



A Flight Replanning Tool for Terminal Area Urban Air Mobility Operations

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Purpose

- Introduce a tool for flight replanning decision-making research in UAM terminal area operations
- Report on the evaluation of version 1 of our trial planner



Overview

1. What is trial planning and why
2. Design strategy
3. UI and trial planning workflow
4. Evaluation
5. Results
6. Future work



What is trial planning?

Identify and evaluate new routes.

Trial planner: automated tool that computes and provides new route options

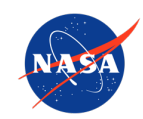
Purpose: Support decision-making research

Intended users:

- ATC
- Airline Dispatchers
- Flight crew
- Fleet manager (Urban Air Mobility)

Why?

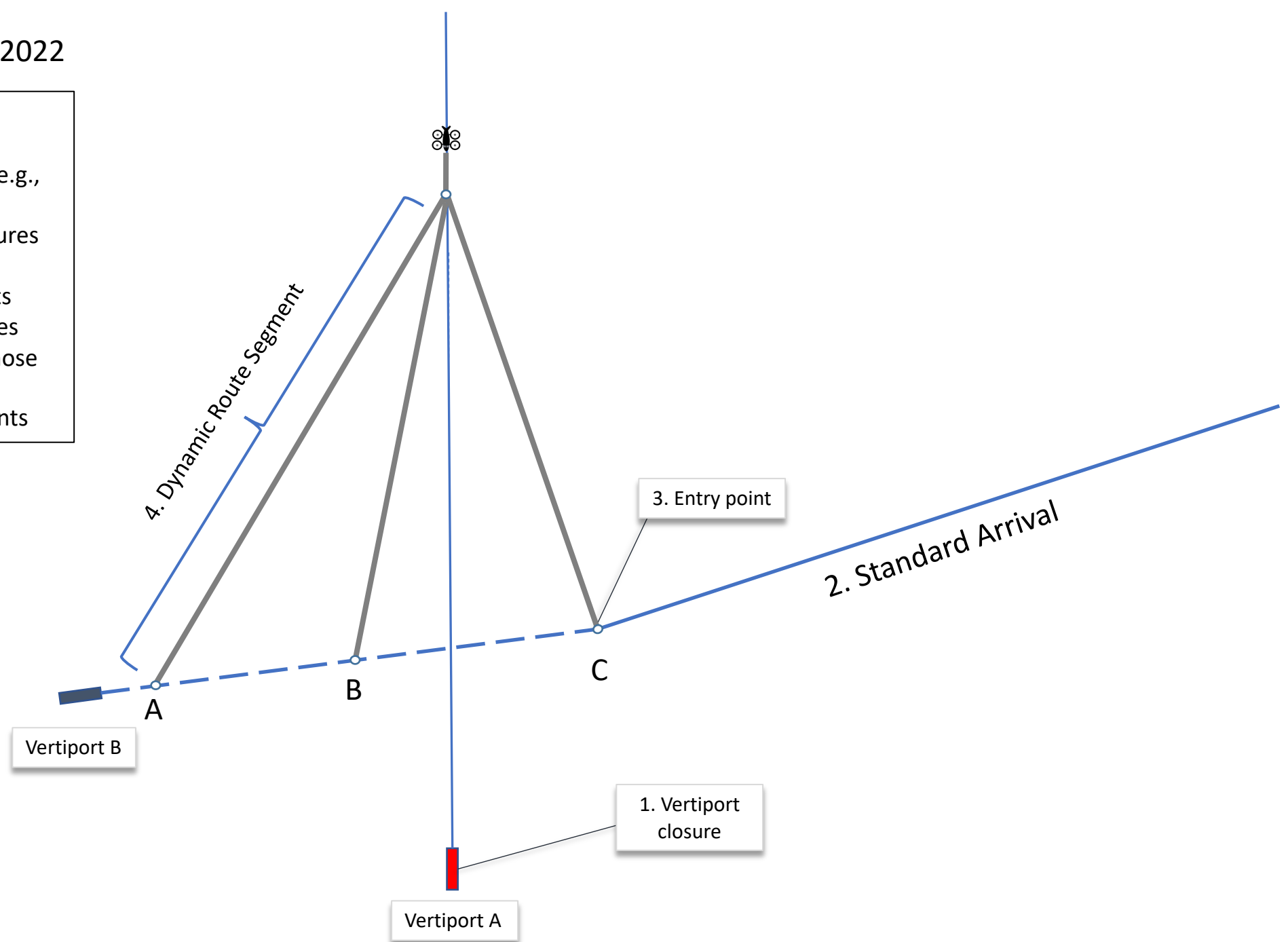
1. Resolve traffic conflicts
2. Avoid hazardous weather
3. **Divert to alternate landing location (may also involve 1 and 2)**
4. Recover from missed approach



Trial Planner Version 2022

Design strategy:

1. Automatic triggering, e.g., vertiport closure
2. Model airspace structures to support replanning
3. Determine entry points along predefined routes
4. Compute route from nose of aircraft to alternate vertiport via entry points

