EDWARD P. FITTS DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

NC STATE UNIVERSITY

Utility of Automation Function Transparency and Usability in Supervisory Control

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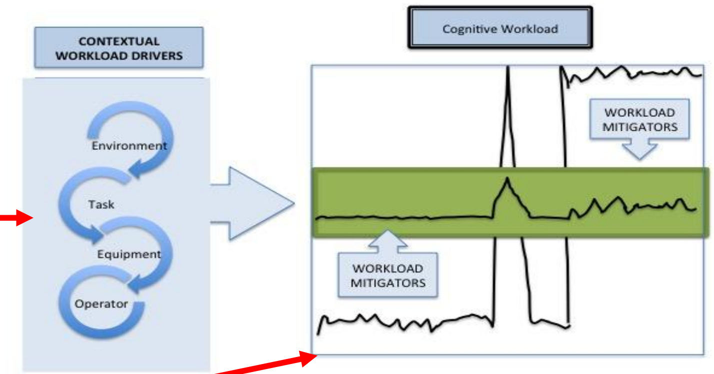
“Unmanned” Systems Research

- Recently completed multi-year **project** with NASA **on unmanned systems interface design and human workload** (NNX16AB23A)
- **Primary** human-automation interaction (HAI) **research need in “unmanned” systems is to manage operator workload in monitoring and control of automation**...
- **Specific research tasks** to address need:
  - **Identify workload “drivers”**
  - **Identify workload “mediators”**
  - **Develop model of** operator **workload**
  - **Develop systematic and objective interface usability analysis tool**
    - Accounting for range of unmanned system interface design principles
  - **Experimental analysis of how interface design deviations from standards/guidelines may increase workload**, reduce knowledge of system states and performance, etc. ← ***Focus of present study***

Progress on Workload Modeling

- Developed **new conceptual framework of cognitive workload in unmanned systems:**
  - **Identified classes of workload drivers**
  - **Identified mitigators** in complex systems **(e.g., automation, interfaces, teamwork)**
  - **Considered "overload", "underload" and mode transition events for classifying drivers and controls.**
  - **Surveyed existing UAV, UUV and UGV technologies to domain constraints on system operation and associated workload issues**



(Hooey, Kaber, Adams et al., 2018; *THMS*)

Created taxonomy of drivers and mediators with projection of impacts on performance

Workload Drivers	Range	UAV	UGV	UUV	Workload Impact
Visibility	High	Clear visibility / Visual Meteorological Conditions Day light	Clear visibility, No precipitation, Day light, absence of shadows, obstructions	Clear water Shallow water	Negligible
	Variable	Patchy fog, clouds	Fog, glare, shadows, sunset/sunrise		Temporary spike
	Low	Instrument Meteorological Conditions Fog/cloud, Darkness, Particulates, rain, hail,	Fog, Darkness, Brightness, Dust / particulates, rain, hail, Positive obstacles (obstruct line of sight - Buildings, boulders, vegetation) Negative Obstacles (holes, ditches, cliffs, canyons, Graded/sloped terrain,	Darkness, Turbidity	Increase
Complexity	Low	High altitude, Over water / Oceanic Unpopulated (air	Arid, barren, desert terrain Stable surface	Submerged, Oceanic	Underload / potential for

Progress on Interface Analysis Tool

- **Developed unmanned aerial vehicle (UAV) interface evaluation tool**

  (Zhang et al., 2016; *IEEE SMC Conf.*)

  - **Conducted survey of UAV usability analysis literature** (e.g., Fuchs et al., 2014; Fong & Thorpe, 2001).
  - **Identified existing ergonomics guidelines for supervisory control interfaces** (GEDIS; Ponsa et al., 2007; Lorite et al., 2013).
  - **Conducted comprehensive survey of existing guidelines relevant to UAV systems** (HFDS; NASA-STD-3000; NORSOK; NUREG 0700; UAS_GCS_HMI).
  - **Integrated supervisory control and UAV interface guidelines in new** enhanced **usability analysis method (see next slide)**:
    - Tool applied to interface prototypes to identify deviation of functional and usability features from "optimal" design, based on guidelines/standards.

New UAV Interface Evaluation ("M-GEDIS") Tool

- **Nine interface evaluation worksheets (addressing major design features)**
- **Analyst identifies conformance / non-conformance with criteria.**
  - ~300 criteria requiring novice ~2.5 hrs. to apply
  - **View videos of operator use of interfaces**
- Workbook **calculates percentage of "non-conformance" across all functional and usability features** of interface.
- **Thresholds for design acceptance or remediation identified in literature**
  - **e.g., Lorite et al. (2013) → 80% of supervisory control display guidelines met = no further revision**.

M-GEDIS-UAV-GLOBAL

This sheet provides a global evaluation of the interface under inspection.
Please refer to the related worksheets for indicator evaluations.
Once evaluations of each subindicator are complete, the workbook will automatically calculate the global interface score.

Indicators	Score
Display Layout (DL)	0%
Information Presentation (IP)	0%
Color (C)	0%
Text (T)	0%
Map and Navigation (MN)	0%
Status and Devices (SD)	0%
Data Entry Commond (DEC)	0%
Alarm (A)	0%
Physical Control (PC)	0%
Global Evaluation Score	**0%**

M-GEDIS-UAV-DL

Indicator: Display Layout (DL)
Score: 0%

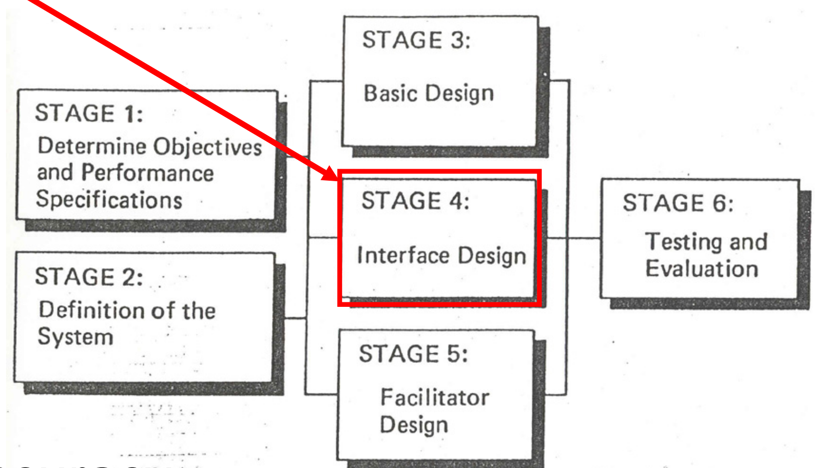
Enter "1" under the "Conformance" column if the interface conforms to the specific design criterion. Enter "NA" if the criteria is not applicable.
If all inputs for a subindicator are "NA", enter "NA" for the "Subindicator score".

Subindicator score	Subindicators	Conformance	ID	Criteria related to this subindicator	Reference
0%	Screen Location (SL)	0	SL1	Displays are readable for users in comfortable positions.	HFDS 5.1.2.1
		0	SL2	Displays are located directly in front of the user.	HFDS 5.1.2.3
		0	SL3	The top of the display is below eye level.	HFDS 5.1.2.4
		0	SL4	The angle between line of sight and the display is less than 30° and avoids excessive operator head tilt.	HFDS 5.1.2.6-7; NASA-STD-3000 9.2.3.2.2
		0	SL5	Critical displays are located within the central 30° of field-of-view.	HFDS 5.1.2.10; NASA-STD-3000 9.2.3.2.4
		0	SL6	The line of sight from the viewer's eyes to the center of the screen is between 10° and 30° below horizontal.	HFDS 5.1.2.5; Ahlstrom & Longo, 2003
0%	Readibility (R)	0	R1	Text and screens are readable and legible without special equipment.	HFDS 5.1.2.2
		0	R2	The viewing distance from the user's eye to the display and control apparatus is between 330 mm (13 in) and 635 mm (25 in). If viewing periods are short or dim signals must be detected, the minimum viewing distance can be 250 mm (10 in).	HFDS 5.1.2.12; HFDS 5.1.2.13; NASA-STD-300 9.2.4.2.2
		0	R3	Users are able to adjust the display viewing distance.	HFDS 5.1.2.16
		0	R4	Dynamic numeric data refresh rates are greater than 0.5 seconds.	HFDS 8.5.1; Wickens, 1992 (based on STSS)
		0	R5	When appropriate, the application provides users the capability to temporarily stop and then resume updating of automatically changing information.	HFDS 8.5.1; Wickens, 1992 (based on STSS)
0%	Information Density (ID)	0	ID1	Overall display density is less than 50%.	NUREG 0700: 1.5-8; HFDS 8.1.1.3
		0	ID2	For text displays, screen density (the ratio of characters to blank spaces) is less than 60%.	NUREG 0700: 1.5-8; HFDS 8.1.1.3
0%	Controls (Ct)	0	Ct1	There are less than 20 digital controls (buttons, etc.) simultaneously displayed on the interface.	JAUS HMI 3.1
		0	Ct2	Digital controls occupy a separate space from any graphical viewport (e.g., active map, imagery, etc.)	JAUS HMI 3.1
		0	Ct3	All emergency action controls are properly marked and readable.	MIL-STD-1472
0%	Menu Structure (MS)	0	MS1	The interface provide an appropriate maximum number of options for different types of graphical controls: (a) Radio buttons: 1-6 options; (b) Static Menus: 3-10 options; (c) Menu Bars: < 10 options; and (d) Scrolling Menus: >10 options.	HFDS 8.7.5.1; HFDS 8.7.5.3.4; HFDS 8.7.5.7.4;
		0	MS2	The number of selections required to reach the desired option in complex menus is no more than 4 steps.	UAS_GCS_HMI 3.2.2.4
		0	MS3	When a user selects a menu option and no computer response is immediately observable, the software provides some other acknowledgment of the selection.	HFDS 8.7.5.3.9
		0	MS4	Menu options are presented in a single vertical column, aligned and left justified (exception: menu bars).	HFDS 8.7.5.6
		0	MS5	Destructive commands (e.g., delete, exit) are placed at the bottom of menus.	HFDS 8.7.5.6
		0	MS6	Options for opposing actions (e.g., save and delete) are not placed adjacent to each other.	HFDS 8.7.5.6
		0	MS7	Primary windows' menu bars extend the full width of the primary window.	HFDS 8.7.5.7.2
		0	MS8	System menus include the following options: end a session, review system status, define user preferences, manage alerts, and change a password.	HFDS 8.7.5.8
0%	Windows (W)	0	W1	Users are able to display and select separate windows on a single screen without obstruction of information on other windows.	HFDS 8.14.1
		0	W2	When using an overlapping window structure, the application presents icons or text-map indicators of all open windows in order to allow users to easily identify open (and hidden) windows.	HFDS 8.14.7
		0	W3	Users are permitted to suppress displayed data that is not required for a task at hand.	HFDS 8.4.1
		0	W4	When the display of information is temporarily suppressed, an indication of this suppression is provided on the display.	HFDS 8.4.1

