Requirements Definition Process
Wave 1 Candidates
Example Test Protocol

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Requirements Definition Process

- Responder-defined scenarios and situations were used to focus thinking, facilitate discussions

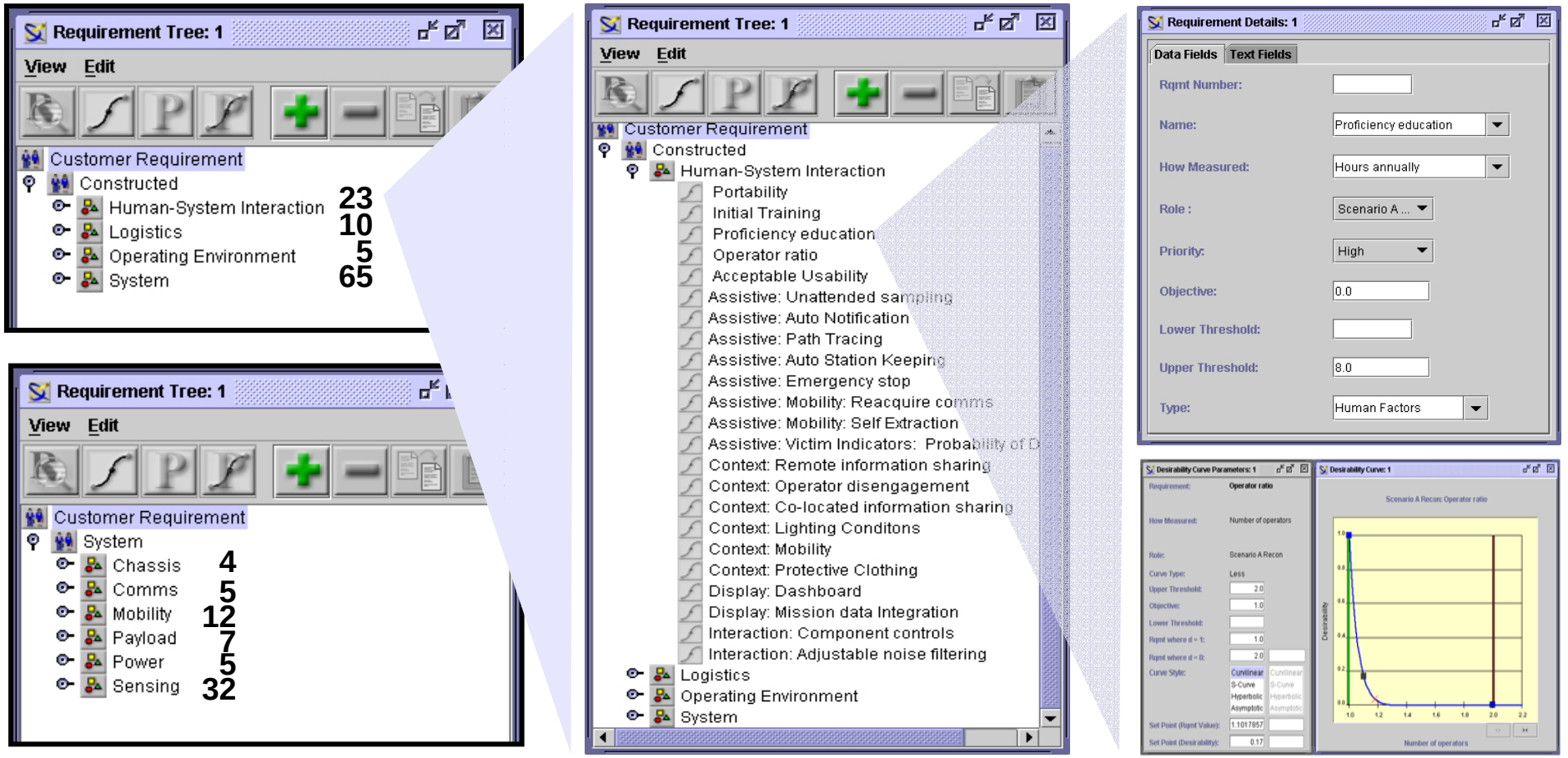
- An integrated product and process development (IPPD) database is being used to capture requirements and (eventually) compare technology solutions
- High level requirement categories and very detailed specifications are defined; candidate technologies will be evaluated against requirements and results visually presented

