HUMAN-CENTERED COMMAND AND CONTROL OF FUTURE AUTONOMOUS SYSTEMS

Track 11 (Autonomy), Paper # 090

Maia B. Cook, PhD
Harvey S. Smallman, PhD
Pacific Science & Engineering Group (PSE)
San Diego, CA
858.535.1661 x156
maiacook@pacific-science.com

Sponsored by
Julie L. Marble, PhD
Program Officer
Hybrid Human Computer Systems
Office of Naval Research

18th ICCRTS
"C2 in Underdeveloped, Degraded, and Denied Operational Environments"
21 June 2013, Alexandria, VA

© Pacific Science & Engineering 2013

Problem

- DoD future vision: role shift for human operator of autonomous systems (DoD, 2009)
- How to achieve vision?
- Challenges with autonomy
- Problems with *today's* single vehicle control systems, support tools, and human-machine interfaces (HMIs)
- Need new decision support
- Need principled basis for designing decision support tools, HMIs, and automation for future user

Supervise and monitor autonomous platforms and agents through HMIs

Make decisions about when and how to intervene

© Pacific Science & Engineering 2013

Assumptions for future

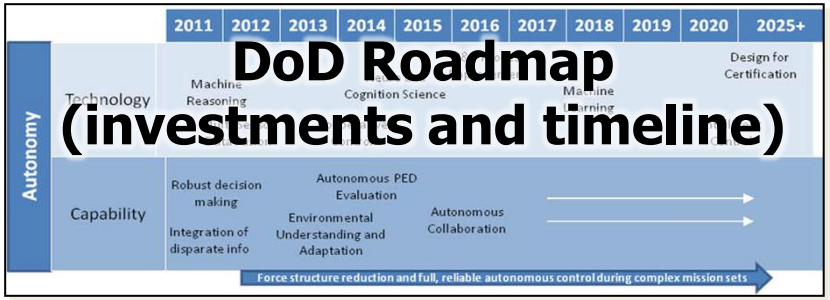
- Dynamic, uncertain, unpredictable, degraded operating environments
- Human role will evolve with sophistication and capabilities of automation
  - Larger span of control (eventually multiple vehicles, systems, missions)
  - Automation limitations (e.g., inherently *brittle* (Layton, Smith, & McCoy, 1994))
  - User will supervise automation and situations, and intervene to correct when necessary

- **Human always needed as decision maker and ultimate arbiter**
- **Shift to supervisory decision making requires accompanying shift in decision support**

© Pacific Science & Engineering 2013

Challenges for achieving DoD autonomous systems vision

- Technology *and* human issues to overcome to support role shift of the human operator



- Primary focus on technology advancement; unresolved user issues
  - Substantial manning requirements
  - ↑ human causal factors in UAS mishaps (Tvaryanas, Thompson, & Constable, 2006)
  - Under-utilized autonomy (OSD, 2012)
  - Inadequate support tools and human machine interfaces (HMIs)
  - Work-arounds to compensate

"It feels like **90% of our training involves developing and teaching work-arounds** to get the system to do what we need"
—Vehicle Pilot Trainer, discussing current systems/HMIs

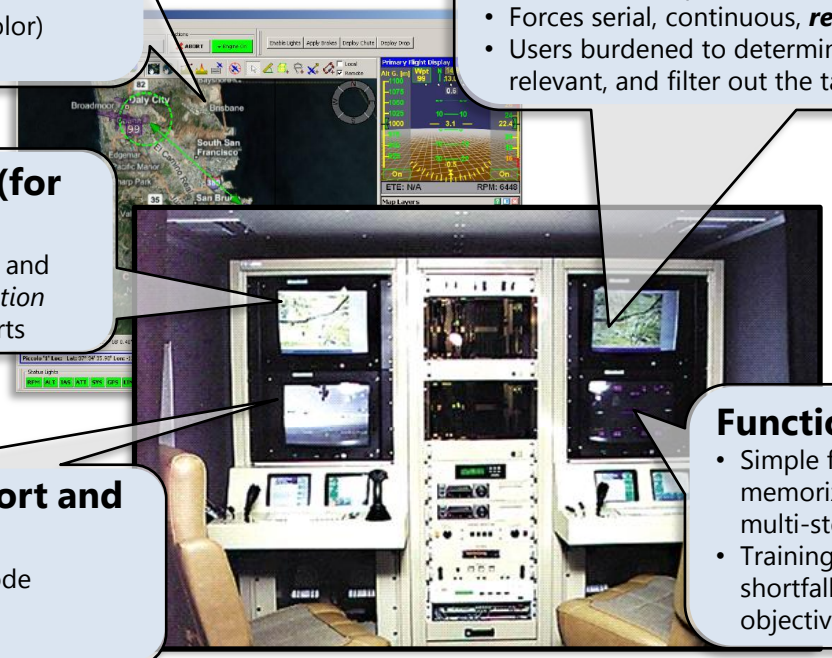
© Pacific Science & Engineering 2013

Support tools and HMIs lagging behind technology

Inconsistencies in coding and meaning across HMIs and platforms
- Cross-platform transfer minimized due to different HMIs and systems for different platforms
- Inconsistent use of visual features (e.g., color) within and across systems

Inadequate attention management support (for *monitor and detect*)
- Poor support for monitoring and comprehension of changes over time, and proactive monitoring
- Forces serial, continuous, ***re***active monitoring stance
- Users burdened to determine and focus on what is task-relevant, and filter out the task-irrelevant

Insufficient decision support (for *assess and decide*)
- User burdened to find, mentally integrate, and transform *data* into decision -evel *information*
- Uninformative and context-***in***sensitive alerts



Lack of automation support and transparency
- Confusing and poorly conveyed mode hierarchy and authority
- Limited insight into automation

Function and task complexity
- Simple functions and tasks require memorization and training of complex, multi-step procedures
- Training focused on compensating for HMI shortfalls detracts from teaching core objectives

Representative Human Machine Interfaces (HMIs)

- **Problems seen today are similar to problems reported in 2004, 2006** (Eaton, Kalita, & Nagy, 2006; Tvaryanas, Thompson, & Constable, 2006; Williams, 2004)
- **Need new approach!**

© Pacific Science & Engineering 2013

Design and domain challenges

- Situation and user population do not yet exist
  - Must evolve traditional methods of analyzing existing work, systems, and users
- Human-automation interaction
  - "Double-edged sword" nature of automation (Bainbridge, 1983)
- System development constraints
  - Technology-centric philosophy
  - Change averse, slow progress and improvements (Tvaryanas, 2012; Williams, 2004)
- Increase in future span of control
  - More information to monitor, but same user cognitive abilities and user "bandwidth"
  - Minimal progress through prior attempts (MAC)

