomy increases capabilities include or replace items from lower levels.

The same behavior operating in different Terrain and/or Environmental conditions may result in different level of autonomy.
ALFUS GENERIC FRAMEWORK
Detailed Model
Characterization of Human Independence

• Intervention frequency/duration
• Robot initiation percentage
• Operator workload
• Operator to UMS ratio
• Operator Skill
ALFUS GENERIC FRAMEWORK

Detailed Model

Characterization of Environmental Complexity

- static: terrain, soil, water,
- dynamic: frequency/density/types of objects
- electronic/electromagnetic
- urban: traffic, road, barriers, controlling devices
- rural: vegetation, biologics,
- weather: climate, lighting, temperature,
- operational: threats, decoy, mapping, mobility,
Autonomy Level Algorithms  
mission complexity axis

1. “Serial”: Add values for all metrics and scale them from 0 to 10.
   - Advantage: simple and mechanic,
   - Drawback: final number may be misleading or vague. For example, a level 7 may be a result of very high subordinate level numbers but very poor latency and that may not be what the user wanted.

2. “Parallel”: line up all the metric values and pick the lowest.
   - Advantage: assurance
   - Drawback: over constraining, high cost for ums development.

3. “Hybrid”: Categorize mission metrics into: O, O, D, and A. Use serial within each category but parallel for the 4 categories?
ALFUS FRAMEWORK
Clarification

Autonomy vs. Automation
- washing machine vs. scouting mission
- human-less operation vs. human-like performance
Some possible uses of the framework

• Classify environments, HRI systems, or missions

• Missions can be certified with the other two axes, e.g., perform mission A in level N environment, mission B is designed to operate with level M HRI, etc.

• Detailed metrics could be used as general performance metrics for intelligent, unmanned systems.
JOINT MISSIONS

MISSION TYPES
- mobility
  - RSTA
- scan
  - react to threats
- maritime reconn
  - sub track and trail

autonomy levels
- low
- high

mission integration
Workshop Accomplishments

- **Inaugural Workshop** (July 18, 2003, NIST)  
  Established Working Group Objectives
- **Second** (September 11, 2003, BWI)  
  Identified Terms and Started Definitions
- **Third** (November 22, 2003, SRS Tech., Arlington, VA)  
  Identified Metrics, Terminology Published
- **Fourth** (February 25-26, 2004, Titan Sys., Huntsville, AL)  
  Identified Summary Model Representation
Workshop Accomplishments

- **Fifth** (May 3-4, 2004, Atlanta Airport, GA)
  Metrics and Measures Presented. Began Interaction with FCS

- **Sixth** (July 28-29, 2004, FCS LSI, Huntsville, GA)
  Tool Conceptualized. Exit Strategy Planned.

- **Seventh** (October 19-20, 2004, AFRL, Dayton, Ohio)
  Tool Updated. Began Summary Model.

- **Eighth** (February 8 - 9, 2005, NIST, Gaithersburg, Maryland)
Workshop Accomplishments

- **Ninth** (May 4-5, 2005, TARDEC, Warren, Michigan)
  
  Focused on Metric Scale Development. TARDEC Programs Presented. ASBS and UACO Programs Briefed.

- **Tenth** (July 20-21, U.S.Army Futures Center Forward, Arlington, Virginia)
  