

m:N Handoff Study

Meghan Chandarana

Jillian Keeler

Conrad Rorie

Scott Scheff

Igor Dolgov

Garrett Sadler

Casey Smith

Dominic Wong

Cindy Pham

Jay Shively



- m:N operations require multiple operators to cooperatively manage multiple vehicles
- One key capability for m:N is the ability to dynamically transfer assets between operators, i.e., to “handoff” a vehicle from one operator to another
- Handoffs can be “planned” or “unplanned”
 - Planned handoffs may occur if a transfer of control is scheduled as a nominal part of operations, e.g., transferring vehicle control from an ‘enroute’ operator to a ‘terminal area/HDV’ operator or crew/shift changeover
 - Unplanned handoffs may occur in response to an in-flight contingency
 - The contingency vehicle may be handed off to a specialist, or the operator may decide to hand off their non-emergency vehicles so that they can focus their attention on the problematic aircraft
 - Interviews with SMEs have indicated that in military operations utilizing m:N configurations, most operators decide to handoff the nominal assets and retain the vehicle experiencing the emergency
- Operators can “initiate” a handoff or “receive” a handoff depending on the situation
 - When on the receiving end, operators must determine if and when they are comfortable taking control of the vehicle
 - Nominally, the Fleet Manager will help coordinate handoffs between operators – the FM should have a high-level view of which operators have the bandwidth to accept one or more vehicles into their control

- The present study collected data on remote operators' use of the handoff capability under an m:N configuration within the Urban Air Mobility (UAM) domain
 - The primary focus of the current study was how participants manage **unplanned handoffs** – i.e., did handoffs occur when one or more vehicles in their fleet experienced an emergency?
 - While planned handoffs was also of interest, it was not a central part of the design of this experiment
- Researchers varied the *level of workload* and the *level of automation support* in each scenario to determine if either variable impacted operators' handoff behavior
- The study provided data on *when* remote operators decided to handoff one or more of their vehicles and *which* vehicles (i.e., nominal vs off-nominal) they decided to off-load
 - Participants also provided input on the utility of the displays and procedures under test

- Independent Variables
 - Workload Level – 2 levels, within-subjects
 - *Low* = 1 vehicle in operator's fleet experiences emergency
 - *High* = 2 vehicles in operator's fleet experience emergencies simultaneously
 - Handoff Assist Level – 2 levels, within-subjects
 - *Manual* = operator must manually select and handoff asset(s)
 - *Assisted* = system prompts handoff at onset of contingency, operator can handoff all nominal aircraft or subset of off-nominals with single click

- Dependent Variables

- Handoff Performance

- Was there a handoff (yes/no)?
 - If yes: how many vehicles? What type of vehicle(s) (off-nominal, nominal, or combination)?
 - If yes: how long did it take to complete the handoff (seconds)?
 - If no: how were the aircraft managed during the contingency scenario?

- Secondary Task Performance

- Do pilots coordinate the the Fleet Manager in a timely fashion (i.e., respond to queries & make necessary route modifications)?