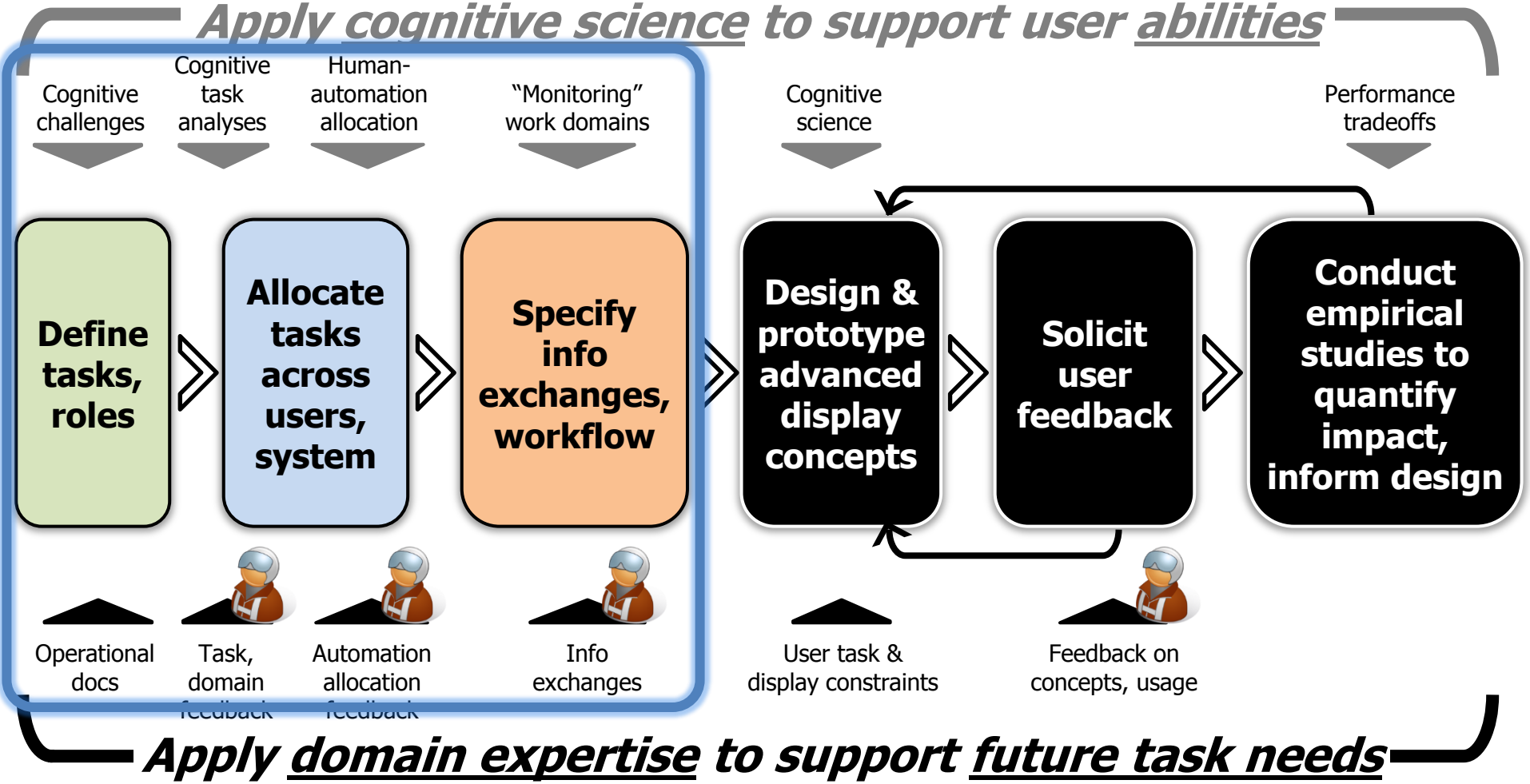
© Pacific Science & Engineering 2013

Design and domain challenges

- Situation and user population do not yet exist
  - *Define core tasks as basis for defining future user task needs*
- Human-automation interaction
  - *Human-centered philosophy, principled method to allocate tasks to humans and autonomy*
- System development constraints
  - *Task-centered to direct focus on users' needs*
  - *Objective basis for selecting HMIs and tools*
- Increase in future span of control
  - *Information presentation and interactions aligned with users' cognitive abilities*

© Pacific Science & Engineering 2013

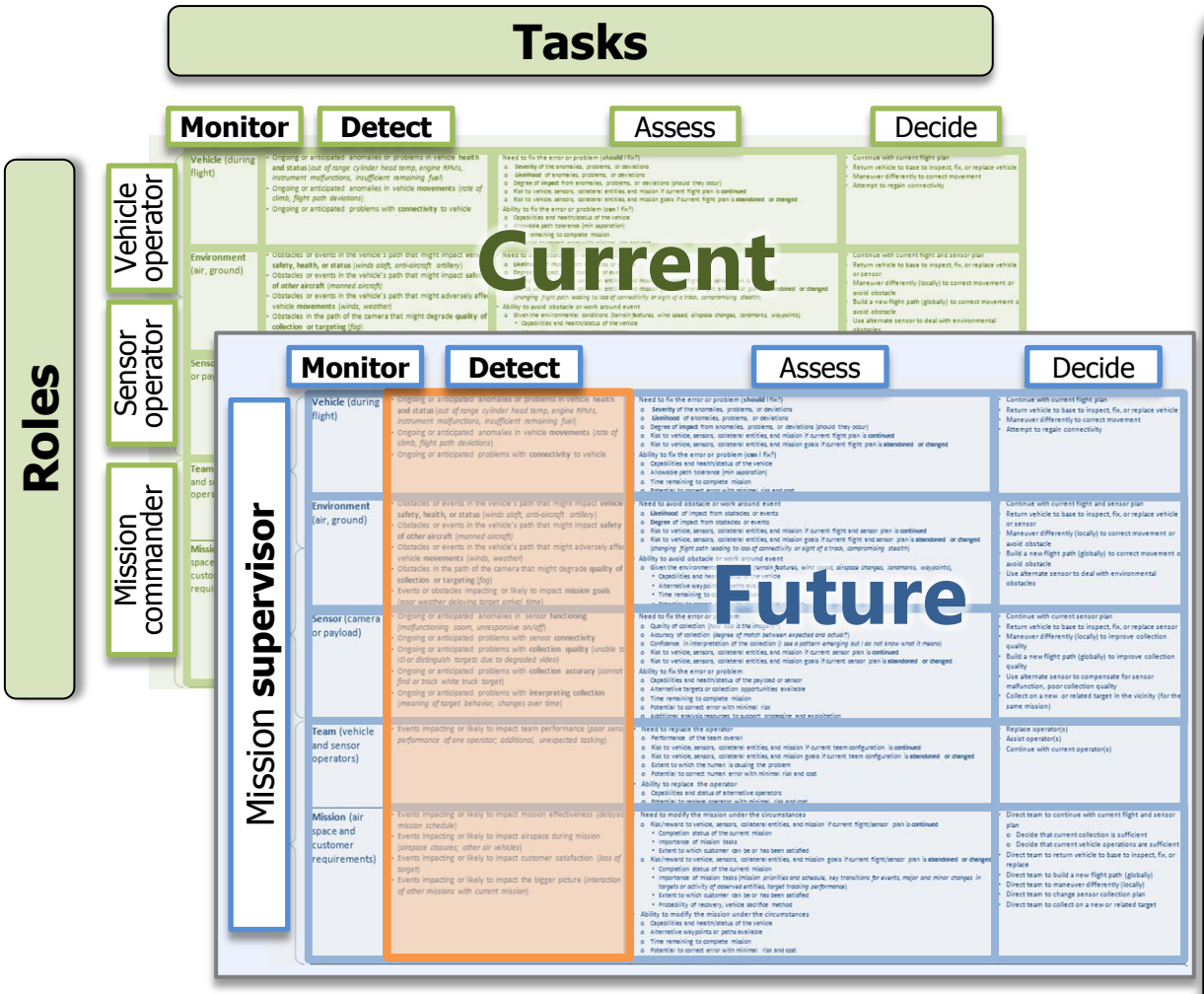
Tailored User-Centered Design (UCD) process



27 military and industry unmanned systems subject matter experts (SMEs)

© Pacific Science & Engineering 2013

Staged SME interview process



Staged task analysis approach

1. **Define and validate core tasks**
2. **Specify allocation of tasks to human and automation for current ("descriptive") and future ("prescriptive") practice**
3. **Specify information exchange between humans and automation for subset of "detect" tasks**

© Pacific Science & Engineering 2013

SME participant characteristics

27 military *and* civilian unmanned system domain experts experienced in:

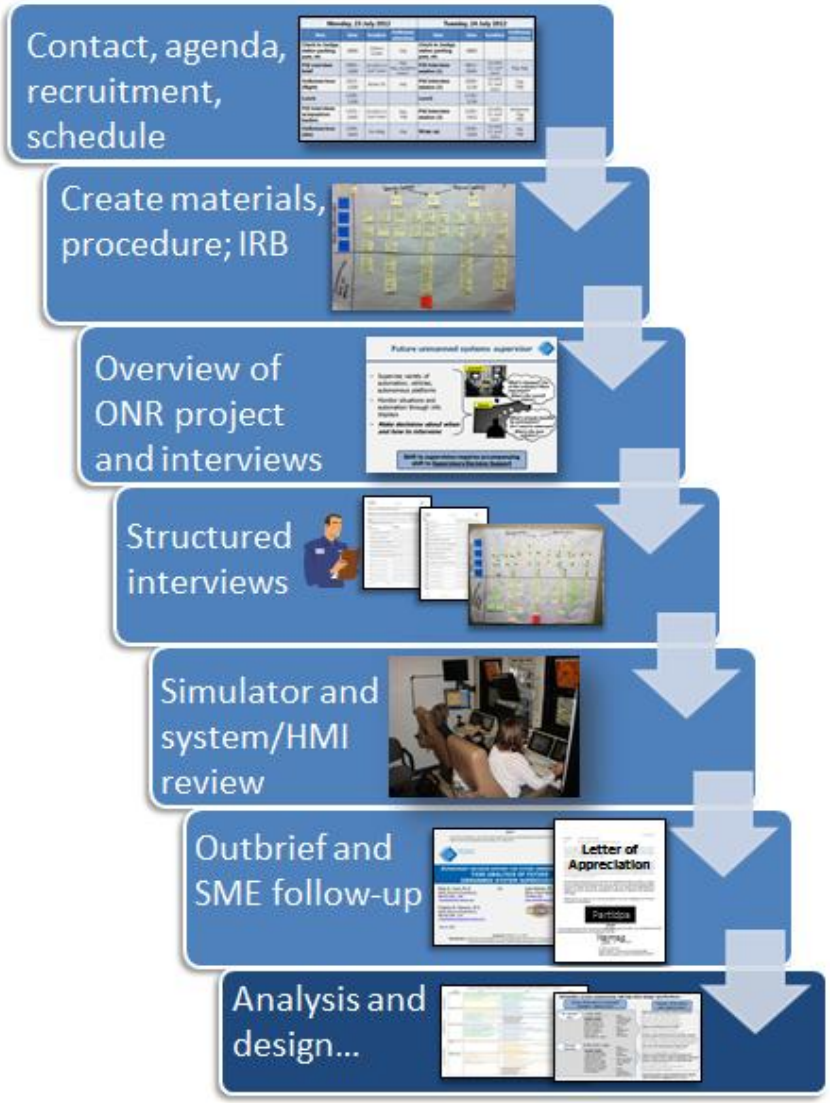
- Vehicle Control, Sensor Control, Mission Command
- Range of unmanned vehicle platforms (DoD UAS Group 1-5)
- Range of missions, from operational tests through theater operations

	Date	Site	Rate & Rank or Civilian	Unmanned Vehicle Role				DOD UAS Group									
								1		2		3		4		5	
				Vehicle	Sensor	MC	Consult	Exp	Yrs	Exp	Yrs	Exp	Yrs	Exp	Yrs	Exp	Yrs
Stage 1	April	Navy exercise	O-5 (CDR) Ret				x										
	May	Military test venue	Capt / 06	x	x	x		Expt	14	Expt	14					Expt	10
	May	Military test venue	Civilian	x	x							Expt	7				
	May	Military test venue	Civilian	x	x	x				Expt	2	Expt	5				
	May	Military test venue	Civilian	x	x	x							7				
	May	Military test venue	Civilian	x		x						Expt	6				
Stage 2	June	Industry UAS	Stan / Eval Instructional Auditor	x	x	x				Expt	4						
	June	Industry UAS	Operations Action Center	x	x					Int	3						
	June	Industry UAS	O2 (former service) / FSR	x	x					Int	2						
	June	Industry UAS	E5 (former) / Field Service rep	x	x					Expt	3.5						
	June	Industry UAS	E6 / Fire Servie Trainer	x	x	x				Int	4						
	June	Industry UAS	E7 (Ret) / Pilot Instructor	x	x	x				Expt	3.5					Expt	4
	June	Industry UAS	UAS Instructor / Operator	x	x					Expt	2.25						
	June	Industry UAS	Airline Pilot / Training Program Mgr	x	x					Expt	5						
	June	Industry UAS	O-4 (Ret) / Director of Mission Support	x	x	x				Int	1	Expt	2				
	June	Industry UAS	Operator Training Mgr	x	x	x						Expt	7				
	June	Industry UAS	O-4 / Advanced Operations Training	x	x	x				Expt	3					Int	2
	June	Industry UAS	Pilot Instructor	x						Expt	3						
	June	Industry UAS	UAS Pilot Instructor	x						Expt	1.25						
Stage 3	July	AF training	O-4 / Maj	x												Expt	3.5
	July	AF training	O-4 / Maj	x												Expt	5
	July	AF training	Maj	x		x								Expt	2	Expt	2.75
	July	AF training	Maj	x										Expt	4.92		
	July	AF training	TSgt		x									Int	1.33	Expt	3.17
	July	AF training	TSgt		x											Expt	11
	July	AF training	TSgt		x									Expt	2	Expt	2
	July	AF training	SSgt		x									Expt	3	Expt	5
	Total	**27**		**22**	**19**	**11**	**1**	**Avg**	**14.0**	**3.7**		**5.7**		**2.7**		**4.8**	

© Pacific Science & Engineering 2013

Interactive interviews

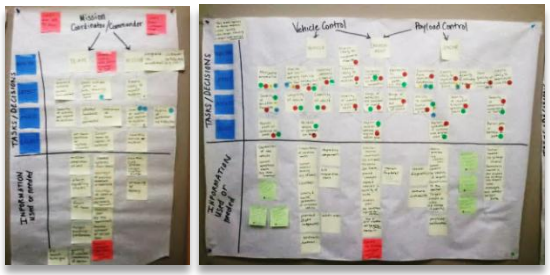
- Draft materials for SMEs to respond to
- SMEs active participants in interviews

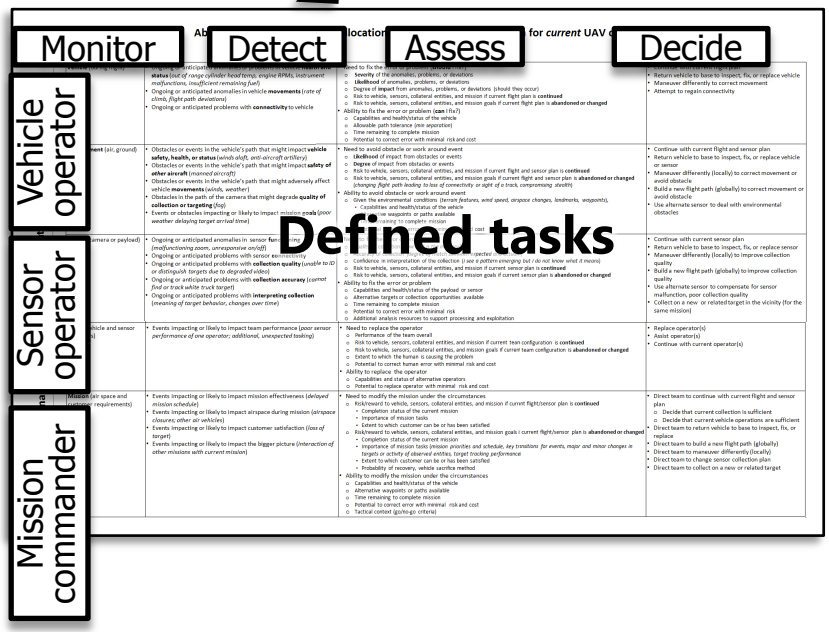


© Pacific Science & Engineering 2013

Stage 1: Defined core tasks in role-task matrix

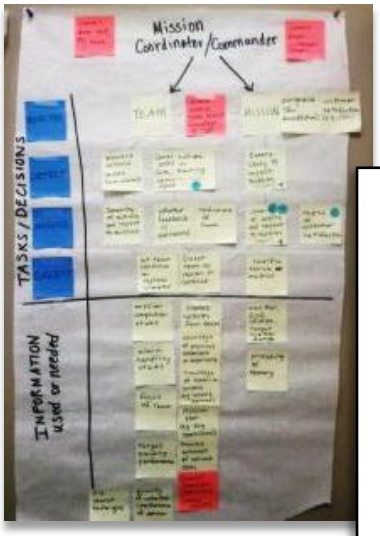
- Drafted role-task matrix for monitoring and problem intervention tasks
- Leveraged from prior task analyses, operational docs and CONOPS (e.g., Cook & Smallman, 2010; Fleet Forces Command, 2008; Gugerty, 2004; Nehme, Crandall, & Cummings, 2007; OSD, 2012; Sibley & Coyne, 2012)
- Tasks
  - **Monitor** (vehicles, environment, sensors, team, mission)
  - **Detect** anomalies or problems
  - **Assess** ability and need to fix problem
  - **Decide** on course of action
- Roles
  - Configuration of users and automation
- Align decision support efforts to task needs
- Reviewed and refined with SME feedback