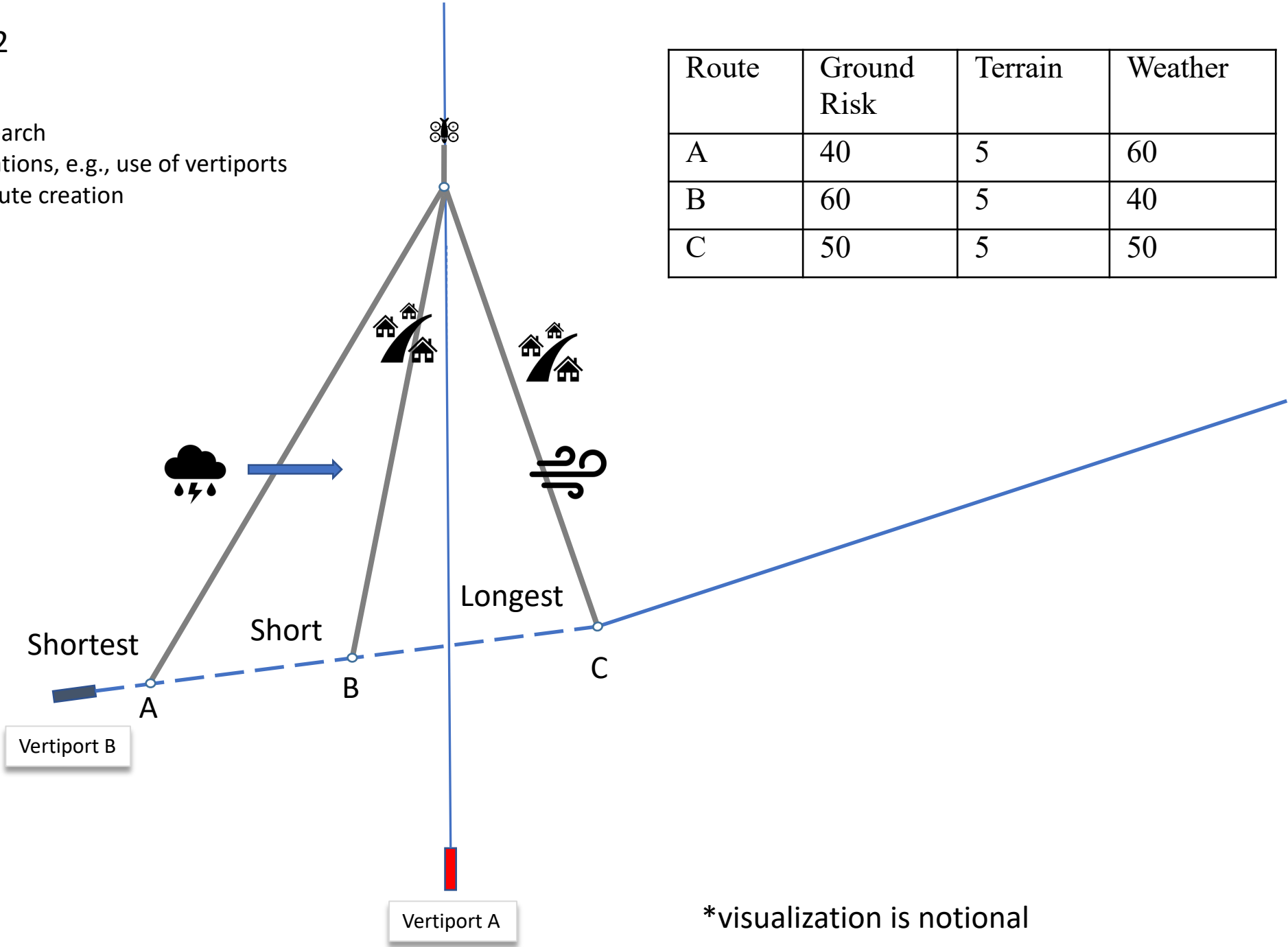




Trial Planner Version 2

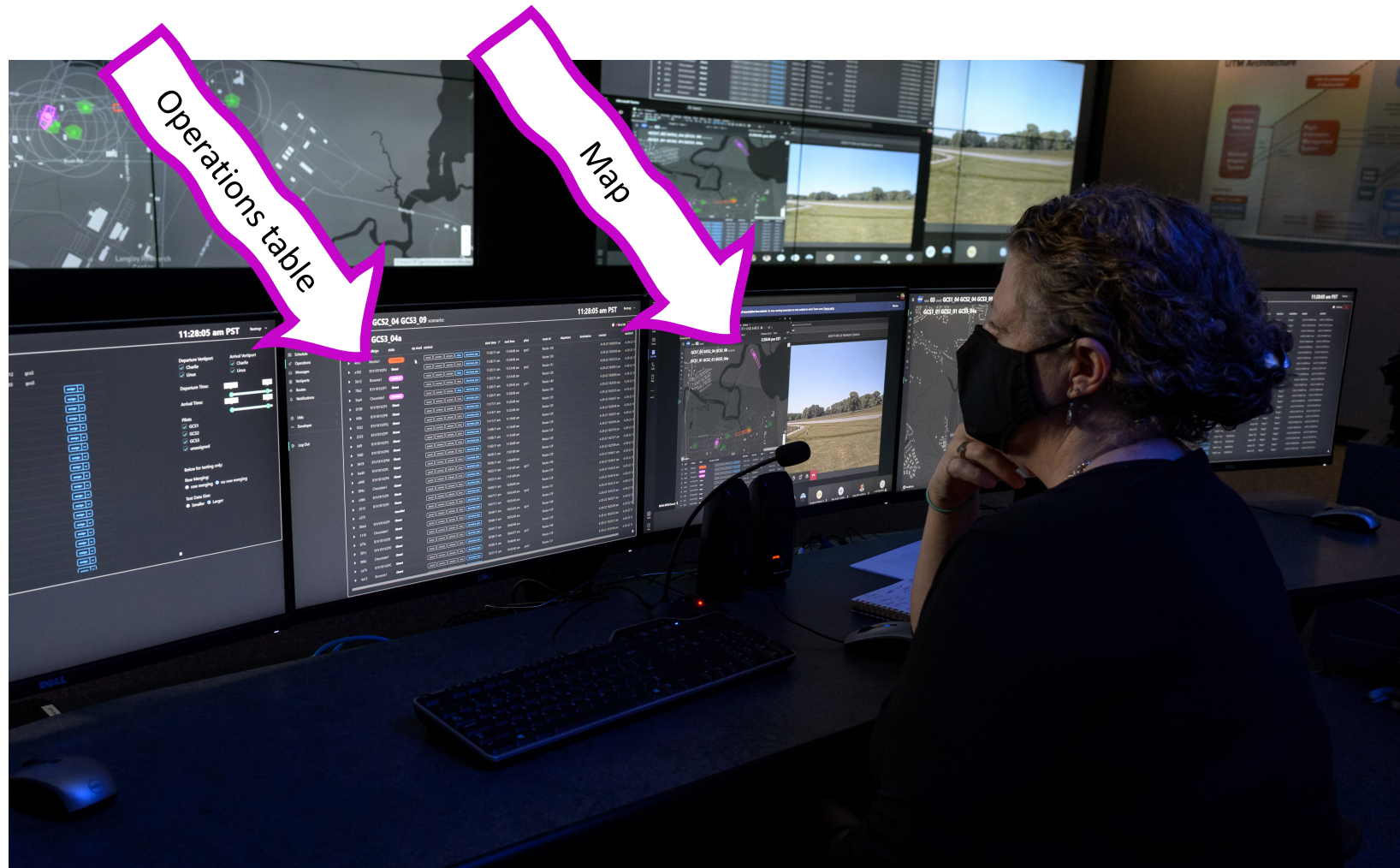
- Our goals with trial planning:
- Support decision-making research
 - Demonstrate for UAM applications, e.g., use of vertiports and airspace structures for route creation