Scenarios

- Responder-defined scenarios and situations were used to focus thinking, facilitate discussions

	Scenario A	Scenario B	Scenario C
Description	Upper stories of a multi-story pancake collapse	Subsurface voids	US&R Type II
Characteristics	Soft stories in the middle, undetermined stability, uneven terrain, sloped floor with holes, variable debris size, high hazmat potential, and poor visibility	Downwardly accessible void spaces, twisted/turning access (i.e., searchcam can't reach or turn necessary corners), variety of materials, complex orientations of support surfaces, sufficiently complex to cause spatial disorientation, hot, may be wet, high hazmat potential, and poor visibility	Rapid extraction of many non-ambulatory live victims from a contaminated (WMD / CBRNE) environment in a large urban area. This assumes that explosions or collapses have not compromised structures. Sample areas include malls, stadiums, several city blocks, etc. Teams may be pre-deployed.
Representative Image			

Requirements Hierarchy



Prioritization of Requirements

- 100+ requirements were analyzed with respect to 13 different situations or possible robot types

Robot Category	Ground: Peek Robots	Ground: Collapsed Structure--Stair/Floor climbing, map, spray, breach bots	Ground: Non-collapsed Structure--Wide area survey Bot	Ground: Wall Climbing Deliver Bots	Ground: Confined Space, Temporary Shore Bots	Ground: Confined Space Shape Shifters	Ground: Confined Space Retrieval Bots	Aerial:High Altitude Loiter Bots	Aerial: Rooftop Payload Drop Bots	Aerial: Ledge Access Bot	Aquatic: Variable Depth Sub Bots	Aquatic: Bottom Crawler Bot	Aquatic: Swift Water Surface Swimmer
Employment Role(s)	Provide rapid audio visual situational awareness; provide rapid HAZMAT detection; data logging for subsequent team work review	Stairway & upper floor situational awareness; mitigation activities; stay behind monitoring	human access stairway & upper floor situational awareness; contaminated area survey; site assessment; victim identification; mitigation activities; stay behind monitoring	Deliver Payloads to upper floors; provide expanded situational awareness when aerial platforms are unavailable or untenable	Adaptive, temporary shoring; provide stay behind monitoring; victim triage & support	Search; provide stay behind monitoring	Retrieve objects from confined spaces; provide stay behind monitoring	Provide overhead perspective & sit. awareness; provide HAZMAT plume detection; provide comm repeater coverage	Payload delivery to rooftops; provide overhead perspective; provide comm repeater coverage	Object retrieval from upper floors; crowd control with a loudspeaker object attached, provide situational awareness	Structural inpsection; leak localization/mitigation; object (body) recovery	Water traverse; rapid current station keeping; object recovery	Upstream access and station keeping; payload delivery; object recovery
Deployment Method(s)	Thrown; chucked, thrown pneumatically, w/surgical tubing; marsupially deployed	Backpacked; self driven; marsupially deployed	Backpacked; self driven; marsupially deployed	Placed; thrown pneumatically, w/surgical tubing; marsupially deployed	Placed; lowered	Placed; lowered	Placed; lowered via tether	Released: baloon or F/W; tethered LTAF (kite)	Launched F/W; tethered LTAF (kite)	Launched VTOL; VTOL	Dropped into water; lowered via tether	Driven across w	Dropped into water; marsupially deployed
Tradeoffs	Trade mobility, duration, sensing for increased expendability	Trade form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant	Trade form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant	trade payload capacity for vertical mobility and stable perching	trade mobility and payload capacity for shoring capacity	trade payload capacity for confined space access	trade sensing capacity for manipulators, confined space access	trade penetration capacity for vertical perspective	trade penetration capacity & loiter time for vertical drop	trade simplicity, penetration capacity, loiter time for precise vertical drop	trade ground mobility for sub surface access & free swim capacity	pursue amphibious mobility at cost of other performance	pursue swift water capacity at cost of other performance

- Responders determined which requirements applied to which situation/robot category

- This data was used to determine the most widely applicable requirements categories, which will be considered for Wave 1 of the standards process

