

Effects of Communication Modality on Pilot-Controller Coordination during a Simulated m:N Operation

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Background and Motivation

- Growing interest in m:N operations
- Situation awareness critical for supervisory control of multiple UAS
 - Requires frequently switching attention/control
 - Research shows this leads to slower reaction times and errors
- Current-day aviation uses radio comms with ATC
- Initial UAM operations are expected to utilize traditional ATC services.
 - Bottleneck for multi-UAS comms

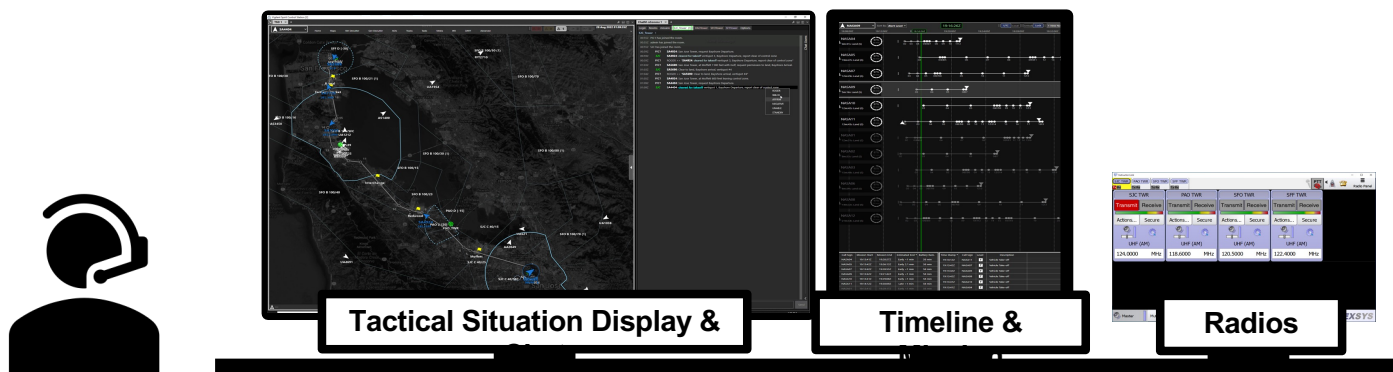


Background and Motivation (cont.)

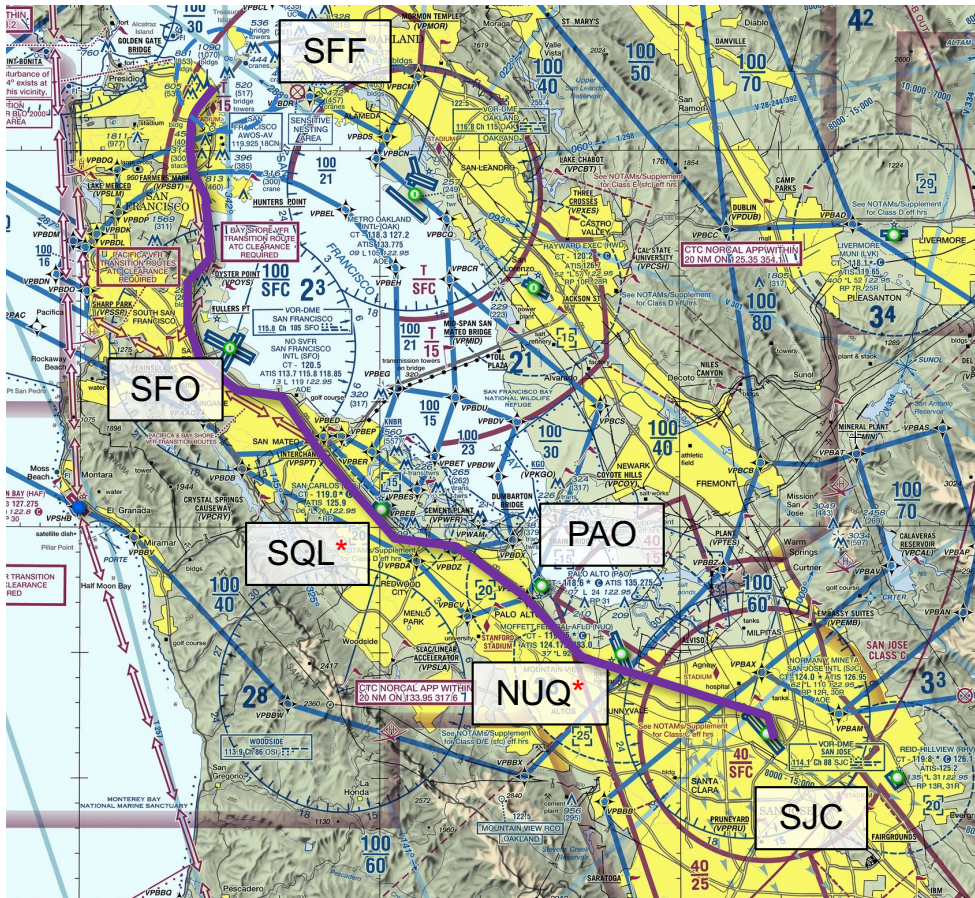
- Previous research on comm modalities
 - Examined use of voice, datalink, and “mixed” comm modes
 - Assumed traditional flight deck (2 pilots, 1 aircraft)
 - Results indicated
 - Voice had shortest comm transaction time
 - Time pressure increased transaction time and errors
- Current study examined pilot-ATC comms in a m:N UAM operation
 - Comm systems: Voice, Datalink, “Hybrid”
 - Two vehicle loads: 4 and 12 aircraft