Route	Ground Risk	Terrain	Weather
A	40	5	60
B	60	5	40
C	50	5	50





Fleet Manager Workstation





1. Create and submit an operation

☰

Map

Schedule

Operations

Messages

Vertiports

Routes

Notifications 1

Utils

Developer

Log Out

10:35:11 am PST

fleetmgr

▼

Operations

■ MavLink

new

▶	gufi	callsign	state	op mod	control	start time	end time	pilot	route id	departure	destination	created	updated
▶	f93b	R1V1R1V2PG	Activated		<div>cancel connect activate close download_plan</div>	10:34:53 am	10:43:22 am		Route-129	Range 1	Range 1	8-05-22 10:32:52 am	8-05-22 10:
▶	9129	R1V1R1V2PH	Accepted		<div>cancel connect activate close download_plan</div>	10:37:53 am	10:46:22 am		Route-129	Range 1	Range 1	8-05-22 10:33:09 am	8-05-22 10:
▶	0aa5	R1V1R1V2PA	Closed		<div>cancel connect activate close download_plan</div>	10:40:53 am	10:49:22 am		Route-129	Range 1	Range 1	8-05-22 10:33:28 am	8-05-22 10:
▶	3310	Chocolate1	Accepted		<div>cancel connect activate close download_plan</div>	10:40:53 am	10:49:22 am	gcs1	Route-130	Range 1	Range 1	8-05-22 10:35:04 am	8-05-22 10:
▶	7a8e	R1V1R1V2PB	Accepted		<div>cancel connect activate close download_plan</div>	10:43:53 am	10:52:22 am		Route-129	Range 1	Range 1	8-05-22 10:33:45 am	8-05-22 10:
▶	6a44	R1V1R1V2PC	Accepted		<div>cancel connect activate close download_plan</div>	10:46:53 am	10:55:22 am		Route-129	Range 1	Range 1	8-05-22 10:34:03 am	8-05-22 10:
▶	4683	R1V1R1V2PD	Accepted		<div>cancel connect activate close download_plan</div>	10:49:53 am	10:58:22 am		Route-129	Range 1	Range 1	8-05-22 10:34:21 am	8-05-22 10:
▶	89d0	R1V1R1V2PE	Accepted		<div>cancel connect activate close download_plan</div>	10:52:53 am	11:01:22 am		Route-129	Range 1	Range 1	8-05-22 10:34:40 am	8-05-22 10:
▶	1f1e	R1V1R1V2PF	Accepted		<div>cancel connect activate close download_plan</div>	10:55:53 am	11:04:22 am		Route-129	Range 1	Range 1	8-05-22 10:34:57 am	8-05-22 10:



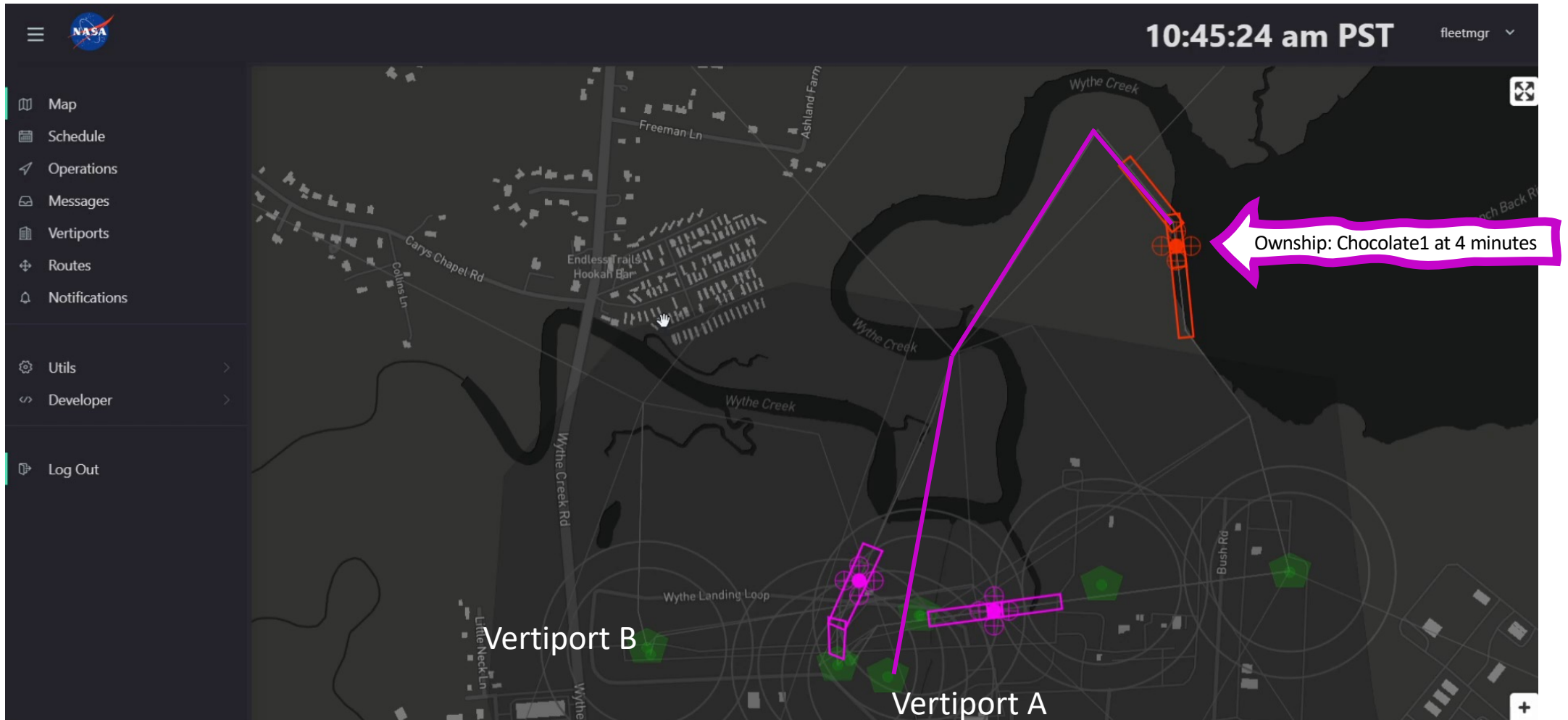
2. Load flight plan and take off

Operations									
gufi	callsign	state	op mod	control	start time	end time	pilot		
▶ f93b	R1V1R1V2PG	Activated		cancel connect activate close download_plan	10:34:53 am	10:43:22 am			
▶ 9129	R1V1R1V2PH	Activated		cancel connect activate close download_plan	10:37:53 am	10:46:22 am			
▶ 0aa5	R1V1R1V2PA	Closed		cancel connect activate close download_plan	10:40:53 am	10:49:22 am			
▶ 3310	Chocolate1	NonConforming		cancel connect activate close download_plan	10:40:53 am	10:49:22 am	gcs1		
▶ 7a8e	R1V1R1V2PB	Accepted		cancel connect activate close download_plan	10:43:53 am	10:52:22 am			
▶ 6a44	R1V1R1V2PC	Accepted		cancel connect activate close download_plan	10:46:53 am	10:55:22 am			
▶ 4683	R1V1R1V2PD	Accepted		cancel connect activate close download_plan	10:49:53 am	10:58:22 am			
▶ 89d0	R1V1R1V2PE	Accepted		cancel connect activate close download_plan	10:52:53 am	11:01:22 am			
▶ 1f1e	R1V1R1V2PF	Accepted		cancel connect activate close download_plan	10:55:53 am	11:04:22 am			
▶ d5c0	R1V1R1V2PI	Accepted		cancel connect activate close download_plan	10:58:53 am	11:07:22 am			
▶ f080	R1V1R1V2PJ	Accepted		cancel connect activate close download_plan	11:01:53 am	11:10:22 am			
▶ 8285	R1V1R1V2PK	Accepted		cancel connect activate close download_plan	11:04:53 am	11:13:22 am			
▶ 306b	R1V1R1V2PL	Accepted		cancel connect activate close download_plan	11:07:53 am	11:16:22 am			
▶ 0594	R1V1R1V2PM	Accepted		cancel connect activate close download_plan	11:10:53 am	11:19:22 am			
▶ ee0a	R1V1R1V2PN	Accepted		cancel connect activate close download_plan	11:13:53 am	11:22:22 am			
▶ a75e	R1V1R1V2PO	Accepted		cancel connect activate close download_plan	11:16:53 am	11:25:22 am			
▶ 3278	R1V1R1V2PP	Accepted		cancel connect activate close download_plan	11:19:53 am	11:28:22 am			
▶ d3d4	R1V1R1V2PQ	Accepted		cancel connect activate close download_plan	11:22:53 am	11:31:22 am			
▶ c5ee	R1V1R1V2PR	Accepted		cancel connect activate close download_plan	11:25:53 am	11:34:22 am			
▶ 6d35	R1V1R1V2PS	Accepted		cancel connect activate close download_plan	11:28:53 am	11:37:22 am			
▶ d4c9	R1V1R1V2PT	Accepted		cancel connect activate close download_plan	11:31:53 am	11:40:22 am			