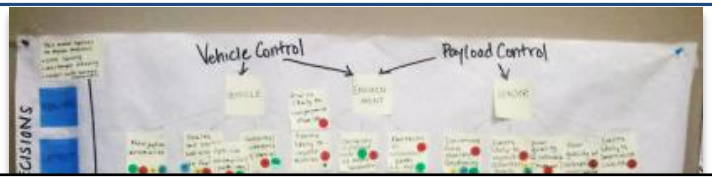




© Pacific Science & Engineering 2013

Stage 1: Defined core tasks in role-task matrix





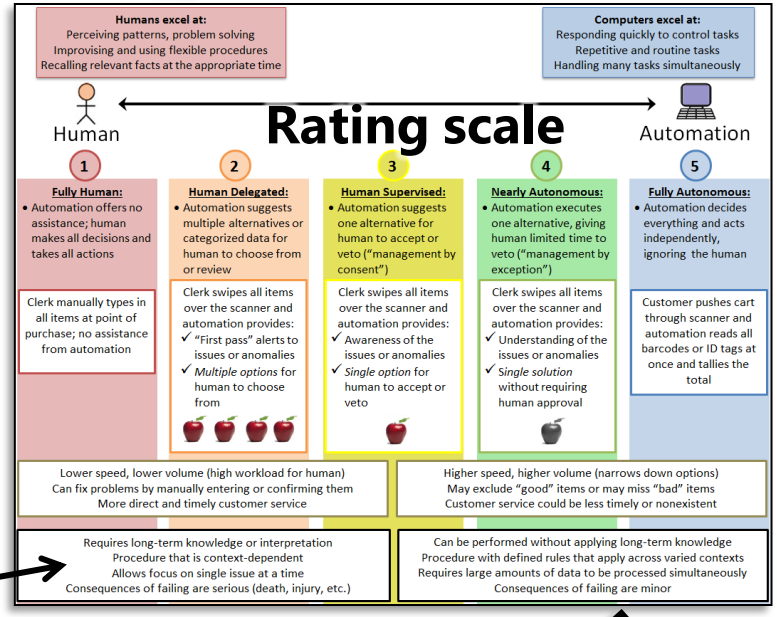
Abstracted tasks and current allocation to humans and automation for *current* UAV operations

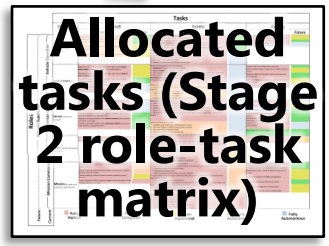
	Monitor	Detect	Assess	Decide
Vehicle Operators	**Vehicle** (during flight)	• Ongoing or anticipated anomalies or problems in vehicle **health and status** (*out of range cylinder head temp, engine RPMs, instrument malfunctions, insufficient remaining fuel*) • Ongoing or anticipated anomalies in vehicle **movements** (*rate of climb, flight path deviations*) • Ongoing or anticipated problems with **connectivity** to vehicle	• Need to fix the error or problem (**should** I fix?) o **Severity** of the anomalies, problems, or deviations o **Likelihood** of anomalies, problems, or deviations o Degree of **impact** from anomalies, problems, or deviations (should they occur) o Risk to vehicle, sensors, collateral entities, and mission if current flight plan is **continued** o Risk to vehicle, sensors, collateral entities, and mission goals if current flight plan is **abandoned or changed** • Ability to fix the error or problem (**can** I fix?) o Capabilities and health/status of the vehicle o Allowable path tolerance (*min separation*) o Time remaining to complete mission o Potential to correct error with minimal risk and cost	• Continue with current flight plan • Return vehicle to base to inspect, fix, or replace vehicle • Maneuver differently to correct movement • Attempt to regain connectivity
Vehicle Operators / Sensor Operators	**Environment** (air, ground)	• Obstacles or events in the vehicle's path that might impact **vehicle safety, health, or status** (*winds aloft, anti-aircraft artillery*) • Obstacles or events in the vehicle's path that might impact **safety of *other* aircraft** (*manned aircraft*) • Obstacles or events in the vehicle's path that might adversely affect vehicle **movements** (*winds, weather*) • Obstacles in the path of the camera that might degrade **quality of collection or targeting** (*fog*) • Events or obstacles impacting or likely to impact **mission goals** (*poor weather delaying target arrival time*)	• Need to avoid obstacle or work around event o **Likelihood** of impact from obstacles or events o **Degree** of impact from obstacles or events o Risk to vehicle, sensors, collateral entities, and mission if current flight and sensor plan is **continued** o Risk to vehicle, sensors, collateral entities, and mission goals if current flight and sensor plan is **abandoned or changed** (*changing flight path leading to loss of connectivity or sight of a track, compromising stealth*) • Ability to avoid obstacle or work around event o Given the environmental conditions (*terrain features, wind speed, airspace changes, landmarks, waypoints*), • Capabilities and health/status of the vehicle • Alternative waypoints or paths available • Time remaining to complete mission • Potential to correct error with minimal risk and cost	• Continue with current flight and sensor plan • Return vehicle to base to inspect, fix, or replace vehicle or sensor • Maneuver differently (locally) to correct movement or avoid obstacle • Build a new flight path (globally) to correct movement or avoid obstacle • Use alternate sensor to deal with environmental obstacles
Sensor Operators	**Sensor** (camera or payload)	• Ongoing or anticipated anomalies in sensor **functioning** (*malfunctioning zoom, unresponsive on/off*) • Ongoing or anticipated problems with sensor **connectivity** • Ongoing or anticipated problems with **collection quality** (*unable to ID or distinguish targets due to degraded video*) • Ongoing or anticipated problems with **collection accuracy** (*cannot find or track white truck target*) • Ongoing or anticipated problems with **interpreting collection** (*meaning of target behavior, changes over time*)	• Need to fix the error or problem o Quality of collection (*how bad is the imagery?*) o Accuracy of collection (*degree of match between expected and actual?*) o Confidence in interpretation of the collection (*I see a pattern emerging but I do not know what it means*) o Risk to vehicle, sensors, collateral entities, and mission if current sensor plan is **continued** o Risk to vehicle, sensors, collateral entities, and mission goals if current sensor plan is **abandoned or changed** • Ability to fix the error or problem o Capabilities and health/status of the payload or sensor o Alternative targets or collection opportunities available o Time remaining to complete mission o Potential to correct error with minimal risk o Additional analysis resources to support processing and exploitation	• Continue with current sensor plan • Return vehicle to base to inspect, fix, or replace sensor • Maneuver differently (locally) to improve collection quality • Build a new flight path (globally) to improve collection quality • Use alternate sensor to compensate for sensor malfunction, poor collection quality • Collect on a new or related target in the vicinity (for the same mission)
Mission Commanders	**Team** (vehicle and sensor operators)	• Events impacting or likely to impact team performance (*poor sensor performance of one operator; additional, unexpected tasking*)	• Need to replace the operator o Performance of the team overall o Risk to vehicle, sensors, collateral entities, and mission if current team configuration is **continued** o Risk to vehicle, sensors, collateral entities, and mission goals if current team configuration is **abandoned or changed** o Extent to which the human is causing the problem o Potential to correct human error with minimal risk and cost • Ability to replace the operator o Capabilities and status of alternative operators o Potential to replace operator with minimal risk and cost	• Replace operator(s) • Assist operator(s) • Continue with current operator(s)
Mission Commanders	**Mission** (air space and customer requirements)	• Events impacting or likely to impact mission effectiveness (*delayed mission schedule*) • Events impacting or likely to impact airspace during mission (*airspace closures; other air vehicles*) • Events impacting or likely to impact customer satisfaction (*loss of target*) • Events impacting or likely to impact the bigger picture (*interaction of other missions with current mission*)	• Need to modify the mission under the circumstances o Risk/reward to vehicle, sensors, collateral entities, and mission if current flight/sensor plan is **continued** • Completion status of the current mission • Importance of mission tasks • Extent to which customer can be or has been satisfied o Risk/reward to vehicle, sensors, collateral entities, and mission goals if current flight/sensor plan is **abandoned or changed** • Completion status of the current mission • Importance of mission tasks (*mission priorities and schedule, key transitions for events, major and minor changes in targets or activity of observed entities, target tracking performance*) • Extent to which customer can be or has been satisfied • Probability of recovery, vehicle sacrifice method • Ability to modify the mission under the circumstances o Capabilities and health/status of the vehicle o Alternative waypoints or paths available o Time remaining to complete mission o Potential to correct error with minimal risk and cost o Tactical context (go/no-go criteria)	• Direct team to continue with current flight and sensor plan o Decide that current collection is sufficient o Decide that current vehicle operations are sufficient • Direct team to return vehicle to base to inspect, fix, or replace • Direct team to build a new flight path (globally) • Direct team to maneuver differently (locally) • Direct team to change sensor collection plan • Direct team to collect on a new or related target