Robot Categories and Deployment Situations

- Responder-ratified situations were used to further focus thinking, facilitate discussions

Robot Category	Ground: Peek Robots	Ground: Collapsed Structure--Stair/Floor climbing, map, spray, breach bots	Ground: Non-collapsed Structure--Wide area survey Bot	Ground: Wall Climbing Deliver Bots	Ground: Confined Space, Temporary Shore Bots	Ground: Confined Space Shape Shifters	Ground: Confined Space Retrieval Bots	Aerial:High Altitude Loiter Bots	Aerial: Rooftop Payload Drop Bots	Aerial: Ledge Access Bot	Aquatic: Variable Depth Sub Bots	Aquatic: Bottom Crawler Bot	Aquatic: Swift Water Surface Swimmer
Employment Role(s)	Provide rapid audio visual situational awareness; provide rapid HAZMAT detection; data logging for subsequent team work	Stairway & upper floor situational awareness; mitigation activities; stay behind monitoring	human access stairway & upper floor situational awareness; contaminated area survey; site assessment; victim identification; mitigation activities; stay behind monitoring	Deliver Payloads to upper floors; provide expanded situational awareness when aerial platforms are unavailable or untenable	Adaptive, temporary shoring; provide stay behind monitoring; victim triage & support	Search; provide stay behind monitoring	Retrieve objects from confined spaces; provide stay behind monitoring	Provide overhead perspective & sit. awareness; provide