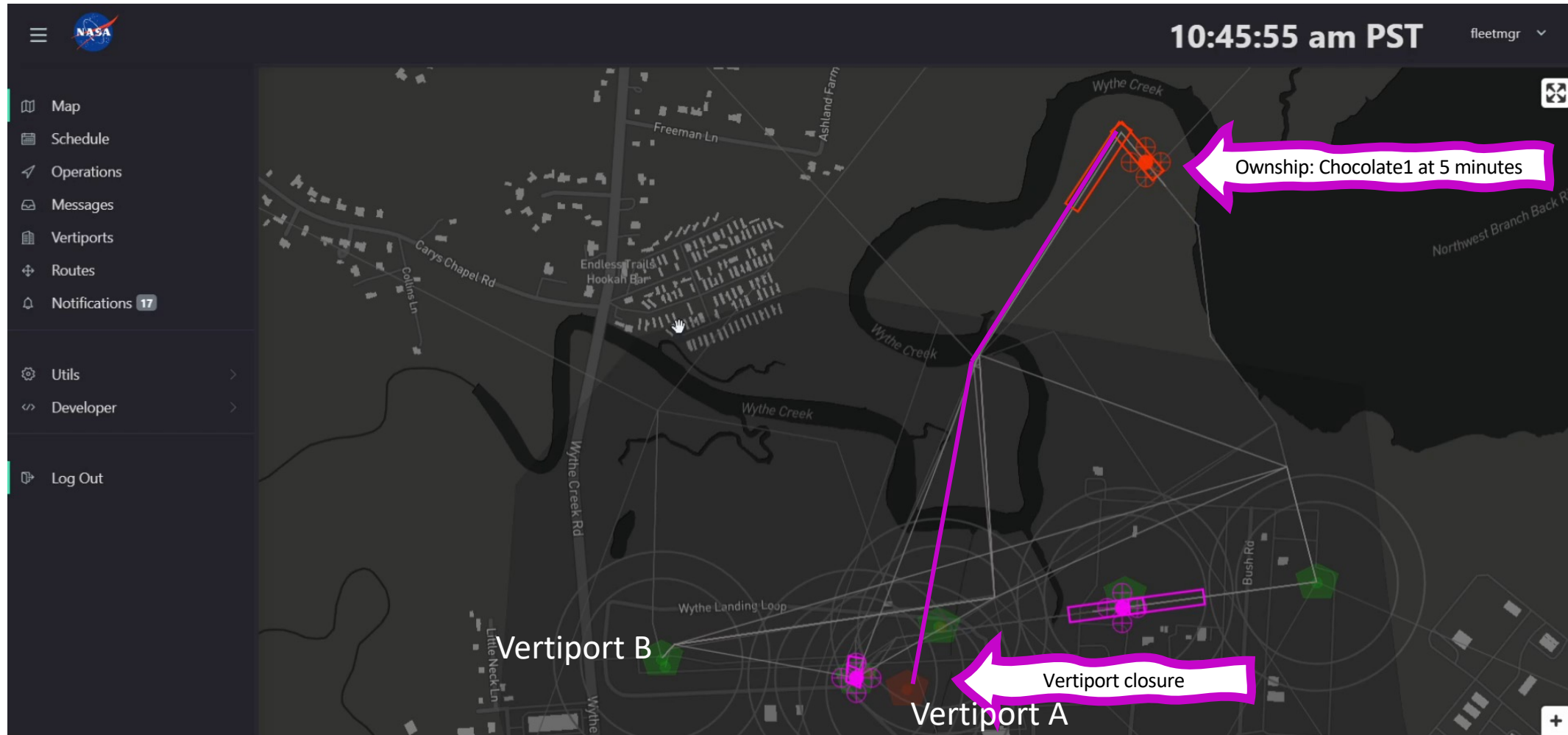


3. GCSO and FMI monitor the airspace





4. Vertiport Closure





5. Trial Planner is activated, and route options were presented

☰

Map

Schedule

Operations

Messages

Vertiports

Routes

Notifications 18

Utils

Developer

Log Out

10:46:20 am PST

fleetmgr

new

Operations

gufi

callsign

state

op mod

control

start time

end time

pilot

route id

departure

destination

created

updated

▶ gufi

R1V1R1V2PG

Closed

cancel

connect

activate

close

download_plan

10:34:53 am

10:43:22 am

Route-129

Range 1

Range 1

8-05-22 10:32:52 am

8-05-22 10:32:52 am

▶ f93b

R1V1R1V2PH

Activated

cancel

connect

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close

download_plan

10:37:53 am

10:46:22 am

Route-129

Range 1

Range 1

8-05-22 10:33:09 am

8-05-22 10:33:09 am

▶ 0aa5

R1V1R1V2PA

Closed

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connect

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download_plan

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Route-129

Range 1

Range 1

8-05-22 10:33:28 am

8-05-22 10:33:28 am

▼ 3310

Chocolate1

Contingent

cancel

connect

activate

close

download_plan

10:40:53 am

10:49:22 am

gcs1

Route-130

Range 1

Range 1

8-05-22 10:35:04 am

8-05-22 10:35:04 am

Messages

Volume Info

Trial Planning

Json Tree

Raw Json

Stop Trial Planning

Invoke Trial Planning

#	id	created	updated	expires	destination	status	duration	distance	casualty	terrain	weather	control
3	758f	10:45:47 am	10:45:47 am	10:47:16 am	Linus	Proposed	3:15	1.72 km	40	5	60	<div>submit</div> <div>reject</div>
2	5450	10:45:47 am	10:45:47 am	10:47:16 am	Linus	Proposed	** 3:15	1.71 km	50	5	50	<div>submit</div> <div>reject</div>
1	0649	10:45:47 am	10:45:47 am	10:47:16 am	Linus	Proposed	3:22	** 1.71 km	60	5	40	<div>submit</div> <div>reject</div>