Experiment Design

- Study Designed in collaboration with commercial partners: Joby and Wisk
- 3x2 Study Design – 12 participants (PPL certificated)
 - Comm Modality – 3 levels, within-subjects
 - Voice, Datalink, Hybrid
 - Vehicle Load – 2 levels, within-subjects
 - Low (4 vehicles), High (12 vehicles)



Route & Airspace Detail



Facilities along route:

- San Jose Int'l – SJC
- Moffett Field – NUQ*
- Palo Alto – PAO
- San Carlos – SQL*
- San Francisco Int'l – SFO
- SF Ferry Terminal – SFF

Checkpoints:

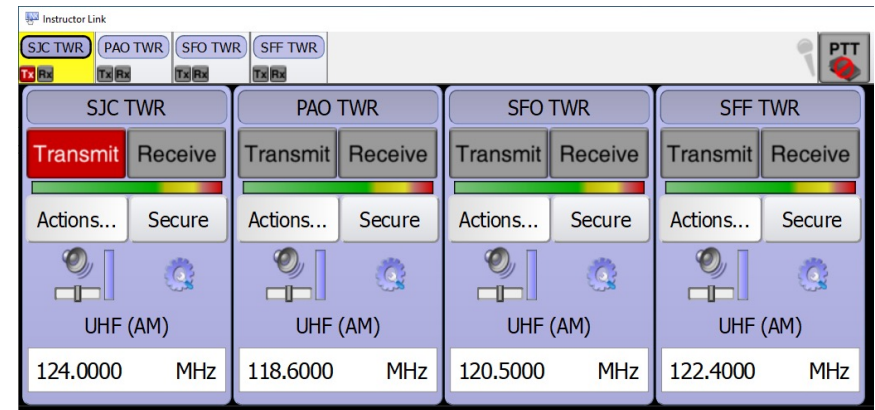
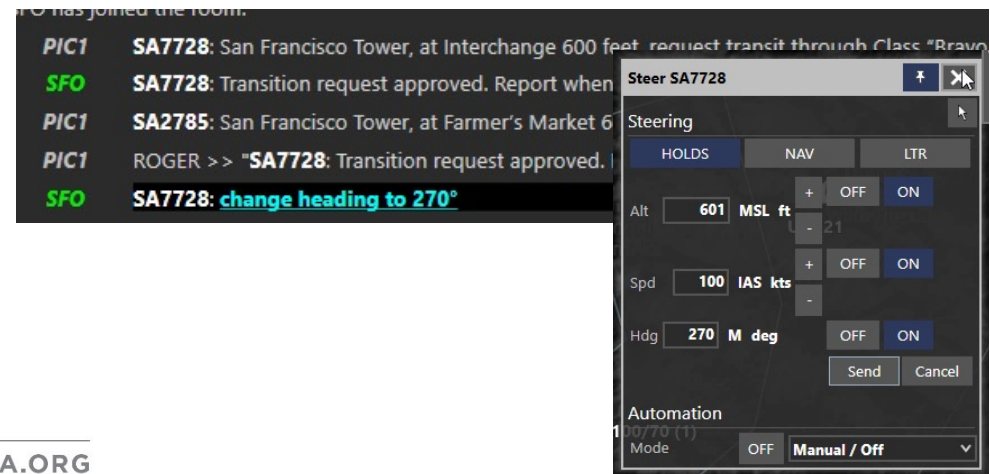
- Moffett
- Redwood
- Interchange
- Farmer's Market
- Bernal