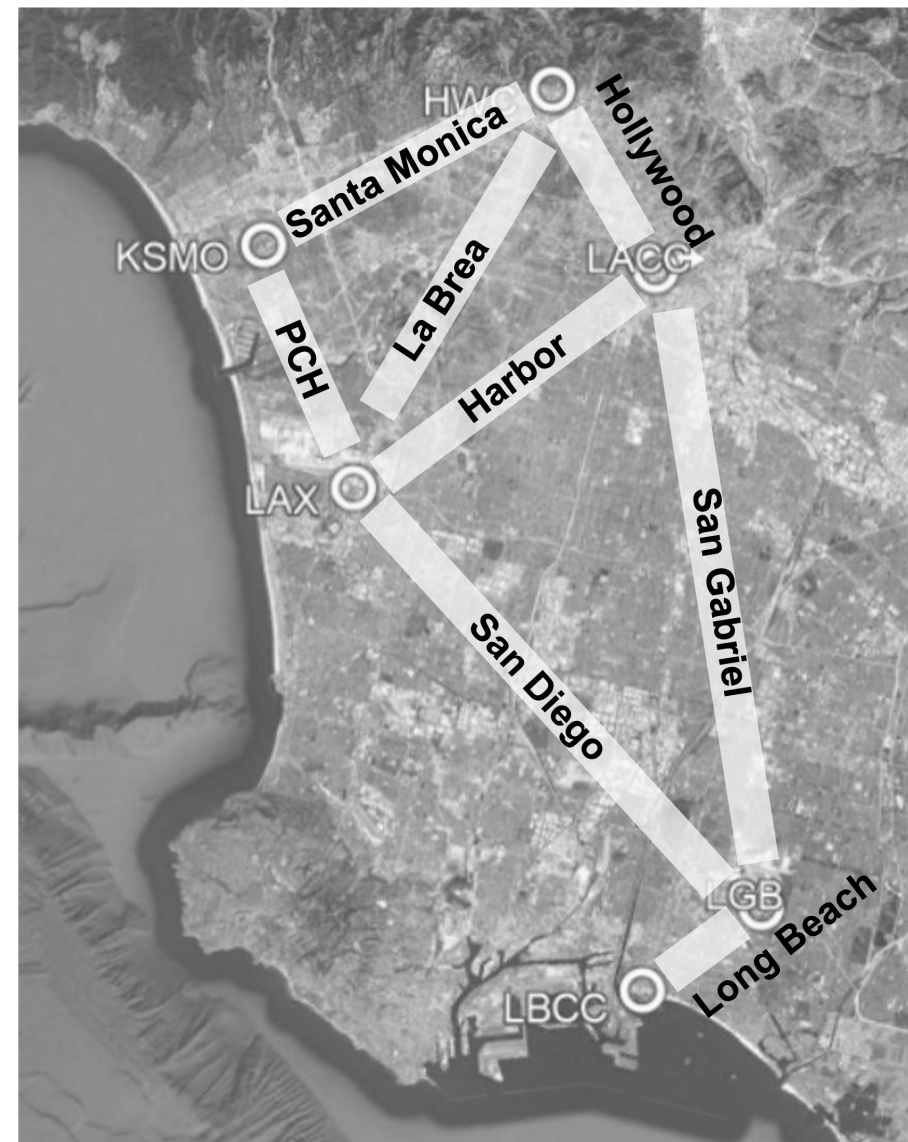
- Contingency Resolution

- Was the contingency resolved (yes/no)?
 - If yes: how long did it take to resolve the contingency (seconds)?
 - If no: why?

- Subjective Ratings

- Workload - NASA TLX (Post Trial)
 - Display/Information Acceptability – ratings on availability & utility of interface elements (Post Trial & Post Sim)
 - Meaningful Human Control – did the interfaces allow for sufficient MHC (Post Sim)
 - Procedural Acceptability – utility of the procedures and confederate roles during the sim (Post Sim)

- Participants
 - 16 Part 107-rated participant were recruited for this study
- Vehicle
 - Participants nominally controlled 6 simulated, passenger-carrying electric Vertical Takeoff and Landing (eVTOL) UAM vehicles
 - Vehicles featured a high level of automation, e.g., autopilot and auto takeoff/landing
 - A second (confederate) operator controlled 6 simulated UAM vehicles in the same airspace
 - Mission altitude: 1,000 - 5,000 ft AGL
 - Maneuverability:
 - Cruise speed: 60 KTAS
 - Turn rate: 3 deg/sec
 - Climb/descent rate: 500 ft/min
- Airspace
 - Los Angeles County
 - Vehicles traveled from vertiport-to-vertiport, with an average trip duration of 15 minutes
 - Vehicles transited via UAM corridors that were said to have been pre-authorized for UAM operations