▶ 7a8e

R1V1R1V2PB

Activated

cancel

connect

activate

close

download_plan

10:43:53 am

10:52:22 am

Route-129

Range 1

Range 1

8-05-22 10:33:45 am

8-05-22 10:33:45 am

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R1V1R1V2PC

Accepted

cancel

connect

activate

close

download_plan

10:46:53 am

10:55:22 am

Route-129

Range 1

Range 1

8-05-22 10:34:03 am

8-05-22 10:34:03 am

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R1V1R1V2PD

Accepted

cancel

connect

activate

close

download_plan

10:49:53 am

10:58:22 am

Route-129

Range 1

Range 1

8-05-22 10:34:21 am

8-05-22 10:34:21 am

▶ 89d0

R1V1R1V2PE

Accepted

cancel

connect

activate

close

download_plan

10:52:53 am

11:01:22 am

Route-129

Range 1

Range 1

8-05-22 10:34:40 am

8-05-22 10:34:40 am

▶ 1f1e

R1V1R1V2PF

Accepted

cancel

connect

activate

close

download_plan

10:55:53 am

11:04:22 am

Route-129

Range 1

Range 1

8-05-22 10:34:57 am

8-05-22 10:34:57 am

▶ d5c0

R1V1R1V2PI

Accepted

cancel

connect

activate

close

download_plan

10:58:53 am

11:07:22 am

Route-129

Range 1

Range 1

8-05-22 10:35:15 am

8-05-22 10:35:15 am

▶ f080

R1V1R1V2PJ

Accepted

cancel

connect

activate

close

download_plan

11:01:53 am

11:10:22 am

Route-129

Range 1

Range 1

8-05-22 10:35:33 am

8-05-22 10:35:33 am

▶ 8285

R1V1R1V2PK

Accepted

cancel

connect

activate

close

download_plan

11:04:53 am

11:13:22 am

Route-129

Range 1

Range 1

8-05-22 10:35:51 am

8-05-22 10:35:51 am

▶ 306b

R1V1R1V2PL

Accepted

cancel

connect

activate

close

download_plan

11:07:53 am

11:16:22 am

Route-129

Range 1

Range 1

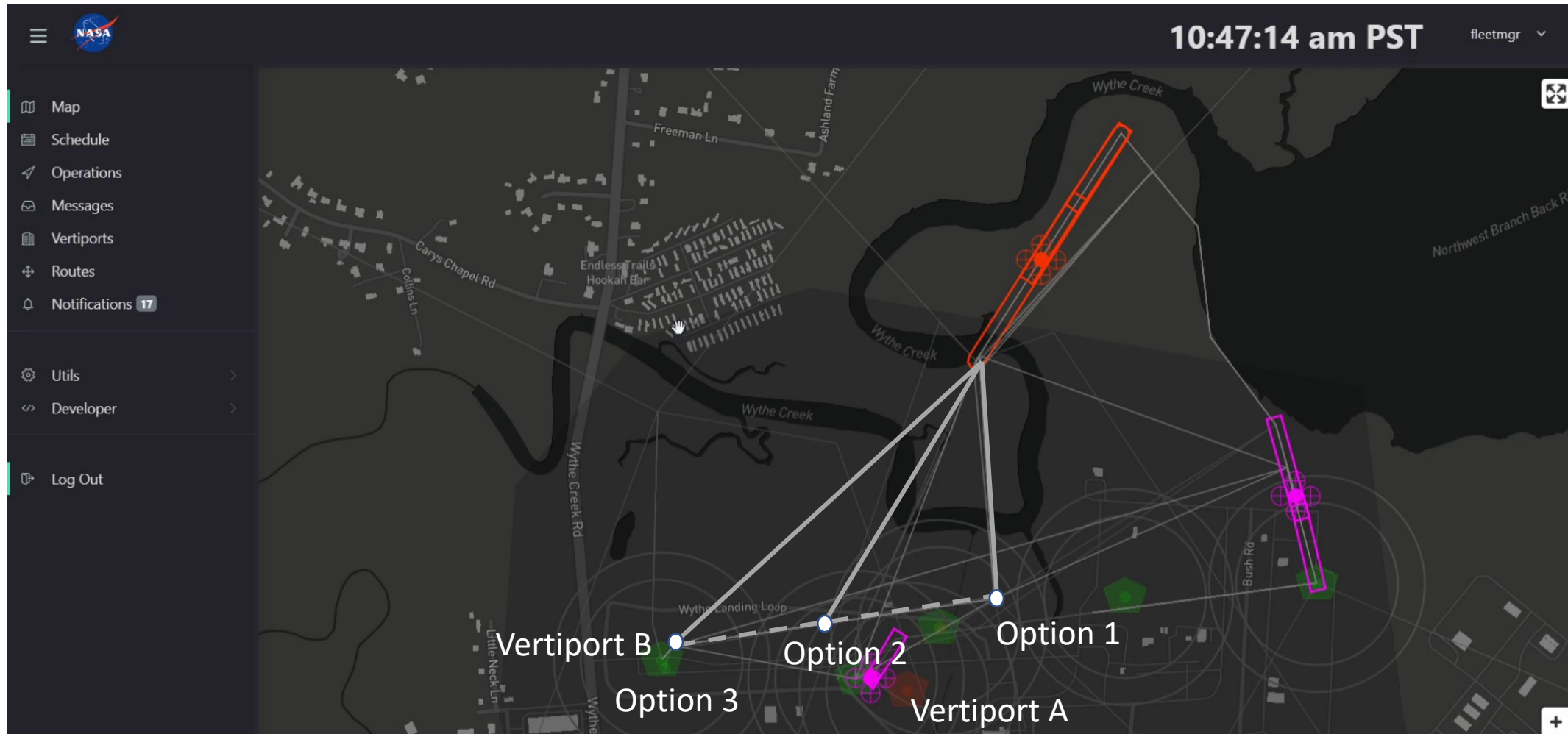
8-05-22 10:36:09 am

8-05-22 10:36:09 am



Route options

*not actually displayed on map





Route	Ground Risk	Terrain	Weather
A	40	5	60
B	60	5	40
C	50	5	50

*Factor values were notional



Route Decision Factors: Distance, Ground Risk (Casualty), Terrain, Weather

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10:46:20 am PST

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Operations

MavLink

new

gufi	callsign	state	op mod	control	start time	end time	pilot	route id	departure	destination	created	updated
f93b	R1V1R1V2PG	Closed		<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	10:34:53 am	10:43:22 am		Route-129	Range 1	Range 1	8-05-22 10:32:52 am	8-05-22 10:32:52 am
9129	R1V1R1V2PH	Activated	⚠	<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	10:37:53 am	10:46:22 am		Route-129	Range 1	Range 1	8-05-22 10:33:09 am	8-05-22 10:33:09 am
0aa5	R1V1R1V2PA	Closed		<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	10:40:53 am	10:49:22 am		Route-129	Range 1	Range 1	8-05-22 10:33:28 am	8-05-22 10:33:28 am
3310	Chocolate1	Contingent	⚠	<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	10:40:53 am	10:49:22 am	gcs1	Route-130	Range 1	Range 1	8-05-22 10:35:04 am	8-05-22 10:35:04 am