© Pacific Science & Engineering 2013

Stage 2: Specified task allocation

- *SMEs* applied expertise about tasks, specifying how users and automation do/can work jointly to accomplish tasks
  - Novel procedure by adapting method used for system designers to allocate tasks (Parasuraman, Sheridan, & Wickens, 2000)
  - Objective basis
  - Rough guidelines to aid ratings
  - Present (*descriptive*)
  - Future (*prescriptive*)





© Pacific Science & Engineering 2013

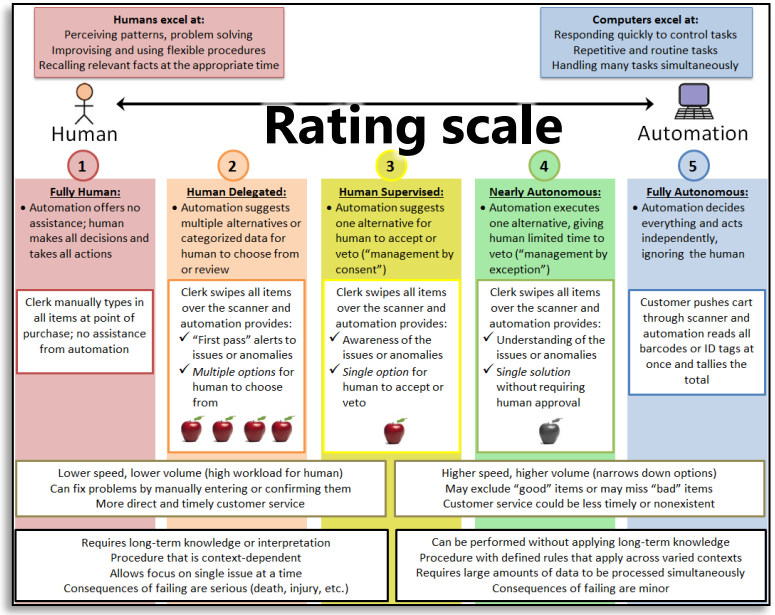
Stage 2: Allocation process

Example task: "Detect ongoing or anticipated anomalies or problems with vehicles' health and status"

- User monitors vehicle health and status and is responsible for detecting all deviations or problems (***1-Fully human***)

For 2 – 5, "detection" automation helps monitor the health and status of vehicles and:

- notifies user of *all* deviations; user must review all notifications and decide which ones are critical and which to dismiss (***2-Human delegated***)
- notifies user of *subset* of most critical deviations, for the user to review and approve or dismiss (similar to "management by consent") (***3-Human supervised***)
- *decides* on the subset of critical deviations; the user can dismiss notifications within a given time period (similar to "management by exception") (***4-Nearly autonomous***)
- decides on the subset of critical deviations; the user has no ability to review or dismiss notifications (***5-Fully autonomous***)



© Pacific Science & Engineering 2013

Stage 2: Specified task allocation

Roles		Tasks: Monitor	Detect – Current	Detect – Future	Assess – Current	Assess – Future	Decide – Current	Decide – Future
Mission Supervisor								
Vehicle Operator		**Vehicle** (health, kinematics)	Ongoing or anticipated anomalies or problems in vehicle **health and status** (*out of range cylinder head temp, engine RPMs, instrument malfunctions, insufficient remaining fuel*) Ongoing or anticipated anomalies in vehicle **movements** (*rate of climb, flight path deviations*) Ongoing or anticipated problems with **connectivity** to vehicle		Need to fix the error or problem (**should** I fix?) o **Severity** of the anomalies, problems, or deviations o **Likelihood** of anomalies, problems, or deviations o Degree of **Impact** from anomalies, problems, or deviations (should they occur) o Risk to vehicle, sensors, collateral entities, and mission if current flight plan is **continued** o Risk to vehicle, sensors, collateral entities, and mission goals if current flight plan is **abandoned or changed** Ability to fix the error or problem (**can** I fix?) o Capabilities and health/status of the vehicle o Allowable path tolerance (min separation) o Time remaining to complete mission o Potential to correct error with minimal risk and cost		Continue with current flight plan Return vehicle to base to inspect, fix, or replace vehicle Maneuver differently to correct movement Attempt to regain connectivity Return to base in event of lost communications	
Vehicle Operator		**Environment** (air, ground)	Obstacles or events in the vehicle's path that might impact **vehicle safety, health, or status** (*winds aloft, anti-aircraft artillery*) Obstacles or events in the vehicle's path that might impact **safety of other aircraft** (*manned aircraft*) Obstacles or events in the vehicle's path that might adversely affect vehicle **movements** (*winds, weather*) Obstacles in the path of the camera that might degrade **quality of collection or targeting** (*fog*) Events or obstacles impacting or likely to impact **mission goals** (*poor weather delaying target arrival time*)		Need to avoid obstacle or work around event o **Likelihood** of impact from obstacles or events o Degree of **Impact** from obstacles or events o Risk to vehicle, sensors, collateral entities, and mission if current flight and sensor plan is **continued** o Risk to vehicle, sensors, collateral entities, and mission goals if current flight and sensor plan is **abandoned or changed** (*changing flight path leading to loss of connectivity or sight of a track, compromising stealth*) Ability to avoid obstacle or work around event o Given the environmental conditions (terrain features, wind speed, airspace changes, landmarks, waypoints), • Capabilities and health/status of the vehicle • Alternative waypoints or paths available • Time remaining to complete mission • Potential to correct error with minimal risk and cost		Continue with current flight and sensor plan Return vehicle to base to inspect, fix, or replace vehicle or sensor Maneuver differently (locally) to correct movement or avoid obstacle Build a new flight path (globally) to correct movement or avoid obstacle Use alternate sensor to deal with environmental obstacles	
Sensor Operator		**Sensor** (camera or payload)	Ongoing or anticipated anomalies in sensor **functioning** (*malfunctioning zoom, unresponsive on/off*) Ongoing or anticipated problems with sensor **connectivity** Ongoing or anticipated problems with **collection quality** (*unable to ID or distinguish targets due to degraded video*) Ongoing or anticipated problems with **collection accuracy** (*cannot find or track white truck target*) Ongoing or anticipated problems with **interpreting collection** (*meaning of target behavior, changes over time*)		Need to fix the error or problem o Quality of collection (how bad is the imagery?) o Accuracy of collection (degree of match between expected and actual?) o Confidence in interpretation of the collection (I see a pattern emerging but I do not know what it means) o Risk to vehicle, sensors, collateral entities, and mission if current sensor plan is continued o Risk to vehicle, sensors, collateral entities, and mission goals if current sensor plan is abandoned or changed Ability to fix the error or problem o Capabilities and health/status of the payload or sensor o Alternative targets or collection opportunities available o Time remaining to complete mission o Potential to correct error with minimal risk o Additional analysis resources to support processing and exploitation		Continue with current sensor plan Return vehicle to base to inspect, fix, or replace sensor Maneuver differently (locally) to improve collection quality Build a new flight path (globally) to improve collection quality Use alternate sensor to compensate for sensor malfunction, poor collection quality Collect on a new or related target in the vicinity (for the same mission) Scan mode set by payload operator or scan continuously	