Class E 4,000 to 17,999 ft		Class B 3,000 ft to 10,000 ft		Class B 2,300 ft to 10,000 ft	Class B 3,000 ft to 10,000 ft	Class B Surface to 10,000 ft	Class B 2,100 ft to 10,000 ft
Class C Surface to 4,000 ft		Class C 2,500 ft to 4,000 ft	Class E 2,001 ft to 2,999 ft	Class E 1,201 ft to 2,999 ft	Class E 1,500 ft to 2,299 ft	Class E 1,201 ft to 2,999 ft	Class E 1,201 ft to 2,099 ft
		Class D Surface to 2,499 ft	Class D Surface to 2,000 ft	Class G Surface to 1,200ft	Class D Surface to 1,499 ft	Class G Surface to 1,200ft	Class G Surface to 1,200ft
~ 62 ft		NUQ*	PAO		SQL*		SFO
SJC Int'l Vertiport							Ferry Building Vertiport
							~ 9 ft

* Cooperative agreement in place with NUQ and SQL to transit airspace

Communication Systems

- Voice
 - All comms over radio
 - Vectoring performed manually
- Datalink
 - All comms over chat system
 - Vectoring automatically loaded into AP
- Hybrid
 - Combination of above
 - Departure, arrival clearances via chat
 - Transition clearances via radio
 - Vectoring automatically loaded into AP

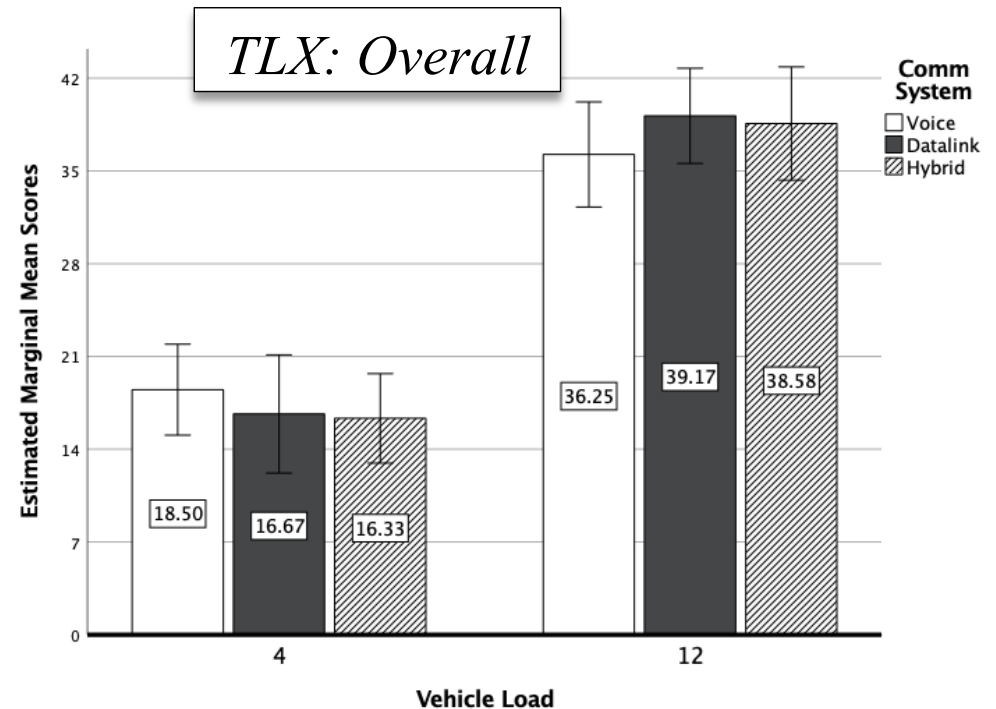


Metrics

- Workload (NASA-TLX)
- Response Times (RT)
 - Communication
 - Maneuver/Return-to-Course
 - Initiation
 - Editing
 - Total Service Time
- Error Rates
 - Wrong Frequency
 - Wrong Callsign
 - Wrong Maneuver
- Clarification Requests
- Missed/Ignored Calls
- “Confusion Loops”