Outstanding Issues with Interface Evaluation Tool

- **Some existing design guidelines conflict with each other** (e.g., which controls should be located in primary visual field)
- **No detailed standardized process for translation of design guidelines to actual interface features**
- **Guidelines are organized according to major design features of systems** (e.g., "maps and navigation", "alarms") **but not according to human performance issues** / criteria:
  - Promote vigilance and system state awareness
  - Reduce workload
  - Promote task processing speed and accuracy

  (Which guidelines should be applied and when?)

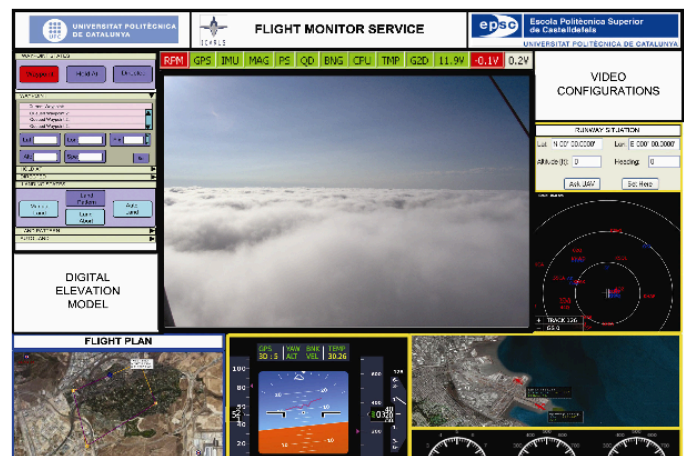


- **Little data exists on relative impact of specific design** concepts / **guidelines on performance and operator workload**
  - Which guidelines are most iimpactful for certain human responses?

Objectives of Present Study

(Extension of work for NASA.)

1. **Identify interface design concept targeted at human performance** issues…**with associated design principles**
2. **Translate specific design principles to actual unmanned system interface design features**
3. **Assess relative utility of application of design principles** on human performance outcomes **in supervisory control of "unmanned" system**:
   - Operator workload
   - Operator dynamic system knowledge
   - Operator task performance



4. **Identify which design principles should be used, and when, for greatest impact on workload, etc.**

Concept of "Automation Transparency"

- **Literature search** on UAV interface design guidelines **revealed design concept ("transparency"; Chen et al., 2014) for ameliorating "pitfalls" of automation** in complex human systems…
  - **"Clumsy automation" design increasing monitoring workload** beyond nominal task workload (Wiener & Currie, 1980)
  - **"Strong and silent automation" absent of feedback and leading to mode awareness issues** for operators (Sarter & Woods, 1994)

- **Definition of automation transparency**…
  - **Quality of interface to afford** users with **comprehension of automation states, current performance information, "reasoning", and intentions** / future plans (Chen et al., 2014)

Some General Principles of Transparency

- Degani et al. (1999) – **automation should alert operators of different modes of operation** and "decisions" in real-time
- Lyons (2013) – **automation should provide rationales for courses of action**; human should know why system is doing what
- DeVisser et al. (2014) – **automation interface** display cues **should instill operator trust in system** and support appropriate trust calibration **by…**
  – e.g., **presenting uncertainty information** on system states and **highlighting automation errors** (Masalonis & Parasuraman, 2003)

- Observation:
  – **Design principles organized around specific construct** (transparency) **and directed at specific human performance issues** (loss of "situation awareness" (SA), vigilance decrements, miscalibration of trust)

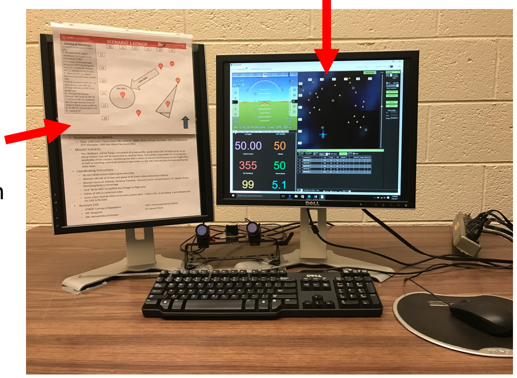
Principles Translated to Design Guidelines

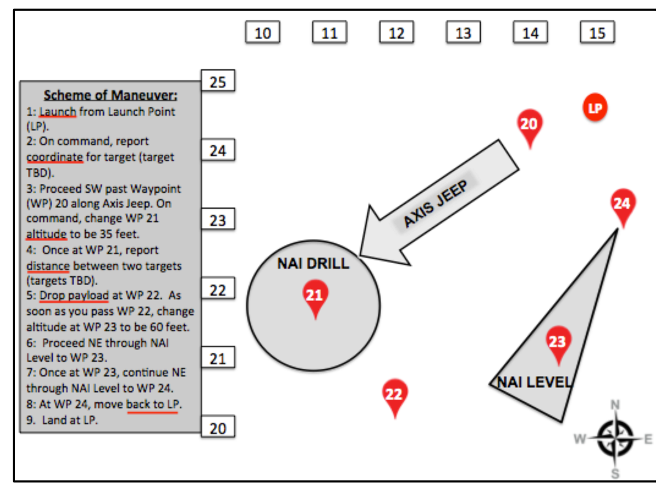
- Kilgore & Voshell (2014):
  - **Ensure perceptual accessibility of task critical info**
    - Present key system variables; use visual coding of map features
  - **Present information in context**; e.g., system **parameter values** should be **presented against** frame/range of expected or **nominal values**
  - Manage user attention by **highlighting critical system process info** (and de-emphasize less critical info)
- Selkowitz et al. (2017):
  - **Use metaphor-based presentation of info** (similar to info in context)
  - **Use integrated displays** – multiple pieces of info in single graphic (e.g., icon, glyph)
  - **Use pre-attentive cueing of stimuli** - shading, color, or size coding **to promote** effortless and **quick processing**

    (Their **experiments revealed features to improve SA and trust with no additional workload "cost".)**

Present Study Method

1. **Translated transparency design guidelines to specific UAV supervisory control interface feature** manipulations
2. **Prototyped multiple interfaces representing different degrees of conformance with concept** of transparency
3. **Conducted** UAV control **experiment to assess utility of concept and design guidelines for supporting operator performance, system awareness, and workload.**
   - **Simulation study similar to mission rehearsal**
   - **Surveillance operation with common vehicle control tasks:**
     - Object coordinate identification
     - Target distance estimation
     - Monitoring system status parameters
     - Prioritizing in-flight warnings and alarms
     - Resolving warnings and alarms
   - **Operators executed "scheme of maneuver"** (**SOM**; sequence of actions) **with different** interface designs and task **event rates**





Confederate co-pilot gave verbal cues for task performance

Interface is “Automation Presentation”