Messages

Volume Info

Trial Planning

Json Tree

Raw Json

Stop Trial Planning

Invoke Trial Planning

#	id	created	updated	expires	destination	status	duration	distance	casualty	terrain	weather	control
3	758f	10:45:47 am	10:45:47 am	10:47:16 am	Linus	Proposed	3:15	1.72 km	40	5	60	<button>submit</button> <button>reject</button>
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7a8e	R1V1R1V2PB	Activated	⚠	<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	10:43:53 am	10:52:22 am		Route-129	Range 1	Range 1	8-05-22 10:33:45 am	8-05-22 10:33:45 am
6a44	R1V1R1V2PC	Accepted		<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	10:46:53 am	10:55:22 am		Route-129	Range 1	Range 1	8-05-22 10:34:03 am	8-05-22 10:34:03 am
4683	R1V1R1V2PD	Accepted		<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	10:49:53 am	10:58:22 am		Route-129	Range 1	Range 1	8-05-22 10:34:21 am	8-05-22 10:34:21 am
89d0	R1V1R1V2PE	Accepted		<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	10:52:53 am	11:01:22 am		Route-129	Range 1	Range 1	8-05-22 10:34:40 am	8-05-22 10:34:40 am
1f1e	R1V1R1V2PF	Accepted		<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	10:55:53 am	11:04:22 am		Route-129	Range 1	Range 1	8-05-22 10:34:57 am	8-05-22 10:34:57 am
d5c0	R1V1R1V2PI	Accepted		<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	10:58:53 am	11:07:22 am		Route-129	Range 1	Range 1	8-05-22 10:35:15 am	8-05-22 10:35:15 am
f080	R1V1R1V2PJ	Accepted		<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	11:01:53 am	11:10:22 am		Route-129	Range 1	Range 1	8-05-22 10:35:33 am	8-05-22 10:35:33 am
8285	R1V1R1V2PK	Accepted		<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	11:04:53 am	11:13:22 am		Route-129	Range 1	Range 1	8-05-22 10:35:51 am	8-05-22 10:35:51 am
306b	R1V1R1V2PL	Accepted		<button>cancel</button> <button>connect</button> <button>activate</button> <button>close</button> <button>download_plan</button>	11:07:53 am	11:16:22 am		Route-129	Range 1	Range 1	8-05-22 10:36:09 am	8-05-22 10:36:09 am



7. Trial Planner is activated, and a new reroute is selected

10:46:20 am PST fleetmgr

Map
Schedule
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Vertiports
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Utils
Developer
Log Out

Operations

gufi callsign state op mod control start time end time pilot route id departure destination created updated

▶ f93b R1V1R1V2PG Closed [cancel] [connect] [activate] [close] [download_plan] 10:34:53 am 10:43:22 am Route-129 Range 1 Range 1 8-05-22 10:32:52 am 8-05-22 10

▶ 9129 R1V1R1V2PH Activated [cancel] [connect] [activate] [close] [download_plan] 10:37:53 am 10:46:22 am Route-129 Range 1 Range 1 8-05-22 10:33:09 am 8-05-22 10

▶ 0aa5 R1V1R1V2PA Closed [cancel] [connect] [activate] [close] [download_plan] 10:40:53 am 10:49:22 am Route-129 Range 1 Range 1 8-05-22 10:33:28 am 8-05-22 10

▼ 3310 Chocolate1 Contingent [cancel] [connect] [activate] [close] [download_plan] 10:40:53 am 10:49:22 am gcs1 Route-130 Range 1 Range 1 8-05-22 10:35:04 am 8-05-22 10

Messages Volume Info Trial Planning Json Tree Raw Json

Stop Trial Planning Invoke Trial Planning

#	id	created	updated	expires	destination	status	duration	distance	casualty	terrain	weather	control
3	758f	10:45:47 am	10:45:47 am	10:47:16 am	Linus	Proposed	3:15	1.72 km	40	5	60	[submit] [reject]
2	5450	10:45:47 am	10:45:47 am	10:47:16 am	Linus	Proposed	** 3:15	1.71 km	50	5	50	[submit] [reject]
1	0649	10:45:47 am	10:45:47 am	10:47:16 am	Linus	Proposed	3:22	** 1.71 km	60	5	40	[submit] [reject]

7a8e R1V1R1V2PB Activated [cancel] [connect] [activate] [close] [download_plan] 10:43:53 am 10:52:22 am Route-129 Range 1 Range 1 8-05-22 10:33:45 am 8-05-22 10

▶ 6a44 R1V1R1V2PC Accepted [cancel] [connect] [activate] [close] [download_plan] 10:46:53 am 10:55:22 am Route-129 Range 1 Range 1 8-05-22 10:34:03 am 8-05-22 10

▶ 4683 R1V1R1V2PD Accepted [cancel] [connect] [activate] [close] [download_plan] 10:49:53 am 10:58:22 am Route-129 Range 1 Range 1 8-05-22 10:34:21 am 8-05-22 10

▶ 89d0 R1V1R1V2PE Accepted [cancel] [connect] [activate] [close] [download_plan] 10:52:53 am 11:01:22 am Route-129 Range 1 Range 1 8-05-22 10:34:40 am 8-05-22 10

▶ 1f1e R1V1R1V2PF Accepted [cancel] [connect] [activate] [close] [download_plan] 10:55:53 am 11:04:22 am Route-129 Range 1 Range 1 8-05-22 10:34:57 am 8-05-22 10