Future / Current

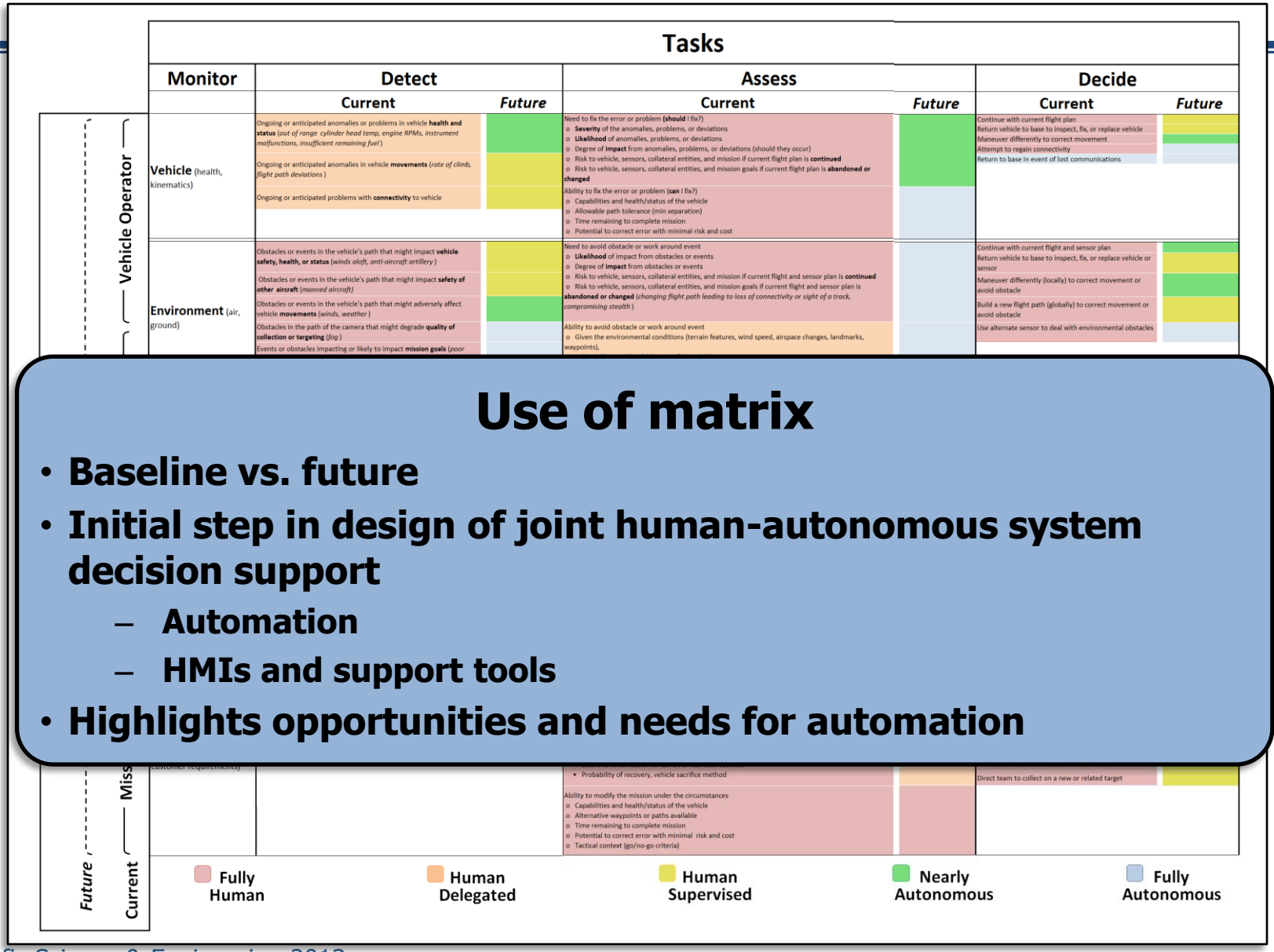
Fully Human | Human Delegated | Human Supervised | Nearly Autonomous | Fully Autonomous

Emergent Patterns

- **Humans heavily involved in most *current* tasks (autonomy under-utilized)**
  - Echoes recent *Role of Autonomy in DoD Systems* OSD report
- **SMEs envision *future* automation helping with "detect" and "assess" for vehicles, sensors, environment**
- ***Relatively* more human involvement reserved for "decide" and mission commander tasks**

© Pacific Science & Engineering 2013

Roadmap for future automation and support tools



		Tasks					
		Monitor	Detect		Assess		Decide	
			Current	Future	Current	Future	Current	Future
Vehicle Operator	Vehicle (health, kinematics)		Ongoing or anticipated anomalies or problems in vehicle **health and status** (*out of range cylinder head temp, engine RPMs, instrument malfunctions, insufficient remaining fuel*) Ongoing or anticipated anomalies in vehicle **movements** (*rate of climb, flight path deviations*) Ongoing or anticipated problems with **connectivity** to vehicle		Need to fix the error or problem (**should** I fix?) o **Severity** of the anomalies, problems, or deviations o **Likelihood** of anomalies, problems, or deviations o Degree of **impact** from anomalies, problems, or deviations (should they occur) o Risk to vehicle, sensors, collateral entities, and mission if current flight plan is **continued** o Risk to vehicle, sensors, collateral entities, and mission goals if current flight plan is **abandoned or changed** Ability to fix the error or problem (**can** I fix?) o Capabilities and health/status of the vehicle o Allowable path tolerance (min separation) o Time remaining to complete mission o Potential to correct error with minimal risk and cost		Continue with current flight plan Return vehicle to base to inspect, fix, or replace vehicle Maneuver differently to correct movement Attempt to regain connectivity Return to base in event of lost communications	
	Environment (air, ground)		Obstacles or events in the vehicle's path that might impact **vehicle safety, health, or status** (*winds aloft, anti-aircraft artillery*) Obstacles or events in the vehicle's path that might impact **safety of other aircraft** (*manned aircraft*) Obstacles or events in the vehicle's path that might adversely affect vehicle **movements** (*winds, weather*) Obstacles in the path of the camera that might degrade **quality of collection or targeting** (*fog*) Events or obstacles impacting or likely to impact **mission goals** (*poor*		Need to avoid obstacle or work around event o **Likelihood** of impact from obstacles or events o Degree of **impact** from obstacles or events o Risk to vehicle, sensors, collateral entities, and mission if current flight and sensor plan is **continued** o Risk to vehicle, sensors, collateral entities, and mission goals if current flight and sensor plan is **abandoned or changed** (*changing flight path leading to loss of connectivity or sight of a track, compromising stealth*) Ability to avoid obstacle or work around event o Given the environmental conditions (terrain features, wind speed, airspace changes, landmarks, waypoints),		Continue with current flight and sensor plan Return vehicle to base to inspect, fix, or replace vehicle or sensor Maneuver differently (locally) to correct movement or avoid obstacle Build a new flight path (globally) to correct movement or avoid obstacle Use alternate sensor to deal with environmental obstacles	
Future / Current	Miss				• Probability of recovery, vehicle sacrifice method Ability to modify the mission under the circumstances o Capabilities and health/status of the vehicle o Alternative waypoints or paths available o Time remaining to complete mission o Potential to correct error with minimal risk and cost o Tactical context (go/no-go criteria)		Direct team to collect on a new or related target	

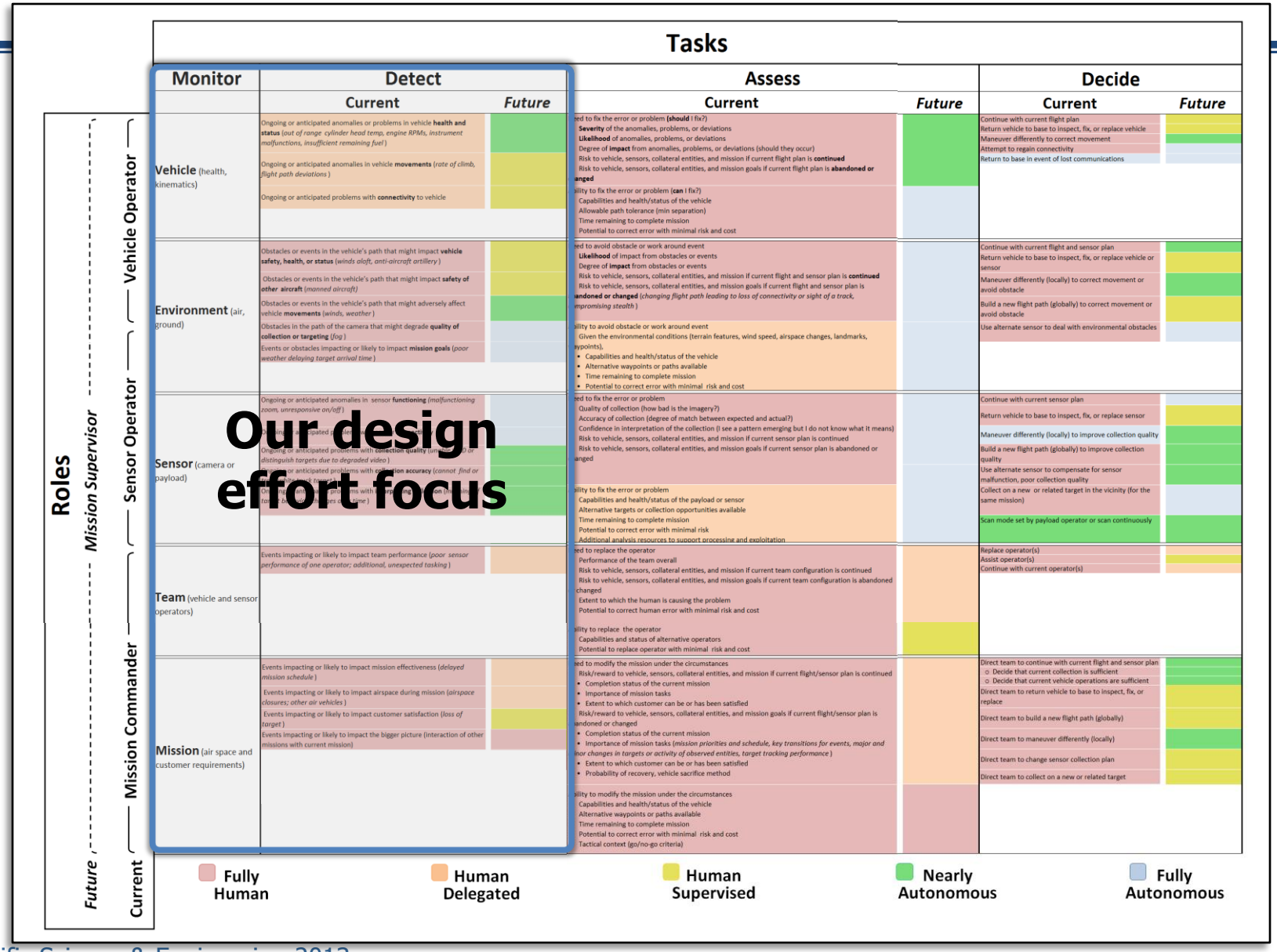
Fully Human | Human Delegated | Human Supervised | Nearly Autonomous | Fully Autonomous