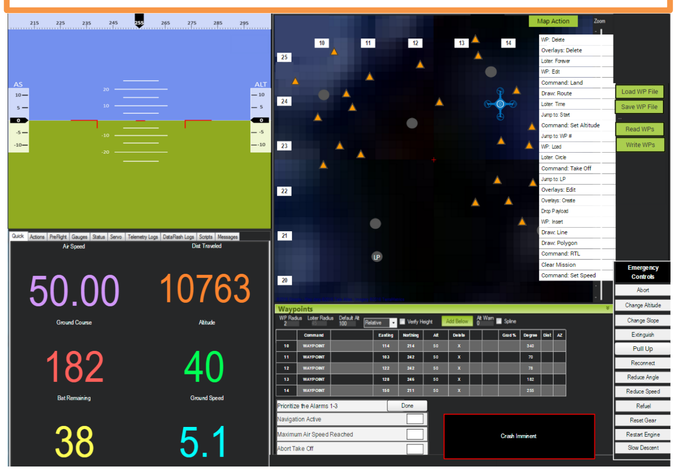
- **Started with ArduPilot Mission Planner (MP) interface** – commercially available UAV ground control station (GCS) interface
- Designed and **prototyped three variations on MP**
- **Three human factors experts evaluated each design for conformance with Molich & Nielsen’s (1991) usability heuristics**
  - Preliminary validation of transparency manipulations – **Application of transparency principles led to differences in usability.**

Baseline Interface

- **Represented current GCS technology**
- **Maintained** most **original MP features**
- **Some automation interface features added for certain control tasks**
- **Usability heuristics: 67 % satisfaction**

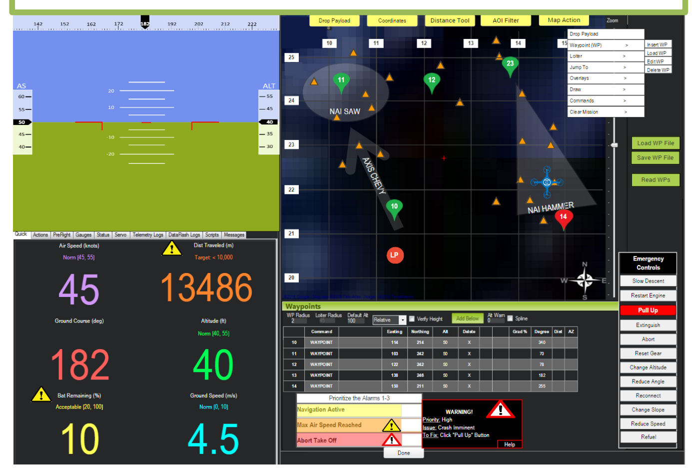
Degraded Interface

- **Variation on baseline interface**
- **Removed some automation interface features relevant to task performance**
- **Usability heuristics: 22 % satisfaction**



Enhanced Interface

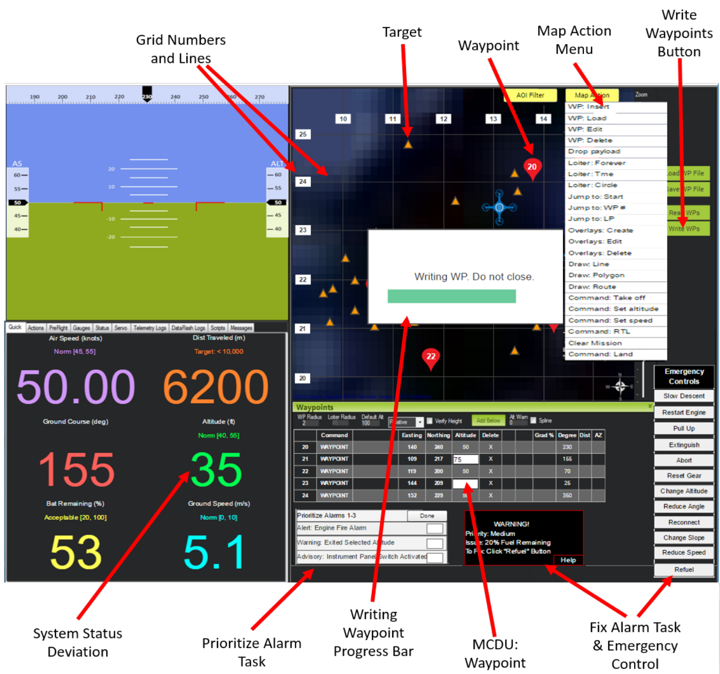
- **Variation on baseline interface**
- **Translated and implemented principles of automation transparency** (more later)
- **Usability heuristics: 100% satisfaction**



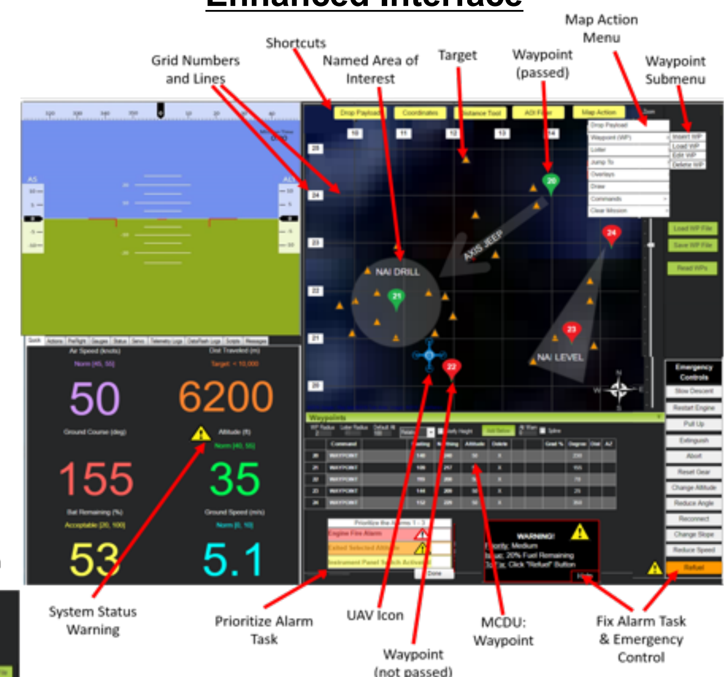
Common Components

- **PFD, ND (map), flight parameter indicators, MCDU (flight path planning), alarm management controls**

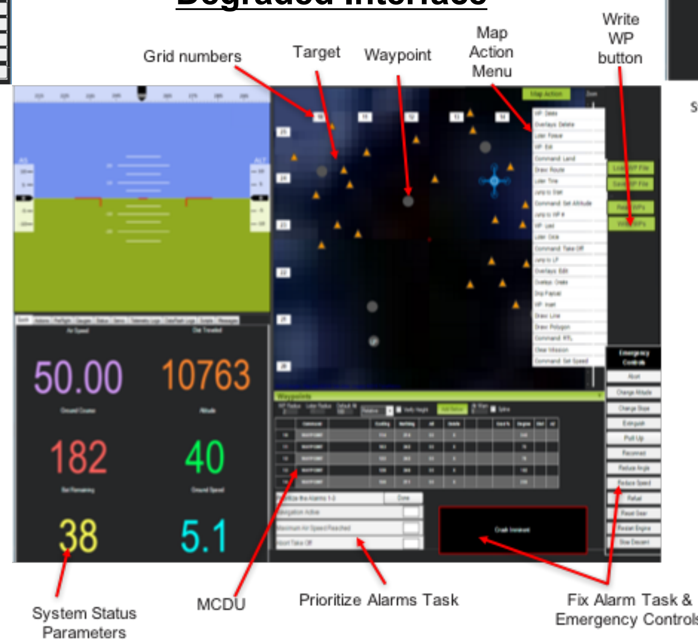
Baseline Interface



Enhanced Interface



Degraded Interface



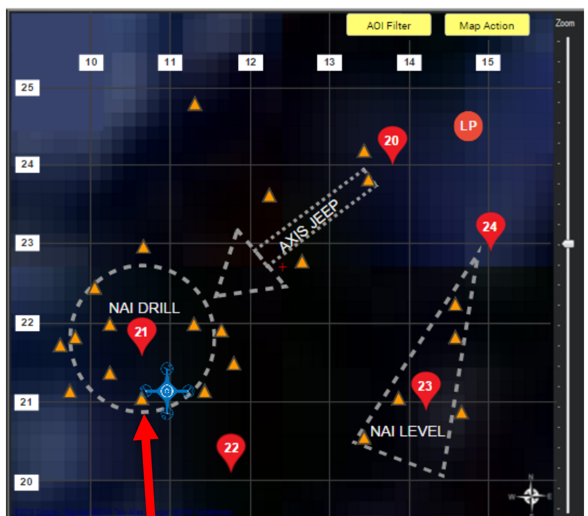
Baseline vs. Enhanced

UAV Control Task	Interface Component	Transparency Principle	Baseline Interface	Enhanced Interface
Determine coordinates; Estimate distance	Target location	Automation assistance	**Guidelines and major coordinate markings** presented on navigation display. No direct target interaction through interface.	Guidelines and major coordinate markings presented. **“Coordinate” and “Distance” shortcut tools available to assist user.**
Determine mission completion status	Waypoint identification	Pre-attentive cueing	**Waypoints are numbered**. Traditional waypoint-style icons are used for reveal against display background.	Waypoints are numbered. Traditional waypoint-style icons are used for reveal against display background. **Waypoint color changes after UAV flies past.**