HAZMAT plume detection; provide comm repeater coverage	Payload delivery to rooftops; provide overhead perspective; provide comm repeater coverage	Object retrieval from upper floors; crowd control with a loudspeaker object attached, provide situational awareness	Structural inpsection; leak localization/mitigation; object (body) recovery	Water traverse; rapid current station keeping; object recovery	Upstream access and station keeping; payload delivery; object recovery
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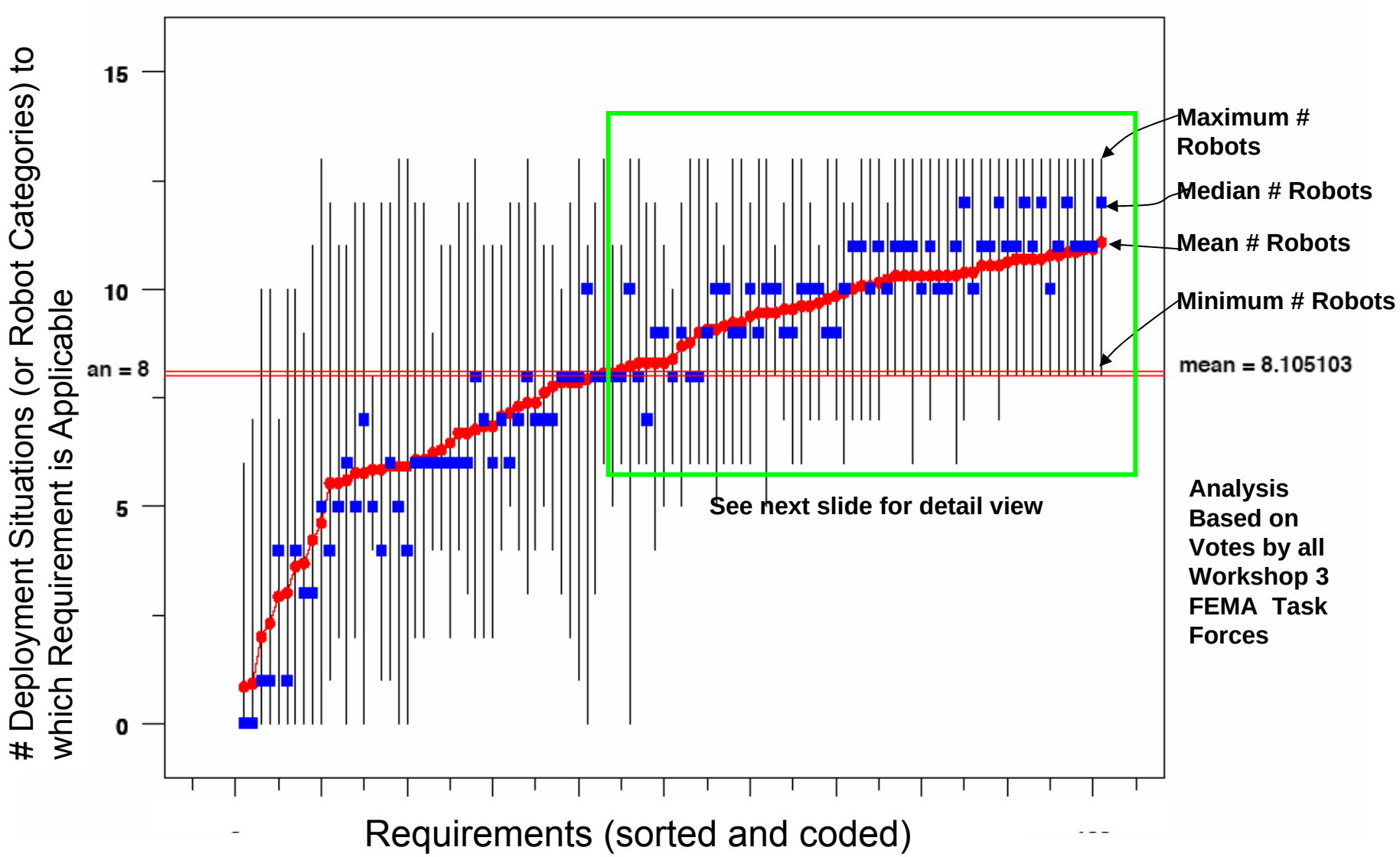
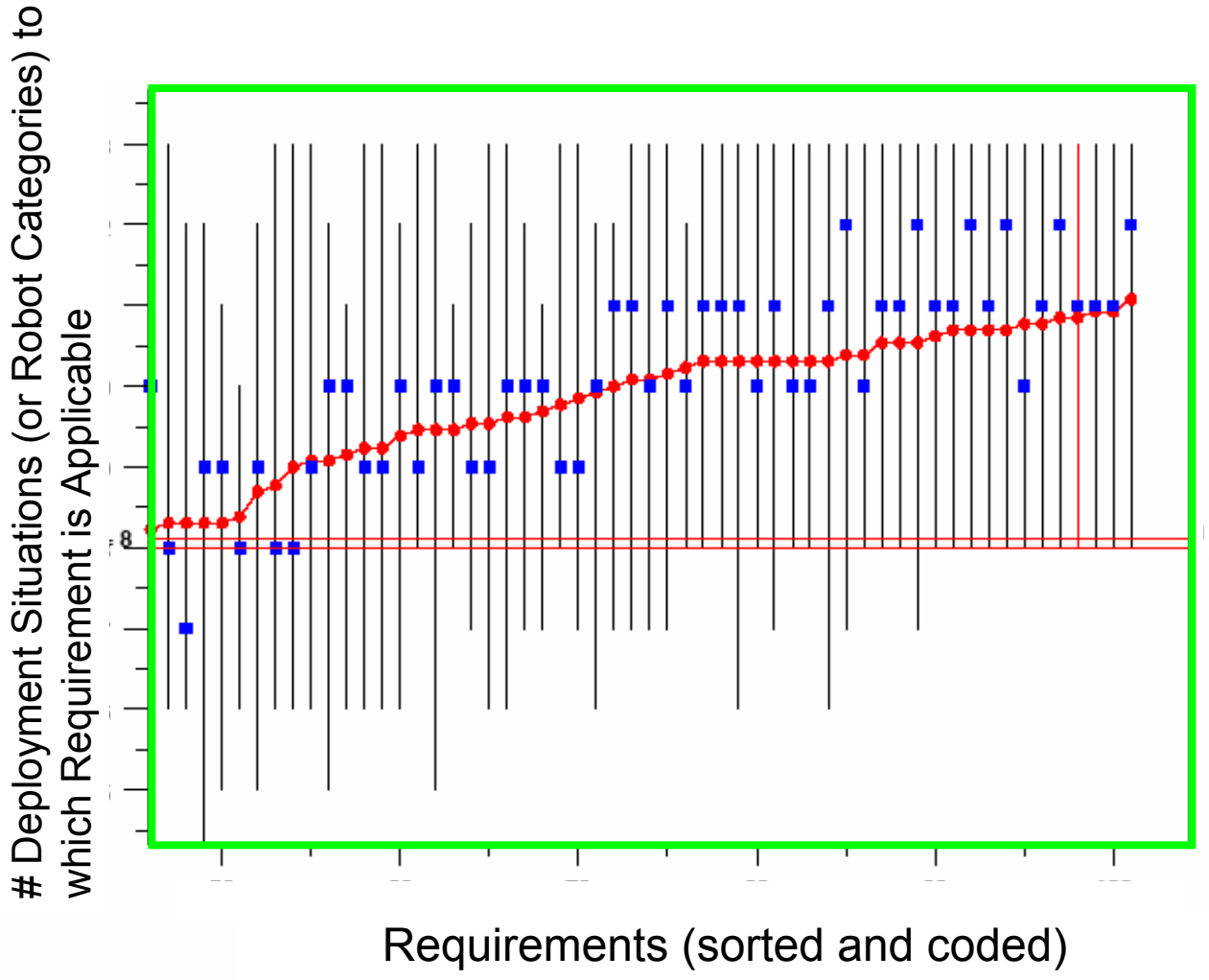
Tradeoffs	Trade mobility, duration, sensing for increased expendability	form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant	form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant	trade payload capacity for vertical mobility and stable perching	trade mobility and payload capacity for shoring capacity	trade payload capacity for confined space access	trade sensing capacity for manipulators, confined space access	trade penetration capacity for vertical perspective	trade penetration capacity & loiter time for vertical drop	trade simplicity, penetration capacity, loiter time for precise vertical drop	trade ground mobility for sub surface access & free swim capacity	pursue amphibious mobility at cost of other performance	pursue swift water capacity at cost of other performance