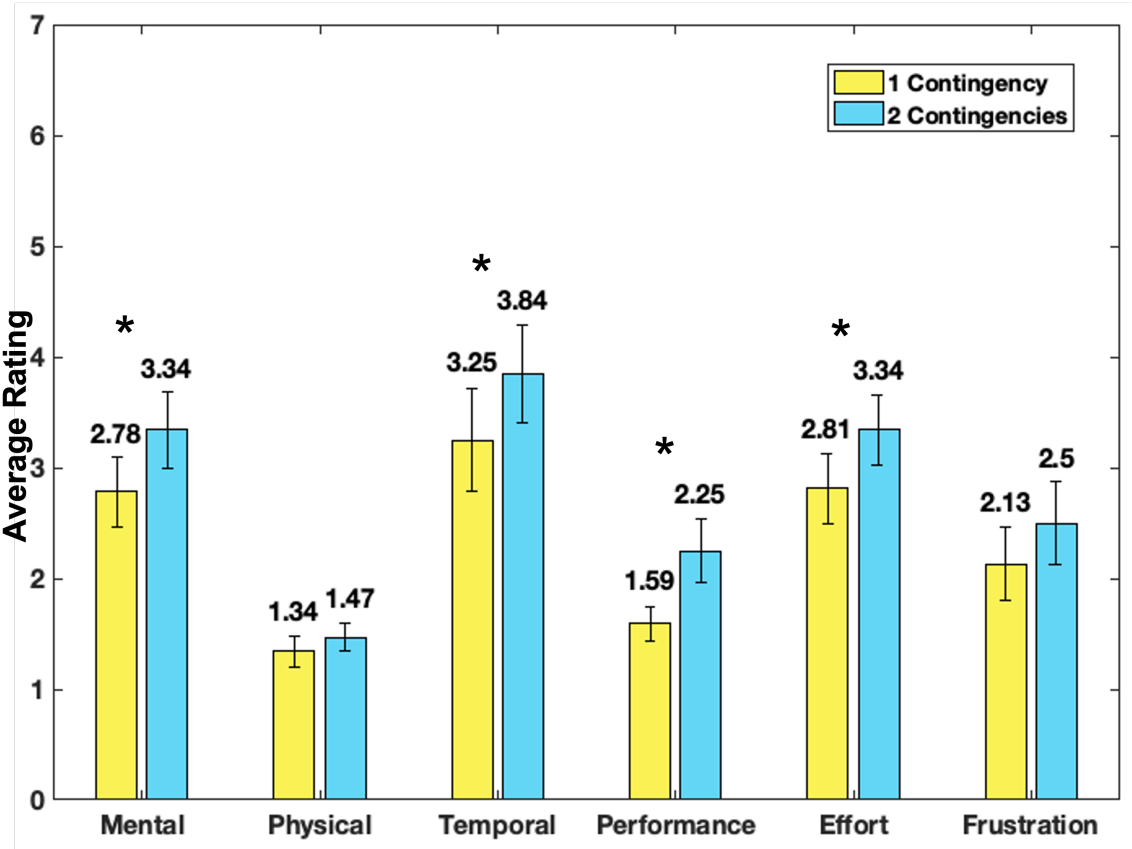


- Primary Task:
 - Ensure the safety of the passengers, the vehicle, and people and property on the ground
 - Since the vehicles are highly-automated, this means participants assumed responsibility primarily for safely managing scripted contingencies
- Secondary Task:
 - Regularly coordinate with their fleet manager (FM) through a chat client
 - The fleet manager routinely asked for updates or informed the participant of needed route modifications for vehicles under their control
- Scripted Events:
 - Medical Emergency: a passenger will activate an on-board emergency signal that necessitated:
 - Coordination with FAM (in contact with MedLink) via a chat client to determine an appropriate medical facility to reroute vehicle to
 - Mechanical Emergency: participant is alerted of on-board mechanical issue that necessitated:
 - Coordination with FAM via the chat to determine a safe emergency landing location to reroute vehicle to
- Experimental Trials:
 - Participants ran through 4 experimental trials (~15 min duration), one per experimental condition
 - Researcher confederates served as the Fleet Manager, the second operator, and the Emergency Service Personnel (all via chat)
 - Cognitive walkthrough at the end of the day for the participants experience *planned* handoffs
 - Purpose was to collect feedback on whether they have the necessary information safely manage both handoff types

- Repeated measures ANOVAs to determine if Workload Level and/or Handoff Automation Level impacted:
 - Number of handoffs
 - Contingency resolution duration
 - Time to choose emergency hospital location/vertistop
 - Handoff durations
 - Workload ratings (NASA TLX)
 - Post Trial ratings
- Descriptive data also captured:
 - Types of vehicles handed off (nominal vs off-nominal vs combination)
 - Secondary task performance
 - Reasoning behind handoff behavior
 - Subjective feedback regarding the displays & procedures under test