[Some differences or how to promote transparency]

- **Added features to reveal automation capabilities**
- **Added pre-attentive cueing of stimuli**
- Aimed at facilitating task performance and improving operator system and mission awareness

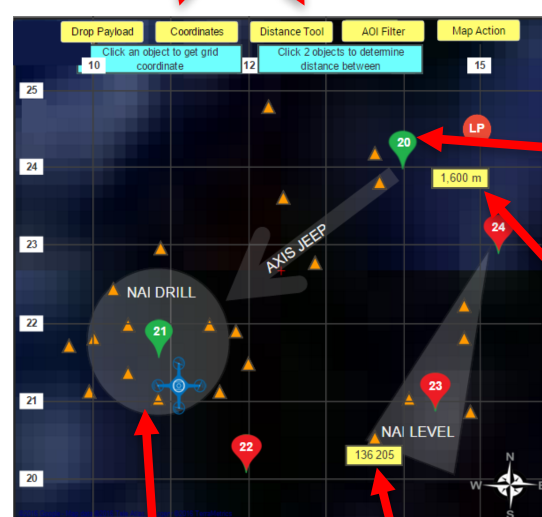
Baseline Interface



Outlined AOI

Enhanced Interface

Coordinates and Distance tool



Color coded WPs (as progress indicators)

Automatic distance estimation (LP – WP24)

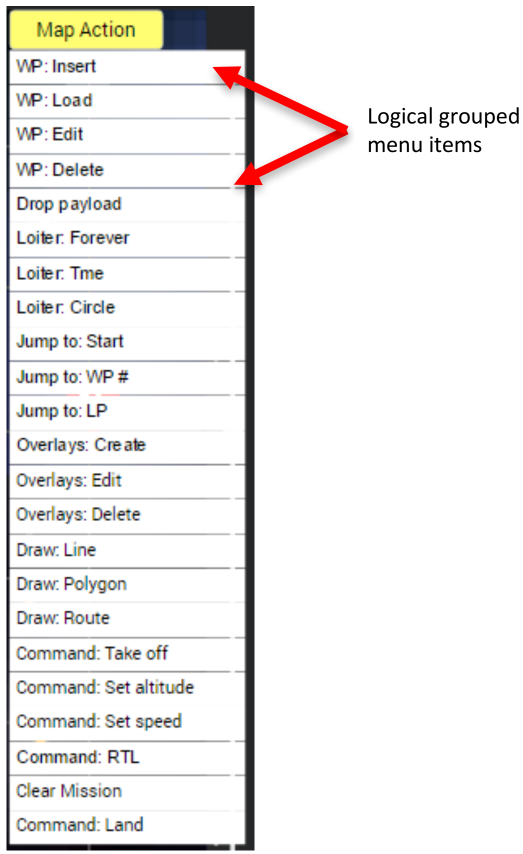
Shaded AOI

Automatic coordinates reading

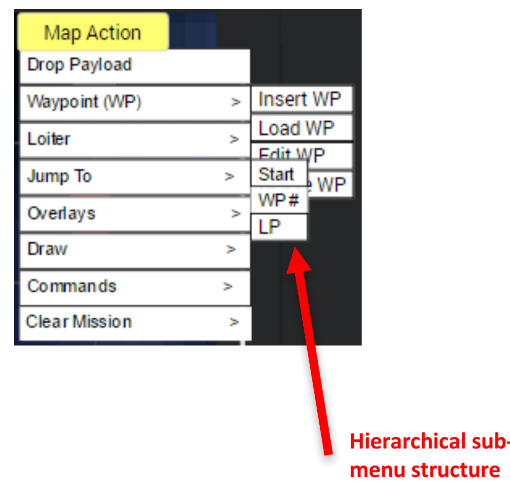
Promoting Transparency

UAV Control Task	Interface Component	Transparency Principle	Baseline Interface	Enhanced Interface
Locate menu options	Control Action selection	Information in context	Menu items are presented in single list, grouped by function.	Menu items are presented in hierarchical sub-menu structure for each UAV function.

Baseline Interface



Enhanced Interface



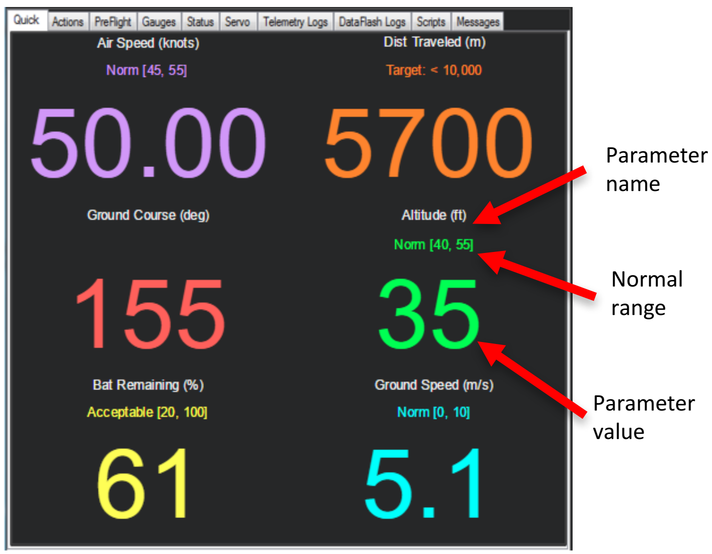
Features support effective use of automation

Promoting Transparency

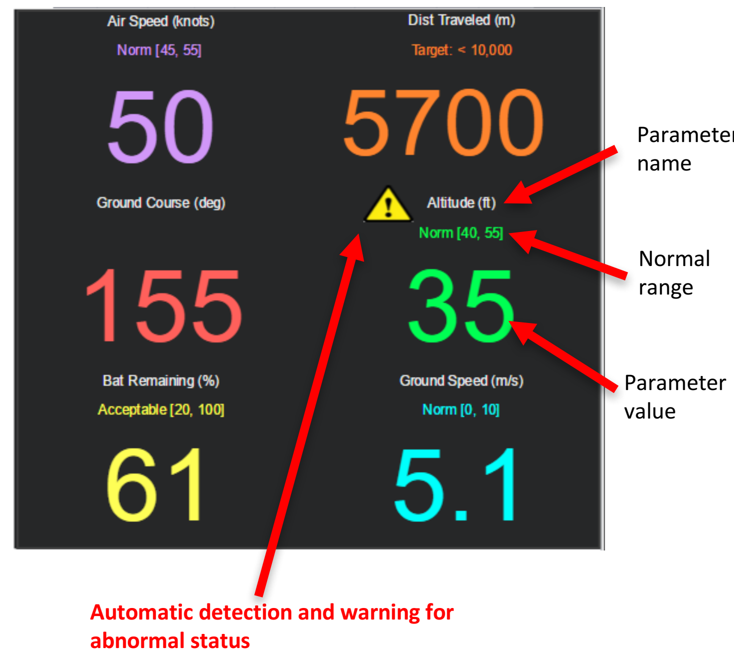
UAV Control Task	Interface Component	Transparency Principle	Baseline Interface	Enhanced Interface
Monitor system status parameter	System Status Parameter monitoring	Pre-attentive cueing and automation assistance	**System status parameters are displayed** along **with acceptable parameter ranges.**	System status parameters are displayed along with acceptable ranges. **Alert icons appear when parameters exceed acceptable ranges**

- **Baseline** interface – **operators must compare system state with nominal range** and identify deviations.
- **Enhanced – parameter deviations are automatically highlighted.**

Baseline Interface



Enhanced Interface



Features reveal automation capabilities for user

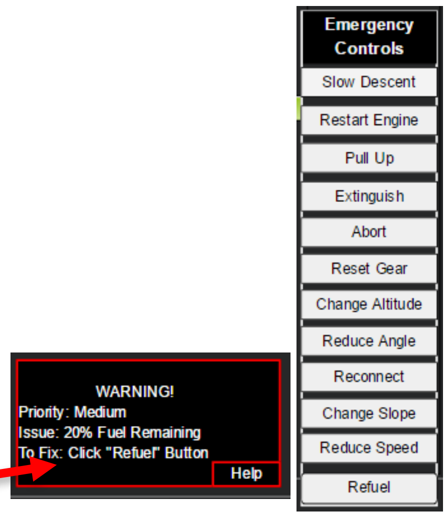
Promoting Transparency

UAV Control Task	Interface Component	Transparency Principle	Baseline Interface	Enhanced Interface
Fix alarm; Prioritize alarm	Alarm presentation	Pre-attentive cueing	Messages provide basic information on priority, indicate cause of alarms, and suggest solution.	Messages **provide priority information by color-coding,** indicate cause of alarms, **and highlight suggested solution with color and icon.**

- Enhanced interface **- automation identifies system alarm/warning** (SA-Transparency (T) Level 1; Chen et al., 2014); **automation identifies associated system parameter deviation and prioritizes all current warnings** (SAT Level 2); **automation** projects and **identifies control** solution for operator (SAT Level 3).)