Use of matrix

- **Baseline vs. future**
- **Initial step in design of joint human-autonomous system decision support**
  - **Automation**
  - **HMIs and support tools**
- **Highlights opportunities and needs for automation**

© Pacific Science & Engineering 2013

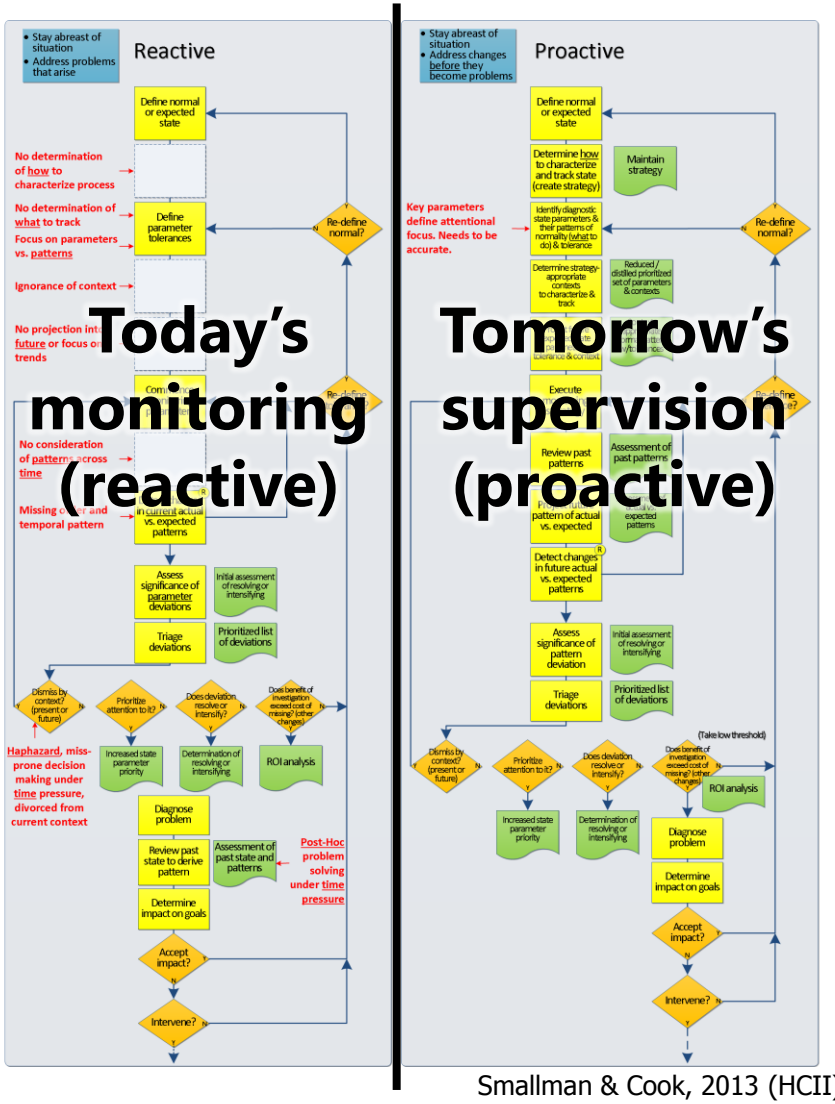
Stage 2: Specified task allocation



© Pacific Science & Engineering 2013

Stage 3: Characterized workflow and information exchanges

Today's support tools and HMIs induce reactivity, as users monitor *real-time* values, and respond to alerts.



Smallman & Cook, 2013 (HCII)

Future tools and HMIs should support proactivity and mission-level ***supervision***.

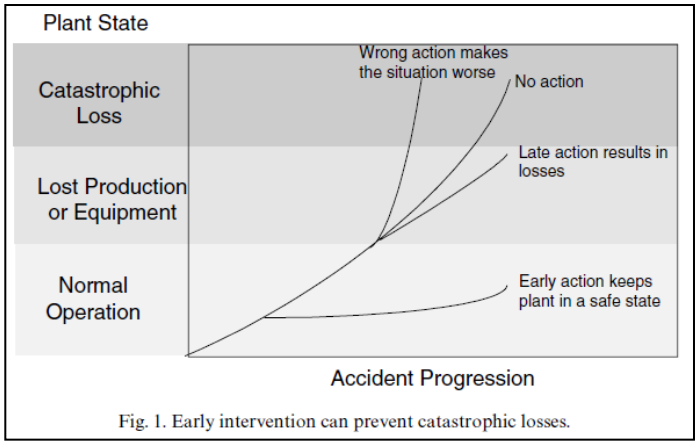


Fig. 1. Early intervention can prevent catastrophic losses.

Importance of proactivity, and decreasing effectiveness as problem intervention is delayed (Burns, 2006)

© Pacific Science & Engineering 2013

Stage 3: Defined information exchanges

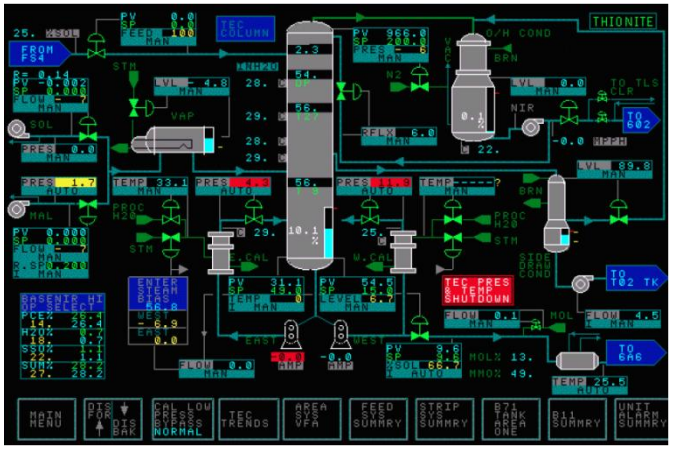
- For subset of detection tasks, defined information inputs and outputs for future problem/anomaly detection automation
- Reviewed and refined with 8 SMEs
- Systematic process for SMEs to indicate *information availability* and *information detail* needed to effectively supervise automation
  - ex: immediate access to general categories of problem types and severity
  - ex: on-demand access to precise values for ongoing and expected problem duration
- HMI design concepts in forthcoming conference paper
  - Smallman, H.S., & Cook, M.B. (2013). Proactive supervisory decision support from trend-based monitoring of autonomous and automated systems: a tale of two domains. *HCI International (HCII)* 2013 Invited Paper, Las Vegas, NV, 21-26 July 2013.
  - Novel trend-based display metaphors for command and control of autonomous systems

© Pacific Science & Engineering 2013

Lessons learned across domains

Smallman, H.S., & Cook, M.B. (2013). Proactive supervisory decision support from trend-based monitoring of autonomous and automated systems: a tale of two domains. *HCI International (HCII)* 2013 Invited Paper, Las Vegas, NV, 21-26 July 2013.