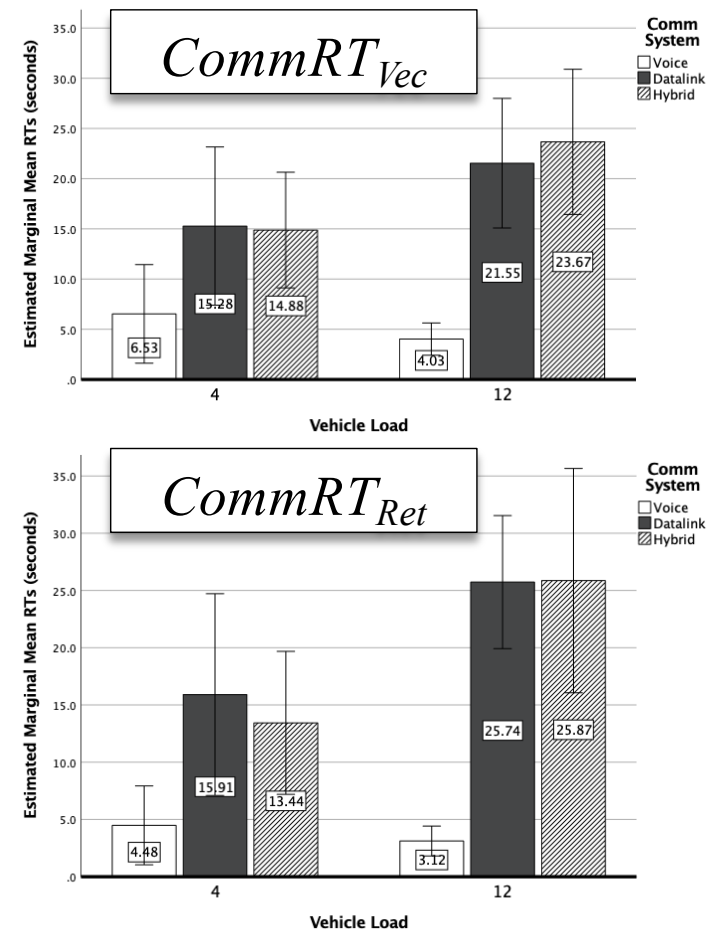
Workload Results

- Significantly higher workload in 12-Vehicle condition
 - Overall and all subscales
 - Nearly maxes out scale
- No effect of Comm Systems
 - Overall and all subscales