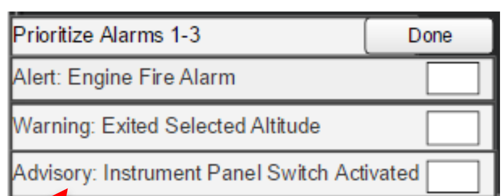
Baseline Interface

Fix alarm



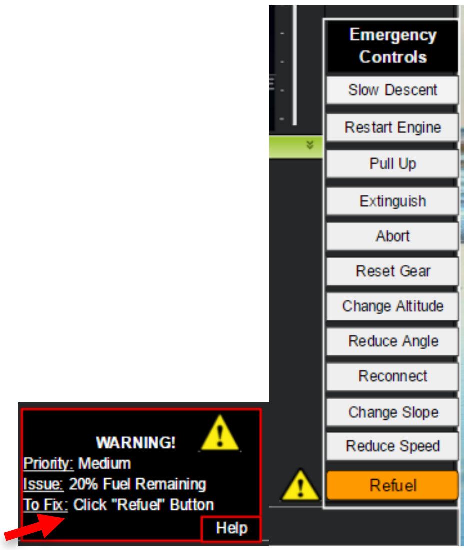
Suggestions on alarm solution

Prioritize alarm



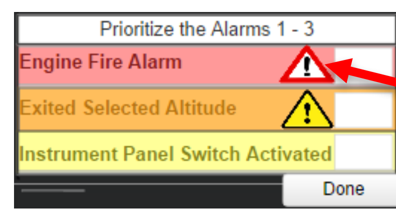
Information on priority

Enhanced Interface



Highlighted solution suggestion

Suggestions on alarm solution



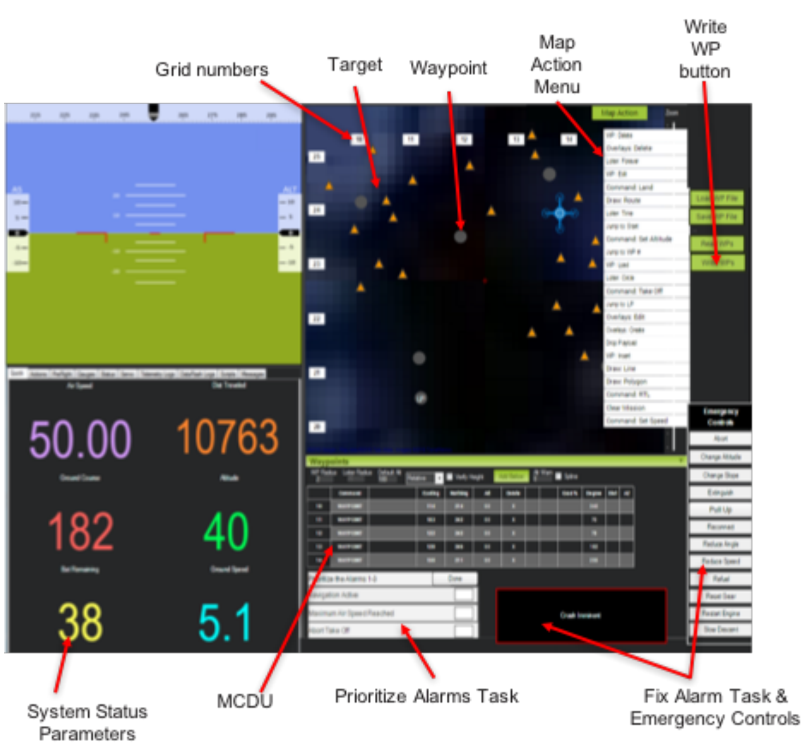
Color & symbol coding for priority

Features reveal automation capabilities for user

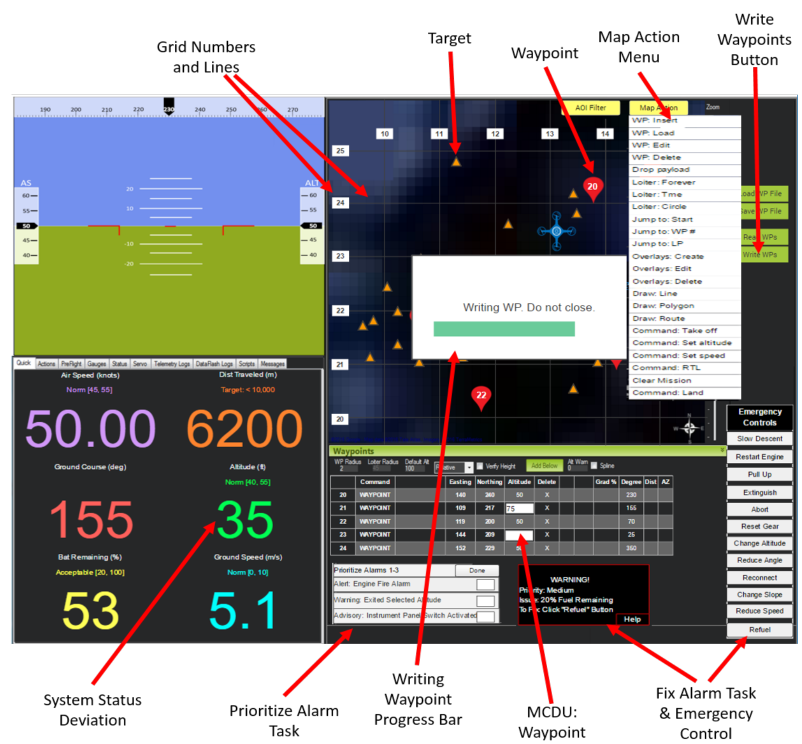
Degraded vs. Baseline Interface

- **Need to also show absence of transparency leads to increases in workload and degradations in awareness and performance**
- **Differences were in ND** (waypoint and AOI presentation), **map action menu** layout, **system parameter warnings, prioritize alarm display and fix alarm menu.**

Degraded Interface



Baseline Interface

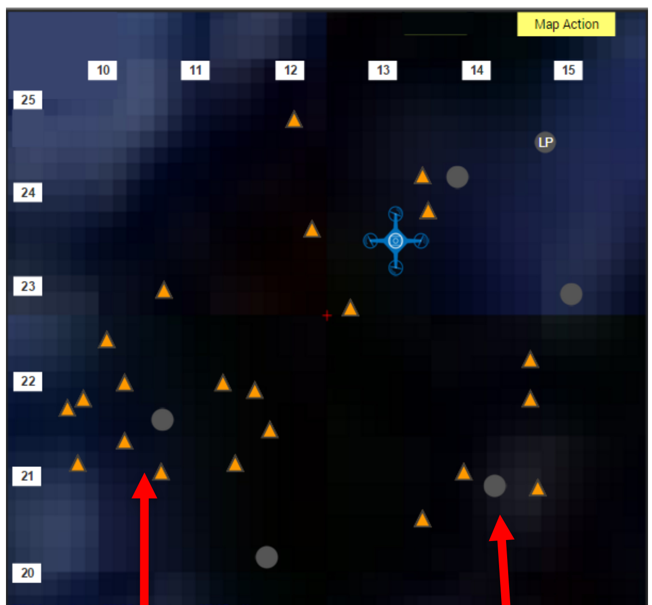


Degraded Transparency

UAV Control Task	Interface Component	Transparency Principle Violation	Degraded	Baseline
Count targets	Area of Interest identification	Automated assistance	**No display filtering of AOIs** available.	A shortcut button provides a **patterned-line filter** (i.e., dotted margin) **to identify AOIs**
Determine coordinates; Estimate distance	Target location	Pre-attentive cueing	**No map guidelines on nav display.** Users cannot interact with targets in navigation display through interface controls.	**Guidelines and major coordinate markings** are presented **on nav display**. No direct target interaction through interface controls.
Determine mission completion status	Waypoint identification	Pre-attentive cueing and automated assistance	**Waypoints not numbered and colored similar to ND** background (grey color).	**Waypoints are numbered. Traditional waypoint-style icons** are used for reveal against display background.