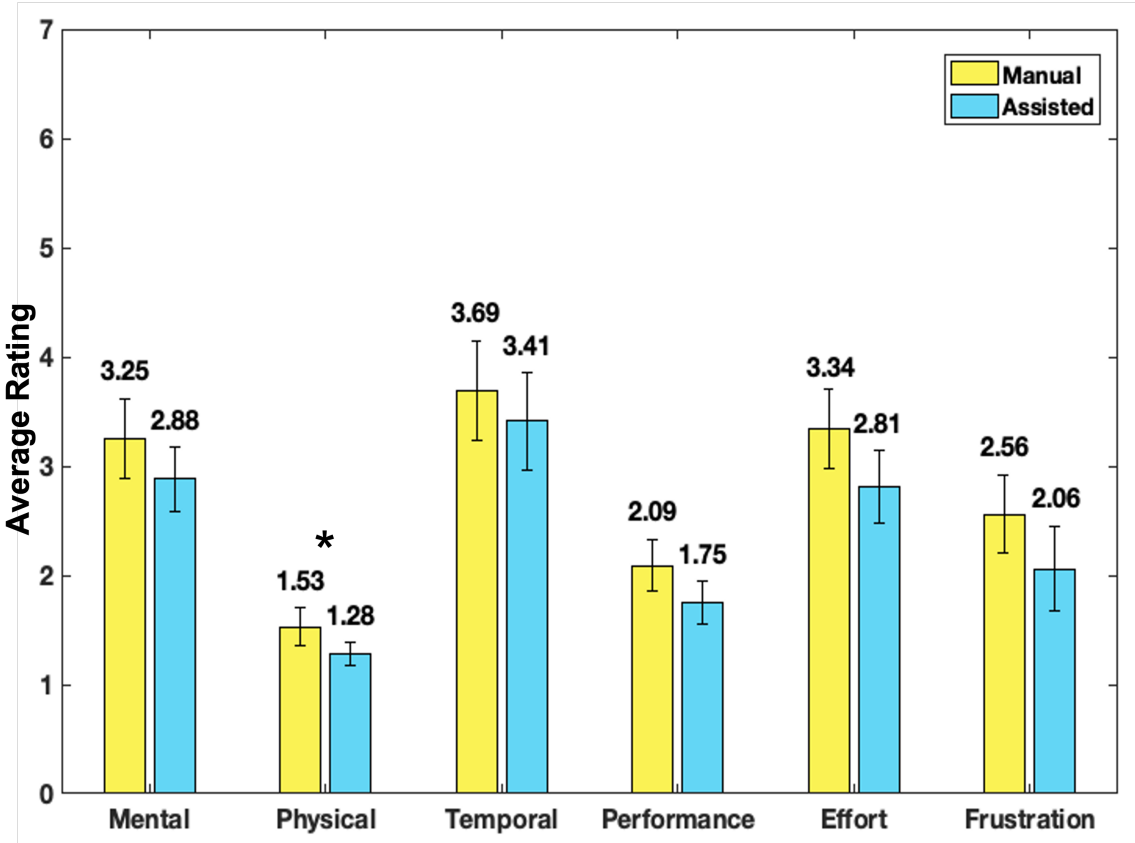
- NASA TLX ratings are higher, on average, for trials where 2 contingencies occurred
- Differences between the 1 and 2 contingency trials is statistically significant for the Mental, Temporal, Performance and Effort subscales
- Subjects handed off vehicles more often when there were 2 contingencies to resolve

	Handoff %
1 Contingency	44%
2 Contingencies	84%



- NASA TLX ratings are higher, on average, for trials that had required manual handoffs
- Differences between the manual an assisted automation condition was statistically significant for the only the Physical subscale
- Subjects handed off vehicles more often when the assisted handoff tool was available

	Handoff %
Manual	56%
Assisted	73%



	1 Contingency	2 Contingencies	Manual	Assisted
Workload Before	1.41	1.47	1.38	1.50
Workload During	3.13	3.69	3.63	3.19
Workload After	1.47	1.69	1.59	1.56
Satisfied with handoff decision	4.59	4.06	4.00	4.66
Interfaces allowed me to perform hand-offs in a timely manner	4.16	4.06	3.91	4.31
Interactions with FAM were manageable	4.09	3.94	3.97	4.06
Interactions with ESP were manageable	4.23	4.16	4.09	4.28
Number of controlled and monitored aircraft was manageable	4.56	4.47	4.47	4.56
Emergencies were manageable	4.50	4.31	4.38	4.44