Wave 1 Requirements Selection Composite Data Statistics



Wave 1 Requirements Selection
Composite Data Statistics



Suggested Selection Criteria

- $\bar{Y}_i \geq \equiv{Y}$ (=8.105)
- $Med_i \geq 10$
- $Min_i \geq 8$
- $Max_i \geq 12$

Yield about 20 Wave 1 requirements that may be considered consensus requirements

Wave 1 Requirements

2	Chassis		System Component Interoperability	Interoperability of task-based requirements beyond Minimum Capabilities. Includes all chassis , payload, and operator interface components.
3	Chassis	**Illumination:**	Adjustable	
5	Comms	**Comms:**	Expandable Bandwidth	Will support additional operational components without loss of data transmission rate sufficient to allow each component to perform its function.
6	Comms	**Comms:**	Range--Beyond Line Of Sight	Must be able to ingress specified number of feet in worst case collapse. Worst case is a reinforced steel structure.
7	Comms	**Comms:**	Security	System must be shielded from jamming interference and encrypted. Scale defined: 1=None, 3=Command; 5=Both data and command.
8	Comms	**Comms:**	Range--Line of Sight	
11	Human Factors		Initial Training	Leads to certification.
12	Human Factors		Proficiency education	Structured environment.
13	Human Factors		Operator ratio	Per robot
14	Human Factors	**	Acceptable Usability	Percent of tasks users can complete.
16	Human Factors	**Assistive:**	Auto Notification	System notifies operator when conditions arise that need attention.
20	Human Factors	**Assistive: Mobility:**	Reacquire comms	
26	Human Factors	**Context:**	Lighting Conditons	Special emphasis on no light and glare.
27	Human Factors	**Context:**	Mobility	Scale; 1=Stationary; 3=Can't run system while moving; 5=Run system while moving. Moving is assumed to be on foot.
28	Human Factors	**Context:**	Mobility	Scale Defined: 1=Wearable; 3= 1+operate while moving; 5=1+2+hands free
29	Human Factors	**Context:**	Protective Clothing	Scale: 1=No protection; 3=Minimum protection (threshold); 5=Complete protection (Objective) while maintaining acceptable usability
30	Human Factors	**Display:**	Dashboard	General chassis system health and status. (e.g. orientation, comm strength, power level). Two types of information: I. Organic: 1) Health--power, motor, sensor. Comm--radio transmission, reception. 2) Pose--location; absolute (x,y,z) or relative. 3) Constraint--inhibitors, manipulator problems, sensing-occluded, blocked. II. External: 1)