- **Removed some automation presentation features**
- **Reduced information context**
- **Reduced visual cueing**
- Control tasks were made more complex

Degraded Interface



No AOI or gridlines

WPs not numbered or colored

Baseline Interface

Colored and numbered WPs

Outlined AOI

Gridlines for assisting visual alignment

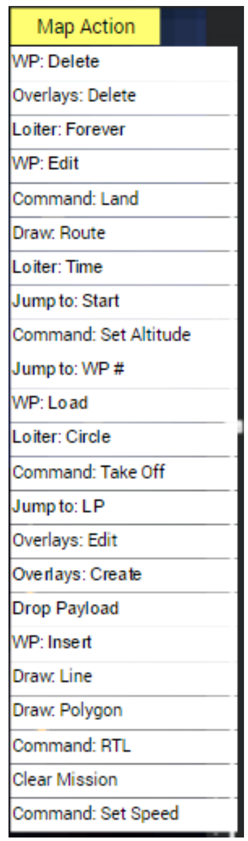
Removal of features conceals automation capabilities

Degraded Transparency

UAV Control Task	Interface Component	Transparency Principle Violation	Degraded	Baseline
Locate menu options	Control Action selection	No information context	Menu items are presented in single list in random order	Menu items are presented in single list and grouped by function.

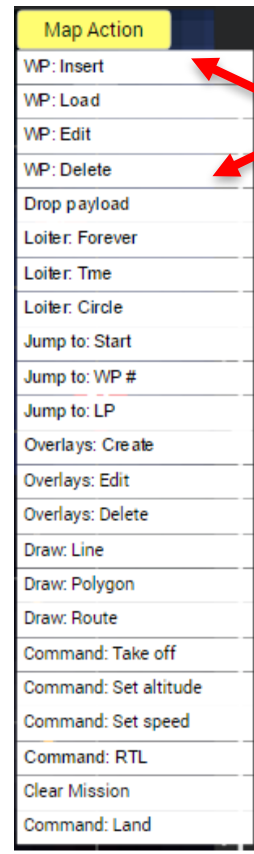
- **Functional organization of menu items provides context** for operator search for options

Degraded Interface



Menu items in random order

Baseline Interface



Logical grouped menu items

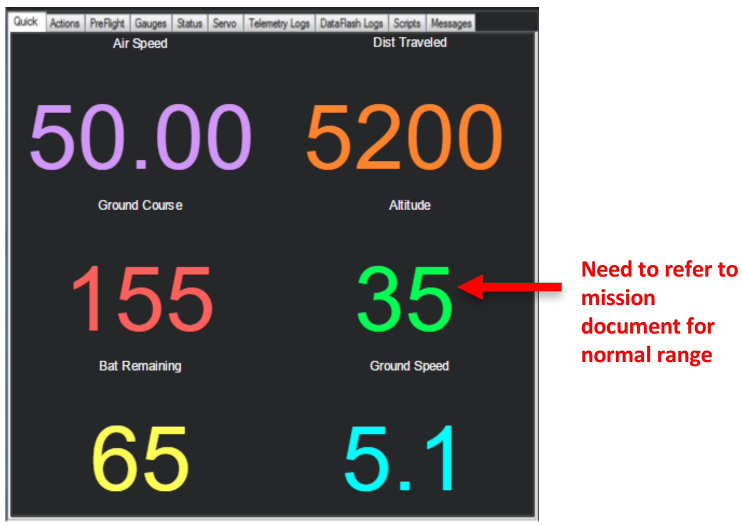
Removal of features inhibits effective use of automation

Degraded Transparency

UAV Control Task	Interface Component	Transparency Principle Violation	Degraded	Baseline
Monitor system status	System Status Parameter Presentation	No information context	Only system status parameters are displayed.	System status parameters are displayed along with acceptable parameter ranges.

- **No nominal parameter ranges in degraded interface** (requires use of memory)

Degraded Interface



Baseline Interface

Removal of features conceals automation capabilities

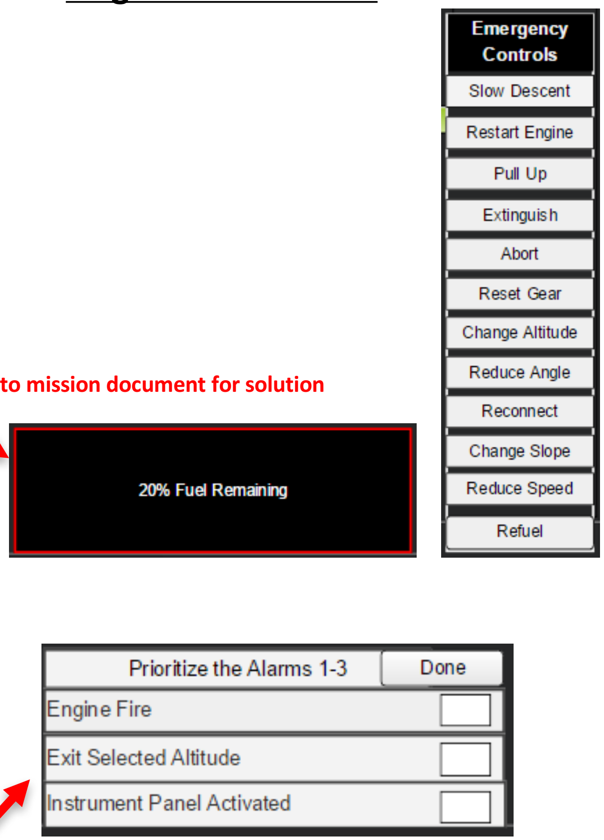
Degraded Transparency

UAV Control Task	Interface Component	Transparency Principle Violation	Degraded	Baseline
Fix alarm; Prioritize alarm	Alarm presentation	Lack of critical information	**Alarms only indicate failure state** and do not indicate cause. **No priority information.**	**Messages provides basic information on priority, indicate cause of alarms, and solution.**

- **Degraded** interface **required operators to recall priorities of various alarms** from memory
- **Baseline** provided **basic classification of alarms** (alert, warning, advisory)

Degraded Interface

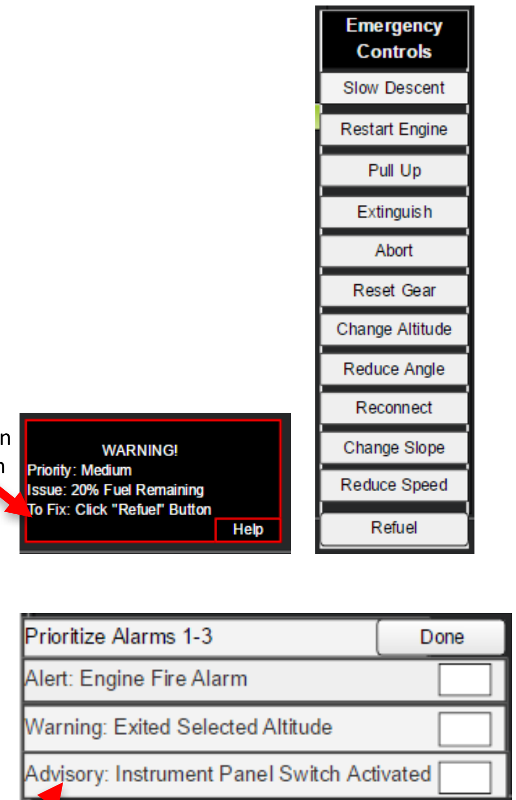
Need to refer to mission document for solution



Need to refer to mission document for priority

Baseline Interface

Suggestions on alarm solution



Information on priority

Removal of features conceals automation capabilities

Experiment Design

- **Independent variables:**
  - **Interface design** variation – Enhanced (E), baseline (B), degraded (D)
  - **Vehicle speed** / event rate – **Fast** (F; 5.5 min./trial) **and slow** (S; 8.5 min.)
    - Fast = 1.5 * slow speed; high demand
- Mixed-factor design:
  - **Interface variation = between-subject; speed = within-subject**
  - Each participant completed **4 trials with 1 interface**
    - 2 vehicle speeds by **2 different mission maps for replications**

- **Dependent variables:**
  - Performance – control **task time and accuracy** (degree of input deviation from truth; e.g., target coordinates, distance to WP)
  - **Dynamic Knowledge Query (DKQ) response accuracy**
    - **Tested operator knowledge of UAV states and mission status**
    - **Accuracy = $\frac{\text{\# correct responses}}{\text{total responses}}$**
  - **Cognitive workload – NASA-TLX** (task load Index) overall **score**
    - Higher rating = Higher workload

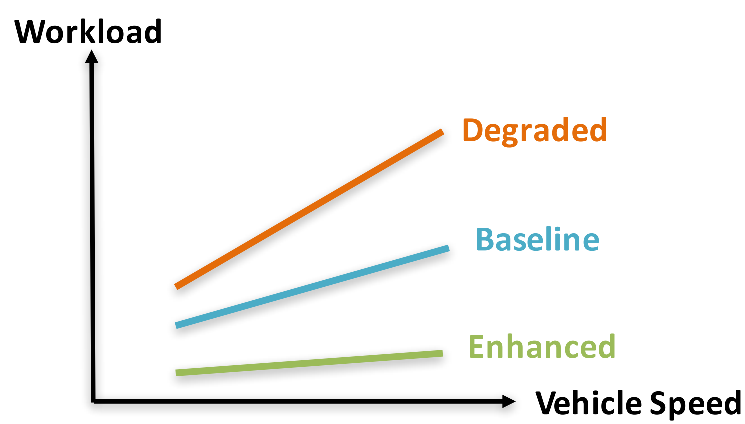
Participants and Training

- **48 subjects** (23 female, 25 male) from NC State and surrounding community (Raleigh, NC)
- Age: 24.8± 3.9
- 20/20 or corrected vision and no color-impairment
- Familiarity with computers but **no prior UAV supervisory control experience** (**to prevent "negative transfer"** effects in interface use)