Workload ratings

- 1 = extremely low
- 5 = extremely high

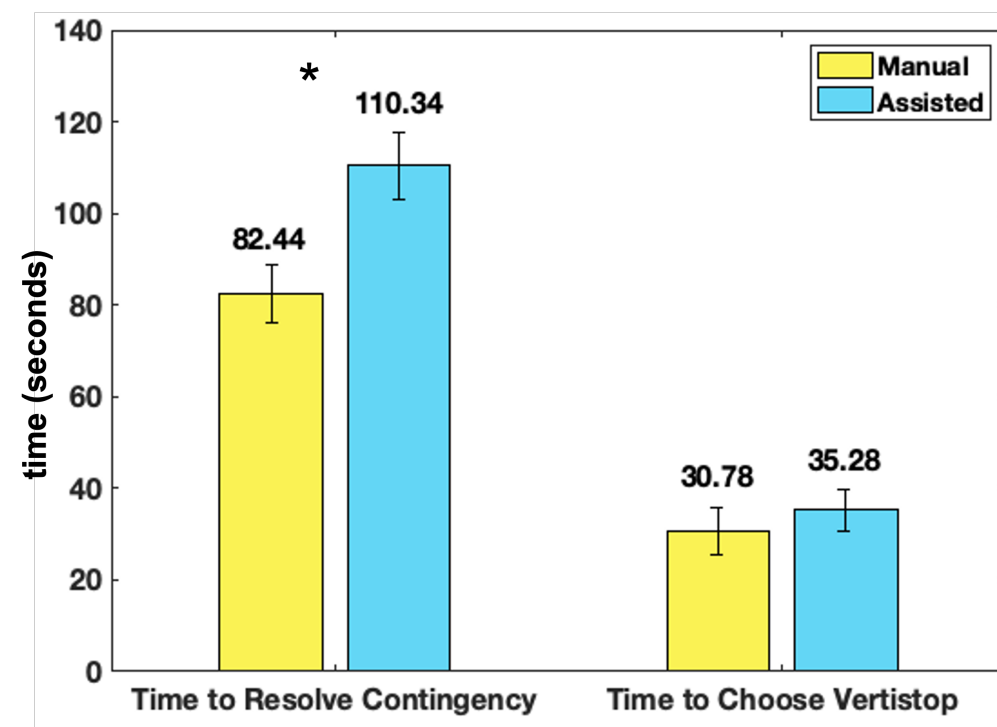
All other subjective ratings

- 1 = strongly disagree
- 5 = strongly agree

- Workload during contingencies was highest, followed by workload after contingencies, which was slightly higher than workload before contingencies
- In general, subjects were satisfied with their decisions, the interactions they had with the interfaces and other roles, and their ability to control and manage vehicles

- Subjects handed off about 2 vehicles no matter how many contingencies there were
- In manual trials, subjects handed off 1 vehicle, whereas in assisted trials they handed off 3
 - Difference was statistically significant
- Most of the time, subjects chose to handoff no vehicles or only nominal vehicles
- Time to resolve a contingency was longer in the assisted automation condition
 - Difference was statistically significant
- Time to choose a new vertistop (emergency landing site or hospital) was longer in the assisted automation condition

Type of Vehicles Handed off	% of Time
No vehicles	39%
Nominal Vehicles only	39%
Contingency Vehicles only	16%
Mixed (nominal + contingency)	6%





Secondary Task Performance



- Subjects handed off the vehicle that had a FAM call associated with it 11.7% of the time
- If the vehicle with a FAM call was not handed off:
 - Subjects correctly responded 94.6% of the time
 - Subjects sent notification of completion chat message to FAM 95.1% of the time

- The displays and procedures developed enabled subjects to maintain a fairly low workload if/when they handed off assets
- Subjects felt higher workload when there were 2 contingencies, which led to more handoffs
- Although subjects felt higher workload in manual trials, they handed off vehicles less
- Subjects took longer to choose vertistops and resolve contingencies in the assisted automation condition even though their workload was lower
 - Subjective ratings show that pilots felt that they interfaces allowed them to perform handoffs in a timelier manner in assisted automation trials

- Subjects were happy with their decision to perform handoffs (or not)
- Workload did not return to the level it was before contingencies although it was lower than during
- Subjects felt that the number of vehicles controlled and interactions with other roles was manageable
- Although some secondary tasks occurred at the same time as contingencies, those vehicles were rarely handed off
- Secondary performance was high, and subjects almost always notified the FAM of completion