Wave 1 Requirements

32	Human Factors	**Interaction:**	Component controls	To include diagnostics.
34	Logistics		Cache packaging--Weight	Per container
35	Logistics		MTBF	Operating hours.
36	Logistics		Cache packaging--Setup Time	Time from on-site delivery to operation.
37	Logistics		Shock resistance	Organic chassis without mission specific components. Organic includes directional audio, position sensors.
38	Logistics		Cache packaging--Volume	Scale defined: 1=Pelican 1650 box; 3=Hardigg box checkable on commercial aircraft; 5=Ropack model 4048, 4039 with drop door
39	Logistics	**Field Maintenance:**	Spares and Supplies	Self sustaining for 72 hours.
40	Logistics	**Field Maintenance:**	Duration	
41	Logistics	**Field Maintenance:**	Tools	Scale Defined: 1=Requires special tools, 3=Simple tools (e.g., screw driver), 5= No tools required
42	Logistics	**Field Maintenance:**	Intervals	Mean time between routine maintenance.
56	Operating Environment	**Oper. Env.:**	Max Temperature	
57	Operating Environment	**Oper. Env.:**	Water	Scale: 1=Not water resistant; 2=Wash down; 3=Submersable; 4=Water resistant to 12 meters.
58	Operating Environment	**Oper. Env.:**	Min Temperature	
66	Power	**Power:**	Dwell Time	Amount of time system can remain active but stationary.
67	Power	**Power:**	Working Time	Must have sufficient power to operate for specified number of hours. Assumes one power charge. One out and back mission.
68	Power	**Power:**	Sustainment	Amount of time system must be able to operate in field before re-supply is needed.
69	Power	**Power:**	Runtime Indicator	Must be able to inform operator of remaining power level (percent).
82	Sensing	**Passive Data Logging Offboard:**	Location	
83	Sensing	**Passive Data Logging Offboard:**	Hazmat	
84	Sensing	**Passive Data Logging Offboard:**	Victim Indicators	
85	Sensing	**Passive Data Logging Offboard:**	System Health	
96	Sensing	**Video:**	Real time remote video system (Near)	
99	Sensing	**Video:**	Real time remote video system (Far)	Resolution of the image will be tested using visual acuity tests at given range. Limiting case could be assessment of structural integrity of the building. Image should be in color and resolution. Operator must read eye chart through entire imaging system

Example Wave 1 Performance Test: Real-Time Video System Acuity

Number:	**03**
Type:	**CHASSIS**
Sub-Type:	**ILLUMINATION**
Requirement:	**ADJUSTABLE**
Metric:	**YES/NO**
Description:	This requirement captures the responders' expectation to use video in confined spaces and for short-range object identification, which can wash out from excessive illumination of the scene.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Number:	**06 ***
Type:	**COMMUNICATIONS**
Sub-Type:	**N/A**
Requirement:	**RANGE – BEYOND LINE OF SIGHT**
Metric:	**METERS**
Description:	This requirement captures the responders' expectation to project remote situational awareness into compromised or collapsed structures or to convey other types of information. They specifically noted that the robot should be able to ingress a specified number of meters into the worst case collapse, which was further defined as a reinforced steel structure. This requirement also covers operations around corners of buildings and other locations beyond line of sight. The responders made no distinction regarding tethered or wireless implementations to address this requirement.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Example Wave 1 Performance Test: Real-Time Video System Acuity

Number:	07 *
Type:	**COMMUNICATIONS**
Sub-Type:	**N/A**
Requirement:	**SECURITY**
Metric:	**SCALE 1-5** 1 = No security 3 = Command security only 5 = Both data and command security
Description:	This requirement captures the responders' expectation to use this system in sensitive public situations where maintaining control of remotes systems is imperative and limiting access to video images and other communications to authorized personnel is prudent. They added that the system should be shielded from jamming interference and encrypted for security, but made no distinction regarding tethered or wireless implementations to address this requirement.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Number:	**08**
Type:	**COMMUNICATIONS**
Sub-Type:	**N/A**
Requirement:	**RANGE – LINE OF SIGHT**
Metric:	**METERS**
Description:	This requirement captures the responders' expectation to project remote situational awareness or to convey other types of information down range within line of sight. The responders made no distinction regarding tethered or wireless implementations to address this requirement.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Example Wave 1 Performance Test: Real-Time Video System Acuity