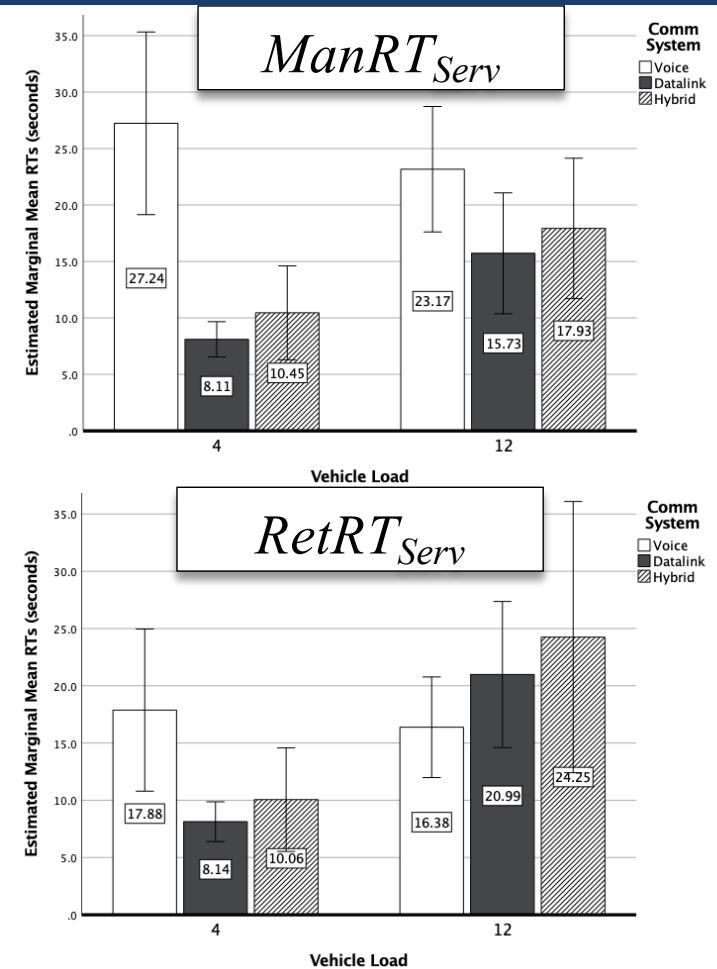
Communication Response Times

- $CommRT_{Vec}$ = comm. response time to vectoring instruction
- $CommRT_{Ret}$ = comm. response time to return-to-course instruction
- Quickest communication response times in the Voice Condition compared to Datalink/Hybrid
 - ~10 s faster in 4-Vehicle condition
 - ~20 s faster in 12-Vehicle condition
- Cases of messages in Datalink/Hybrid went unnoticed/unacknowledged for long periods of time
 - Over 6 minutes (376 s) in the worst case!

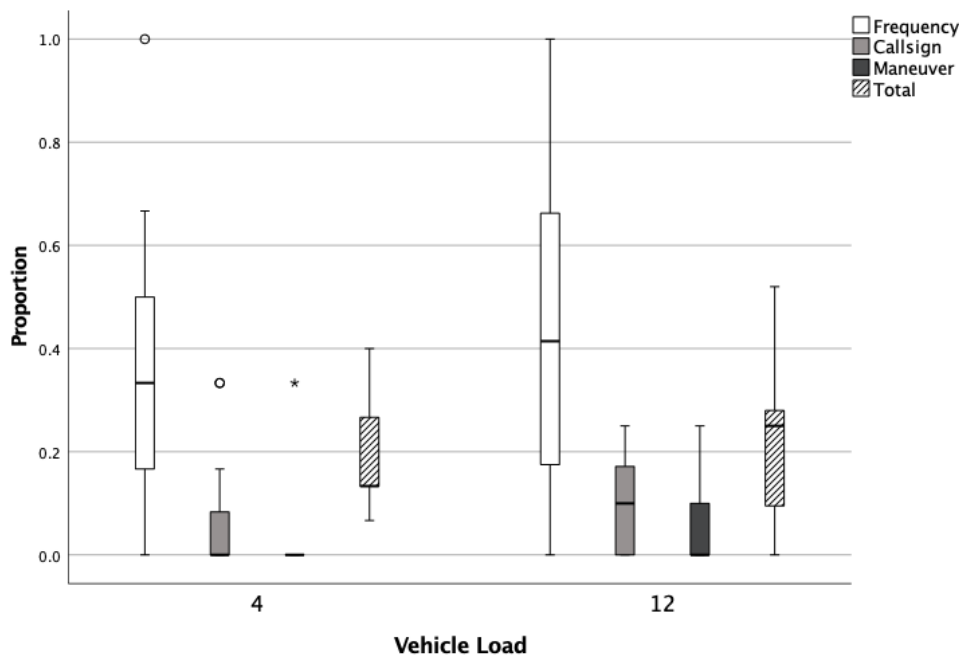


Total Service Time

- *Service Time* = the time spent interacting with a aircraft to perform an action
- $ManRT_{Serv}$ = total vectoring maneuver compliance service time
- $RetRT_{Serv}$ = total return-to-course maneuver compliance service time
- Datalink and Hybrid systems led to the quickest overall service time, in most cases.