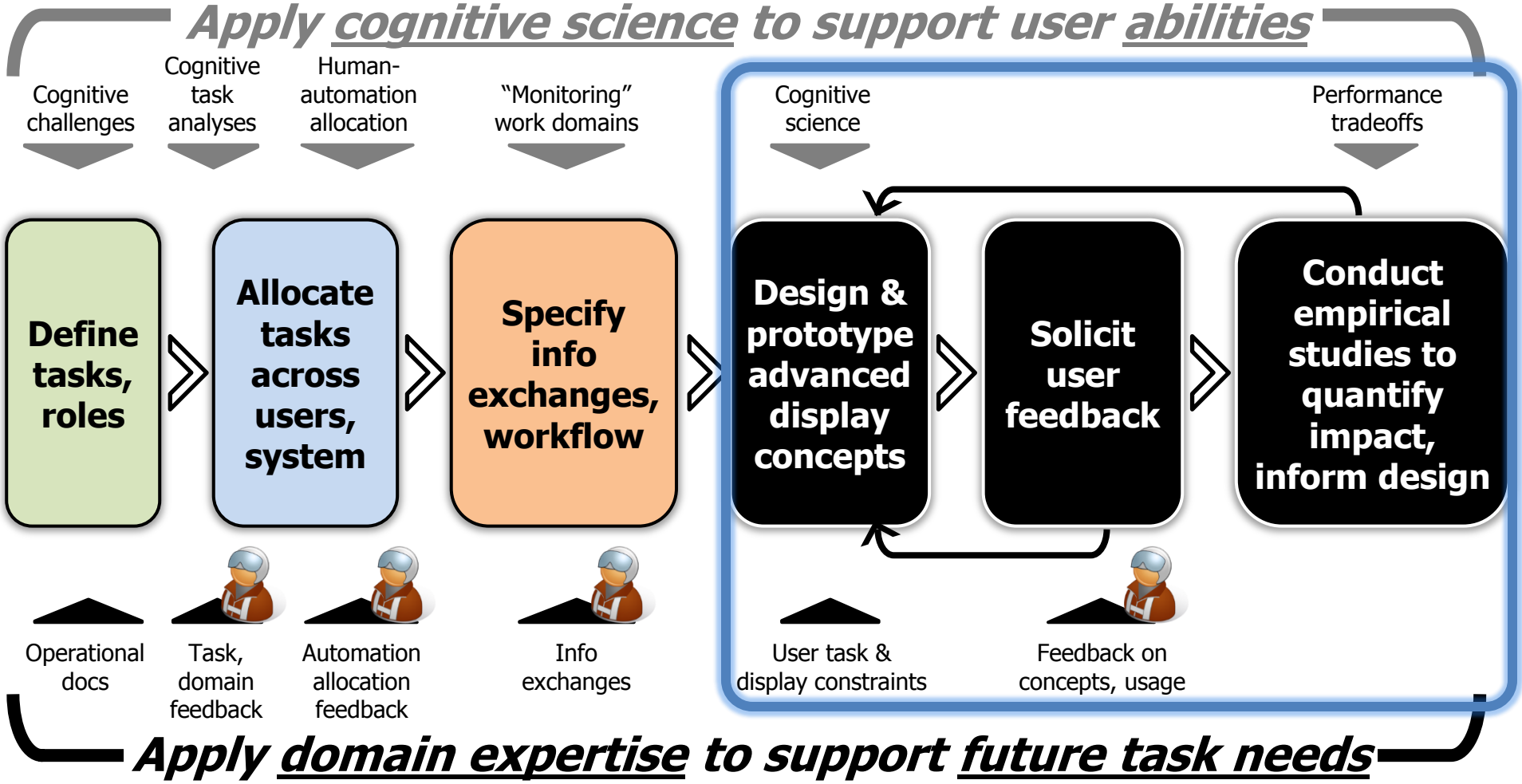
Industrial process control



Unmanned systems

© Pacific Science & Engineering 2013

Next steps



27 military and industry unmanned systems subject matter experts (SMEs)

© Pacific Science & Engineering 2013

Summary and application

- Abstracted and defined future autonomous system supervision tasks
- Descriptive and prescriptive allocation of tasks to humans and automation
  - Novel, systematic approach for involving SMEs in allocation decisions
- Developed organizing task-centered framework for future decision support
  - Design
  - Assessment
- Stimulates design of new C2 metaphors
  - Novel trend-based display metaphors for command and control of autonomous systems (Smallman & Cook, 2013)
  - Starting point and guidance for research and design community

© Pacific Science & Engineering 2013

References cited

Bainbridge, L. (1983). Ironies of automation. *Automatica*, 19, 775–779.

Bloomberg, 17 June 2012. Drones most accident-prone U.S. Air Force craft. http://www.bloomberg.com/news/2012-06-18/drones-most-accident-prone-u-s-air-force-craft-bgov-barometer.html.

Cook, M. B. & Smallman, H. S. (2010). When plans change: Task analysis and taxonomy of 3-D situation awareness challenges of UAV replanning. In *Proceedings of the 15th International Command and Control Research and Technology Symposium.* Santa Monica, CA.

Department of Defense (2009). *FY2009-2034 Unmanned Systems Integrated Roadmap*. Washington, DC: U.S. Department of Defense.

Department of Defense, Defense Science Board. (2012). *The Role of Autonomy in DoD Systems*. Task Force Report, July, 2012.

Eaton, G., Kalita, S., & Nagy, J. (2006). *U.S. Air Force unmanned aircraft systems performance analyses: Predator pilot and sensor operator front end assessment (FEA) and report*. Wright-Patterson AFB, OH: Survivability/Vulnerability Information Analysis Center.

Fleet Forces Command (2008). *Fleet Unmanned Aircraft Systems Concept of Operations*. Naval Network Warfare Command, 31 July 2008, Norfolk, VA.

Gugerty, L. (2004). Using cognitive task analysis to design multiple synthetic tasks for uninhabited aerial vehicle operation. In S. Schiflett, L. Elliott, E. Salas & M. Coovert (Eds.), *Scaled Worlds: Development, Validation, and Application*, (pp. 240-262). London: Ashgate Publishers.

Layton, C., Smith, P.J., & McCoy, E. (1994). Design of a cooperative problem-solving system for en-route flight planning: an empirical evaluation. *Human Factors*, 36, 94-119.

Nehme, C.E., Crandall, J.W., & Cummings, M.L. (2007). An Operator Function Taxonomy for Unmanned Aerial Vehicle Missions. In *Proceedings of the 12th International Command and Control Research and Technology Symposium.* Newport, RI.

Office of the Under Secretary of Defense. (2012). *Unmanned Aircraft Systems (UAS) Ground Control Station (GCS) Human-Machine Interface (HMI) Development and Standardization Guide*.

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans, 30* (3), 286-297.

Sibley, C. & Coyne, J. (2012). *Fort Pickett trip report*. Naval Research Laboratory Technical Report. Washington, DC.

Smallman, H.S., & Cook, M.B. (2013). Proactive supervisory decision support from trend-based monitoring of autonomous and automated systems: a tale of two domains. *HCI International (HCII)* 2013 Invited Paper, Las Vegas, NV, 21-26 July 2013.

Tvaryanas, A. (2012). Human Systems Integration: Focusing on the Means. *US Navy Aerospace Experimental Psychologist Society Call Signs*, 3(2), Winter, 2012, (pp. 2-4).

Tvaryanas, A. P., Thompson, W. T., & Constable, S. H. (2006). Human factors in remotely piloted aircraft operations: HFACS analysis of 221 mishaps over 10 years. *Aviation, Space, and Environmental Medicine*, 77(7), 724-732.

Williams, K. W. (2004). A summary of unmanned aircraft accident/incident data: Human factors implications. Washington, DC: U.S. Department of Transportation, Federal Aviation Administration, Office of Aerospace Medicine. Technical Report Publication No. DOT/FAA/AM-04/24.

© Pacific Science & Engineering 2013

Questions?
Thank you!

Contacts

Maia B. Cook
maiacook@pacific-science.com

Harvey S. Smallman
smallman@pacific-science.com

Pacific Science & Engineering Group
9180 Brown Deer Road
San Diego, CA 92121
(858) 535-1661

The views expressed are those of the authors and do not reflect the official policy or position of the Office of Naval Research, Department of Defense, or the US Government.

© Pacific Science & Engineering 2013