- **Training**:
  - **Familiarization with control interface** (i.e., functions and locations of features)
  - **Familiarization with mission scenarios** (flight trajectories, SOMs)
  - **Performed simplified mission** with action commands and knowledge queries
    - (Repeated training mission until successful in all tasks and correct answers to all queries.)
  - **Ranked TLX demand components** based on training experience

Testing and Hypotheses

- Trial content:
  - **Briefing on mission scenario and scheme of maneuver** (by Army captain with experience in writing over 800 SOMs for UAV missions)
  - **Action commands presented auditorily** (digital audio system)
  - **DKQs presented by experimenter**
  - **Responses to queries and parameter warning callouts recorded by experimenter**
  - UAV flew flight path at fixed speed (fast or slow)
  - **TLX demand ratings at end of trials**
  - 2-min. rest between trials
- **Enhanced interface expected to produce:**
  - **Greatest task accuracy (H1)**
  - **Shortest task times (H2)**
  - **Highest dynamic knowledge (H3)**
  - **Lowest cognitive workload (H4)**
- **High speed expected to degrade performance, dynamic knowledge and workload (H5)**
- **Differences among interfaces expected to be greatest under high demand condition** (fast speed; **H6**)



Performance Results

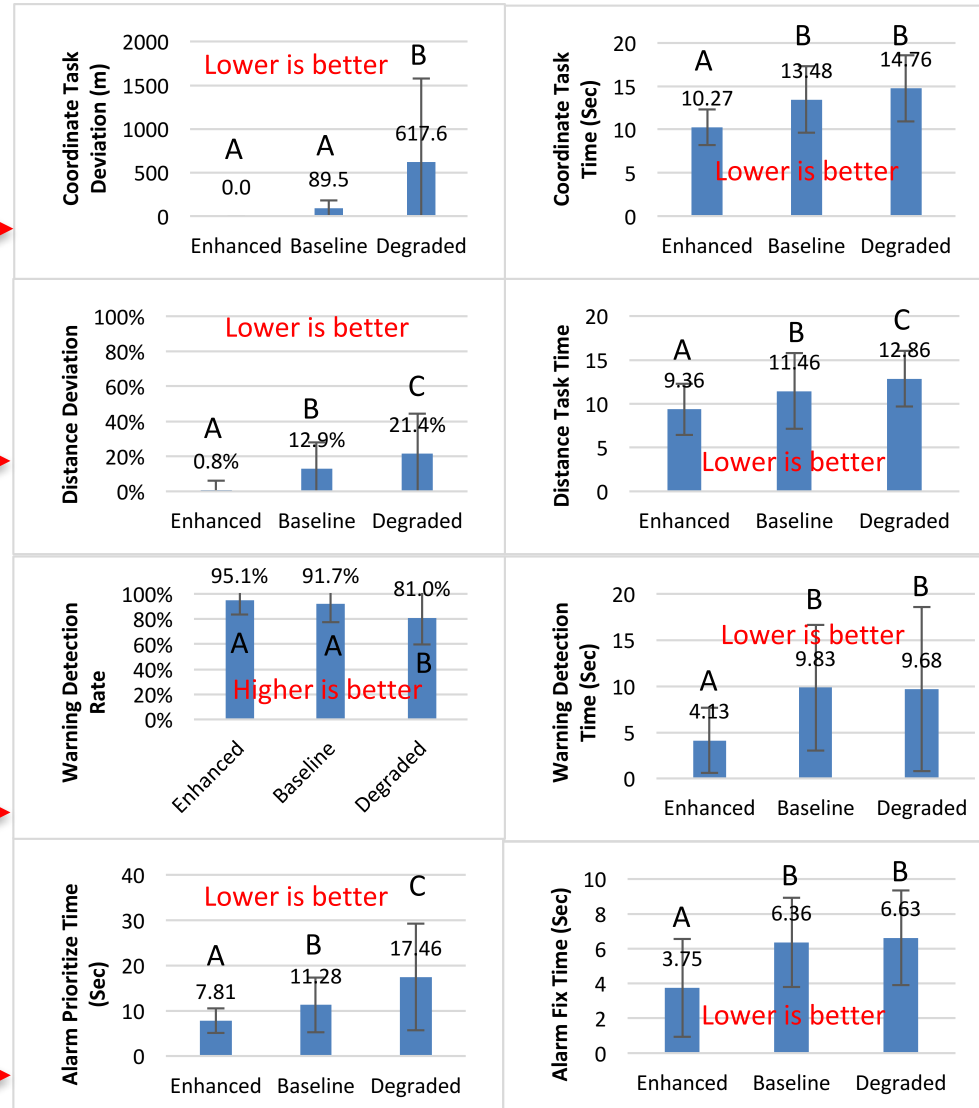
- **Interface design significant for** all DVs (task **time and accuracy**)
  - **Trends generally as hypothesized (H1-2)**
  - **E & B > D or E > B & D** for accuracy and time (for most responses)
- **Vehicle speed** / event rate **significant for specific tasks**:
  - **Distance estimation time** (p=.0157)
  - **Fixing alarm time** (p=.0446)
  - **Trend was** as hypothesized (H5) – **worse performance at high speed**
- **No interaction effect**
  - **Counter to expectation (H5); fast speed was "manageable" for subjects**

Specifying coordinates for target

Specifying distance to target

Number of warnings detected and time to detection

Time to prioritize alarms and time to fix



Dynamic Knowledge Accuracy

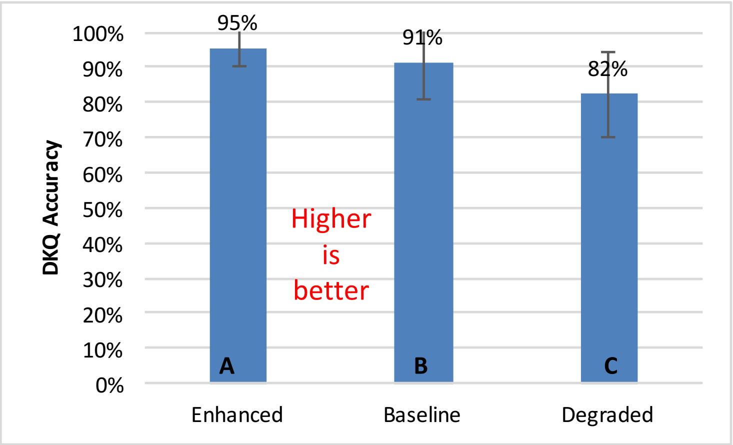
- **Example (real-time) queries (no freezes):**

What is the name of the [flight] Axis?
What is the normal range for UAV altitude?
In Map Action, how many "Delete" options are available?
What Northing is Waypoint 12 closest to?
What is your current ground speed?
What is your current completion percentage for this mission?

- **Significant effect of interface design with trend as expected** (H3)
  - E > B > D
- **No effect of speed or interaction;** counter to expectations (H5-6)

Effect	F-Statistic	P-Value
Interface	F(2,45) = 16.43	< .0001
Speed	F(1,45) = 1.04	0.3133
Interface*Speed	F(2,45) = 2.03	0.1431

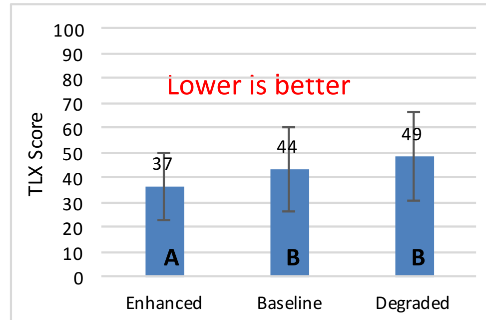
(Note: A few missing data points due to equipment or recording issues.)