Number:	**96**
Type:	**SENSING**
Sub-Type:	**REAL-TIME COLOR VIDEO**
Requirement:	**SYSTEM ACUITY - NEAR**
Metric:	**MILLIMETERS**
Description:	This requirement captures the responders' expectation to use video for key tasks such as maneuvering (hence the real-time emphasis), object identification (hence the color emphasis), and detailed inspection (hence the emphasis on short-range system acuity). The responders noted the need to consider the entire system, including possible communications signal degradation and display quality, when testing this capability. They also noted that this requirement is closely tied to the need for adjustable illumination to avoid washing out the image of close objects. The responders made no distinction regarding tethered or wireless implementations to address this requirement.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Number:	**99 ***
Type:	**SENSING**
Sub-Type:	**REAL-TIME COLOR VIDEO**
Requirement:	**SYSTEM ACUITY - FAR**
Metric:	**METERS**
Description:	This requirement captures the responders' expectation to use video for key tasks such as maneuvering (hence the real-time emphasis), object identification (hence the color emphasis), and path planning (hence the emphasis on long-range system acuity). The responders noted the need to consider the entire system, including possible communications signal degradation and display quality, when testing this capability. They also noted that the limiting case for long-range system acuity is probably assessment of structural integrity of buildings. This requires identifying and measuring cracks in walls, inspecting the tops/bottoms of load bearing columns, and generally assessing the squareness of walls, ceilings, and floors. The responders made no distinction regarding tethered or wireless implementations to address this requirement.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Example Wave 1 Performance Test: Real-Time Video System Acuity

Number:	**101**
Type:	**SENSING**
Sub-Type:	**REAL-TIME COLOR VIDEO**
Requirement:	**FIELD OF VIEW**
Metric:	**DEGREES**
Description:	This requirement captures the responders' expectation to use real-time video for a variety of tasks. The responders noted that this requirement is closely tied to requirements addressing independent pan/tilt capabilities.
Test Method:	**SEE REAL-TIME VISION SYSTEM ACUITY TEST**

Example Wave 1 Performance Test: Real-Time Video System Acuity

GOALS

- Test video system image resolution, near and far
- Test ability to remotely direct perception of robot/camera
- Test effectiveness of variable illumination
- Test effect on resolution from degradation of comms signal
- Test security of video signal

METRICS

- Time to read three charts sequentially (seconds)
- Best visual acuity for each chart (range/icon size)

TEST METHOD

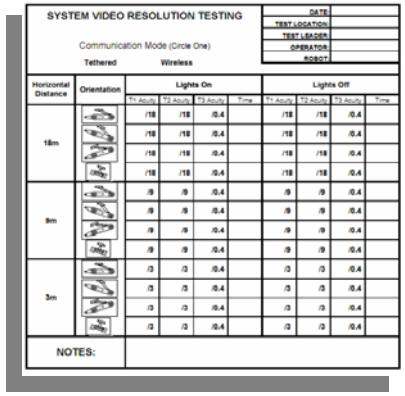
The operator shall sequentially read three eye charts (T_1, T_2, T_3) to discern the smallest possible line (100% correct). Two far field charts will be placed at ground level and at 3m elevation, while a third near field chart will be placed 90 degrees from the down-range axis. Repeat the test with the following variations:

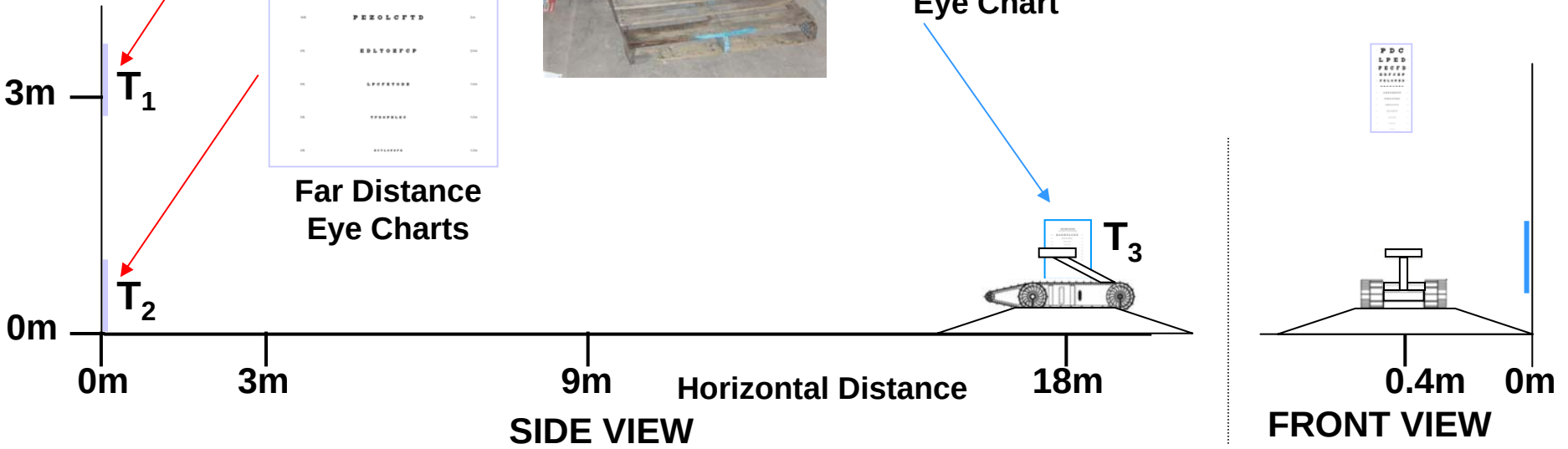
- Ranges: far field charts (18m, 9m, 3m), near field chart (0.4m)
- Robot orientation (level, forward pitch, rear pitch, side roll)
- Ambient lighting of charts (lighted, dark)
- Communication mode (tethered, wireless)

Example Wave 1 Performance Test: Real-Time Video System Acuity

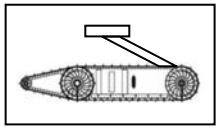
Far Distance Eye Charts

Near Distance Eye Chart

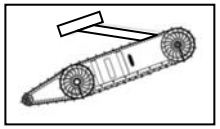




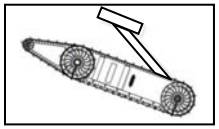
Robot Orientations



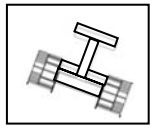
Level



Forward-Pitch



Rear-Pitch



Side-Roll

DHS Standard Test Methods for Performance and Use of US&R Robots

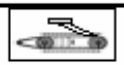
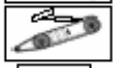
Example Wave 1 Performance Test: Real-Time Video System Acuity

SYSTEM VIDEO RESOLUTION TESTING

Communication Mode (Circle One)

Tethered **Wireless**

DATE:	
TEST LOCATION:	
TEST LEADER:	
OPERATOR:	
ROBOT:	

Horizontal Distance	Orientation	Lights On				Lights Off			
		T1 Acuity	T2 Acuity	T3 Acuity	Time	T1 Acuity	T2 Acuity	T3 Acuity	Time
18m		/18	/18	/0.4		/18	/18	/0.4	
		/18	/18	/0.4		/18	/18	/0.4	
		/18	/18	/0.4		/18	/18	/0.4	
		/18	/18	/0.4		/18	/18	/0.4	
9m		/9	/9	/0.4		/9	/9	/0.4	
		/9	/9	/0.4		/9	/9	/0.4	
		/9	/9	/0.4		/9	/9	/0.4	
		/9	/9	/0.4		/9	/9	/0.4	
3m		/3	/3	/0.4		/3	/3	/0.4	
		/3	/3	/0.4		/3	/3	/0.4	
		/3	/3	/0.4		/3	/3	/0.4	
		/3	/3	/0.4		/3	/3	/0.4	
NOTES:									

DHS Standard Test Methods for Performance and Use of US&R Robots