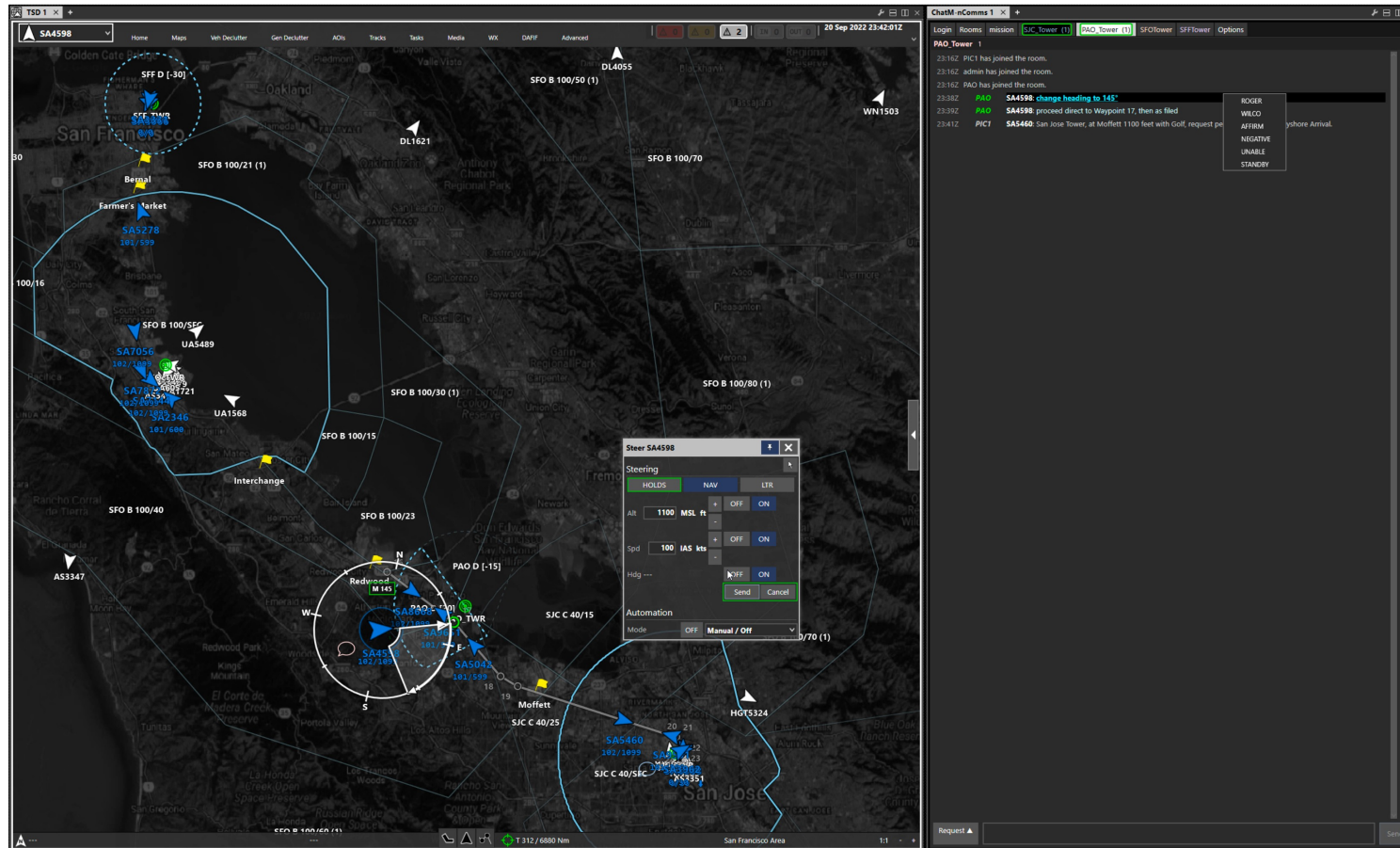
Error Rates (Voice Condition Only)



Distributions of *individual pilot* error rates by condition

- Examined errors only possible in Voice condition
 - Datalink/Hybrid chat system auto-loaded message recipients, callsign, parameters
- Most common error: speaking on wrong frequency
 - Wrong Frequency Error Rate:
 - Overall: 40.8%
 - 4-Vehicle: 34.3%
 - 12-Vehicle: 45.0%

Confusion Loop Video



Conclusions

- Simultaneous control of 12 vehicles led to workload saturation, degraded performance
- Tradeoffs in benefits/drawbacks of comm systems
 - Voice quickest for communication
 - High error rates, particularly frequency errors, in both Vehicle Load conditions
 - Datalink/Hybrid quickest for service time
 - No errors in uplinked maneuvers
 - Cases where messages went unacknowledged for long periods
 - Created conditions for "confusion loops"

Recommendations

- If voice comms utilized, a system to ensure pilot transmits on correct frequency is required.
- If digital messages are sent, an attention grabbing UI should alert the pilot of any messages that go unacknowledged.
- System should be smart enough to prevent confusion loops.

Questions/Comments

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