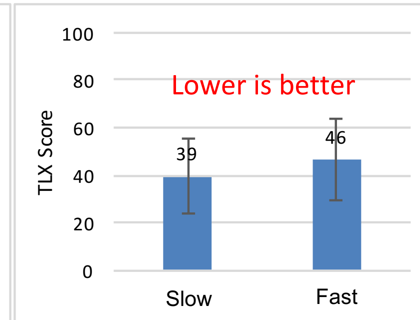


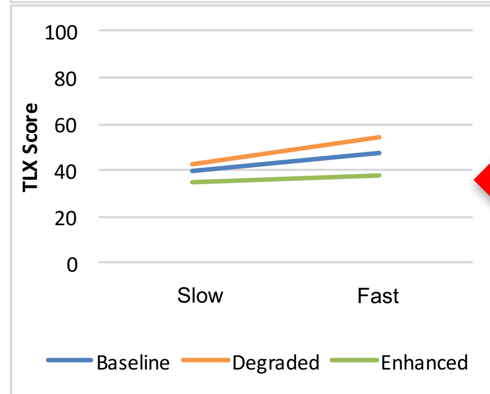
Workload Results

- **NASA TLX:**
  - Overall score – rank weighted sum of demand ratings for trial
  - Demand component ratings
  - **Significant interface design and speed effects; trends** generally **as expected (H4-5)**
    - **E < B & D; S < F**
  - **Marginal interaction effect with trend as expected (H6); At fast speed** (high event rate), **E << B < D**

Effect	F-Statistic	P-Value
Interface	F(2,45) = 3.88	0.0278
Speed	F(1, 45) = 17.83	0.0001
Interface*Speed	F(2,45) = 2.70	0.0778







Enhanced was superior to baseline and degraded and more so under high demand condition

Where were differences in demand ratings?

Interface Variation Effect on TLX Sub-component Ratings

	ANOVA Results	Tukey HSD Results
Mental	F(2,46) = 0.84, p = 0.4383	-
Physical	F(2,46) = 1.17, p = 0.3185	-
Temporal	F(2,46) = 1.11, p = 0.3375	-
Performance	F(2,46) = 2.86, p = 0.0676	-
Effort	F(2,46) = 4.23, p = 0.0206*	E < B ≈ D
Frustration	F(2,46) = 4.06, p = 0.0239*	E < B < D

Vehicle Speed Effect on TLX Sub-component Ratings

	ANOVA Results	Trends
Mental	F(1, 46) = 7.84, p = 0.0075*	Low < High
Physical	F(1, 46) = 6.88, p = 0.0118*	Low < High
Temporal	F(1, 46) = 22.39, p < .0001*	Low < High
Performance	F(1, 46) = 14.07, p = 0.0005*	Low < High
Effort	F(1, 46) = 3.03, p = 0.0886	Low < High
Frustration	F(1, 46) = 3.79, p = 0.0578	Low < High

Discussion

- UAV control **performance**:
  - **Differences in** task **accuracy primarily between baseline and degraded interfaces**:
    - **Absence of info context** (functional grouping) **and pre-attentive cueing of stimuli** (color, shape) **compromised transparency and response accuracy**
    - **Addition of auto features in enhanced interface did not improve** (coordinate or warning detection) **accuracy**
  - **Differences in time primarily between enhanced and baseline interfaces:**
    - **Information analysis automation features expedited performance** (coordinate identification, warning detection, fix alarm)
    - **Pre-attentive cueing of alarm types reduced search time**
    - **Pre-attentive cueing of alarm fixes reduced reading time**

Take-home Message #1

- **Implementing "transparency" principles, including (1) providing information context and (2) pre-attentive cueing of task stimuli may primarily influence task performance accuracy**
- **Implementing "transparency" principle of providing automation features may primarily influence task time.**

More Discussion

- **Dynamic knowledge of UAV status** and mission:
  - **Enhanced interface supported increased user awareness**
    - **Pre-attentive cueing of stimuli** (map features, parameter deviations, alarm priorities, alarm fixes) **increased accuracy of responses to queries**
    - **Information context** (provided by hierarchical, functional grouping of menu items) **increased system awareness**
  - **Degraded interface reduced user awareness of UAV environment and subsystem states due to…**
    - **Lack of pre-attentive cues** (e.g., waypoint numbering and color coding)
    - **Absence of (information acquisition) automation features** (e.g., AOI filters)

    (Participants frequently referred to printed mission materials or used memory & guessing.)

<u>Take-home Message #2:</u>

- **Implementing "transparency" principles of (1) pre-attentive cueing of task stimuli, (2) providing information context and (3) revealing automation (info acquisition) features can improve system user dynamic knowledge.**

Final Discussion

- Operator **workload responses and manipulation**:
  - **Enhanced interface features revealing auto capabilities** (e.g., distance tool) **lead to reduction in perceived workload** relative to baseline interface
    - Baseline and degraded remained comparable in absence of enhanced automation features
    - Substantial workload reductions occur when auto features are made accessible to address user info processing needs (Kaber et al., 2005)
  - Speed manipulation / **task event rate influenced perceptions of workload and** some **task times** (distance estimation, alarm fix) but not all
    - **Fast speed may not have been sufficiently demanding to influence performance in certain control tasks** (coordinate identification, warning detection, alarm prioritization)
  - **Enhanced interface was most effective for moderating operator workload perceptions under high demand conditions**

<u>Take-home Message #3:</u>

- **Prior work only showed principles of "transparency" may promote performance with no additional workload cost.**
- **Present study showed enhanced transparency interface can reduce perceived workload.**

Conclusions

- **Results** were **consistent with** some **other studies**:
  - **Mercado et al. (2016)** – agent **transparency increased operator performance**, trust and perceived usability
  - **Wright et al. (2016)** – agent reasoning **transparency improved human performance** [and reduced automation bias in decision making]

- **Novelty of present work:**
  - **Automation aids were "perfect"** (no reliability issues), participants "trusted" aids, and we **observed effect of implementing principles of "automation transparency" without confound of auto reliability issues**
  - **Identified utility of transparency in automation presentation in terms of several types of responses (performance, dynamic knowledge and workload)**

Applications and Limitations

- **"Transparency" may be useful concept for motivating and organizing automation interface design principles to support specific human performance outcomes**
  - Pre-attentive cueing and information context increases accuracy
  - Automation assistance reduces task time and workload
- **Interface prototypes not fully interactive**; some functions disabled:
  - **Users could not make inadvertent control activations** like real UAV operators in actual mission execution
  - **Participants were aware "total system failure" was not possible**
  - **Only investigated three interface designs** (based on MP GCS)
  - **Need to investigate** other GCS concepts (e.g., **military technologies**)
- **Only examined performance of common control tasks under nominal conditions**
  - **Need to study "transparent" interface use under off-nominal conditions**

Future Research

- Have **developed cognitive performance models of generic UAV control tasks** (using GOMSL (executable cognitive task modeling language).
- Models **provide basis for deriving workload responses** (cognitive operation counts/ durations, longest sequences, WM chunks)
- **Models** have been **validated against** actual **performance** responses (time).
- Plan to **use models to assess application of M-GEDIS-UAV tool and principles of transparency for managing workload responses.**
  - **Are tool and principles predictive of UAV operation workload outcomes?**

ID	Step	Goal	Method	Prev	Next	Para	Operator	Description	#	Goal	Object	Memory (Tag)	Condition	Value	P Class	M Class	C Class	Step Executio	Operator Tim	Total Time
MR		Monitor route	Method_for_goal:<goal>														1	50	0	
	1						Recall_LTM_item_whose <property,ROUTE_LOCATION> is <va					Route_location		Route_location			2	100	1200	
	2			MR1			Look_at <object>				Route_location				1			50	200	
	3			MR2			Accomplish_goal:<goal>			Track UAV presence					**1**	**0**	**5**	**300**	**1200**	
	4			MR3			Accomplish_goal:<goal>			Track UAV direction					**2**	**0**	**7**	**450**	**1400**	
	5			MR4			Delete <tag>					Route_location					1	50	0	
	6			MR5			Return_with_goal_accomplished										1	50	0	
														Monitor rout	4	0	17	1050	4000	5050
MR3		Track UAV presence	Method_for_goal:<goal>														1	50	0	
	1						Look_for_object_whose <property,UAV_LOCATION> is <value:					UAV_location		UAV_locatior	1		1	100	1200	
	2			MR3.1			Decide: If <condition> is "YES" Then						<UAV_location> is on <Route_location>?				1	50	0	
	3			MR3.2	MR3.4	N	Accomplish_goal:<goal>			Physical control for re-route execution										
	4			MR3.2		Y	Delete <tag>					UAV_location					1	50	0	
	5			MR3.4			Return_with_goal_accomplished										1	50	0	
														Track UAV pr	1	0	5	300	1200	1500
MR4		Track UAV direction	Method_for_goal:<goal>														1	50	0	
	1						Look_at <object>				UAV				1			50	200	
	2			MR4.1			Store <value> under <tag>					UAV_direction		UAV_direction			1	50	0	
	3			MR4.2			Look_for_object_whose <property, ROUTE_DIRECTION> is <va					Route_direction		Route_direct	1		1	100	1200	
	4			MR4.3			Decide: If <condition> is "YES" Then						<UAV_direction> is_equal_to <Route_direction>?				1	50	0	
	5			MR4.4	MR4.6	N	Accomplish_goal:<goal>			Physical control for re-direction execution										
	6			MR4.4		Y	Delete <tag>					UAV_direction					1	50	0	
	7			MR4.6			Delete <tag>					Route_direction					1	50	0	
	8			MR4.7			Return_with_goal_accomplished										1	50	0	
														Track UAV di	2	0	7	450	1400	1850

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