▶ d5c0 R1V1R1V2PI Accepted [cancel] [connect] [activate] [close] [download_plan] 10:58:53 am 11:07:22 am Route-129 Range 1 Range 1 8-05-22 10:35:15 am 8-05-22 10

▶ f080 R1V1R1V2PJ Accepted [cancel] [connect] [activate] [close] [download_plan] 11:01:53 am 11:10:22 am Route-129 Range 1 Range 1 8-05-22 10:35:33 am 8-05-22 10

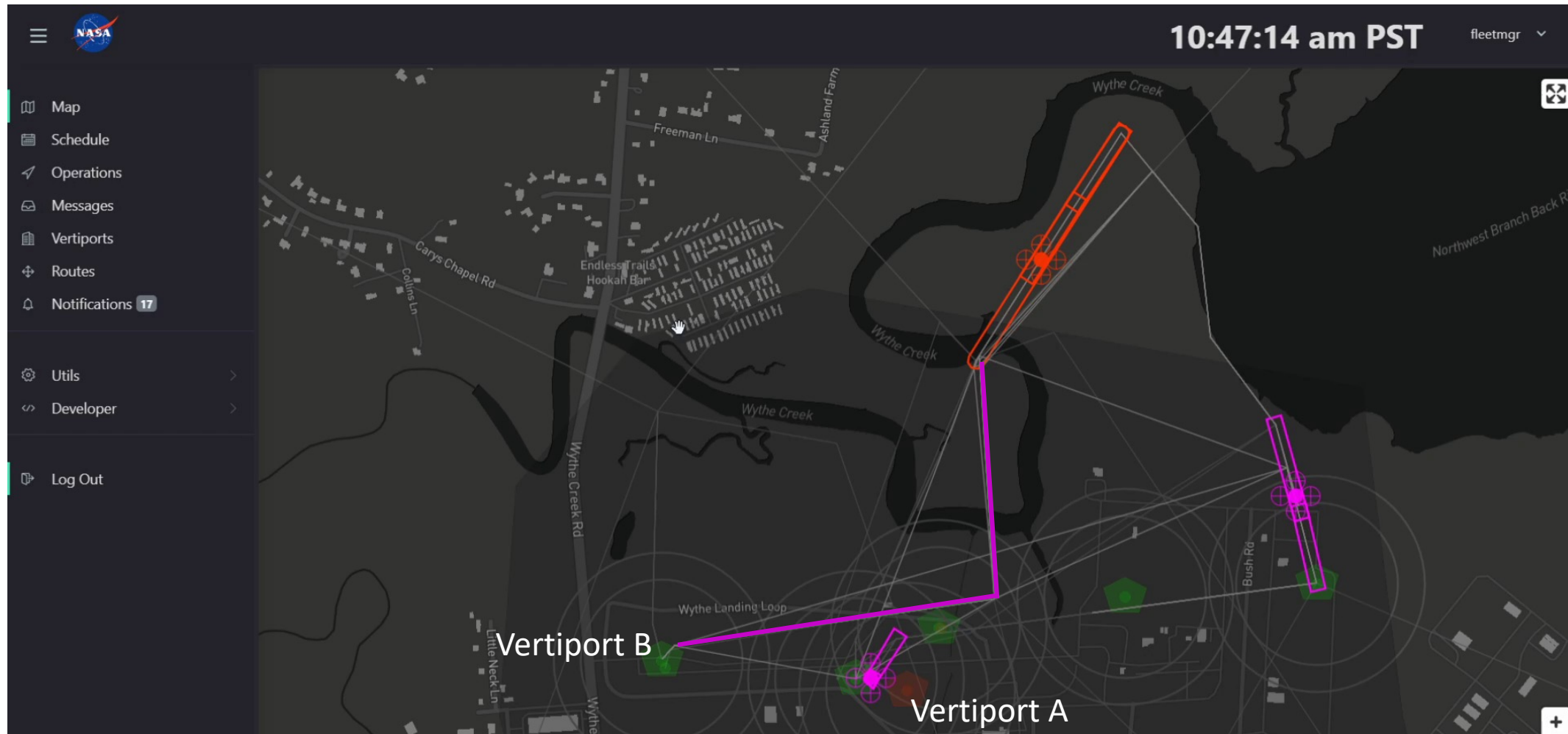
▶ 8285 R1V1R1V2PK Accepted [cancel] [connect] [activate] [close] [download_plan] 11:04:53 am 11:13:22 am Route-129 Range 1 Range 1 8-05-22 10:35:51 am 8-05-22 10

▶ 306b R1V1R1V2PL Accepted [cancel] [connect] [activate] [close] [download_plan] 11:07:53 am 11:16:22 am Route-129 Range 1 Range 1 8-05-22 10:36:09 am 8-05-22 10

Route selection button



8. Flight crew reviewed and executed new route





Evaluation

Purpose: Evaluate the quality of the interaction with the trial planner

Goals:

- Collect human factors data on workload, situation awareness, and trust in automation
- Improve the FMI software through usability data collected

Participants:

- 3 air traffic control SMEs at NASA Ames
- 6 pilots at NASA Langley





Testing Schedule

- 1 hour training session with the fleet manager workstation
- 3 FM participants ran 3, 30 minute runs every day for 4 days, for a total of 12 runs
- 20 minutes for the scenario, 10 minutes for the questionnaire
- Run example:
 1. Pilot performs preflight checklist
 2. FM confirms FMI connectivity
 3. Pilot commands takeoff
 4. Pilot and fleet manager monitored the airspace
 5. Scenario Types:
 - A. Scenario 1: Nominal automated landing occurred at scheduled vertiport
 - B. Scenario 2: Original vertiport closes, and diverted route created through use of the trial planner and automated landing at an unscheduled alternate vertiport

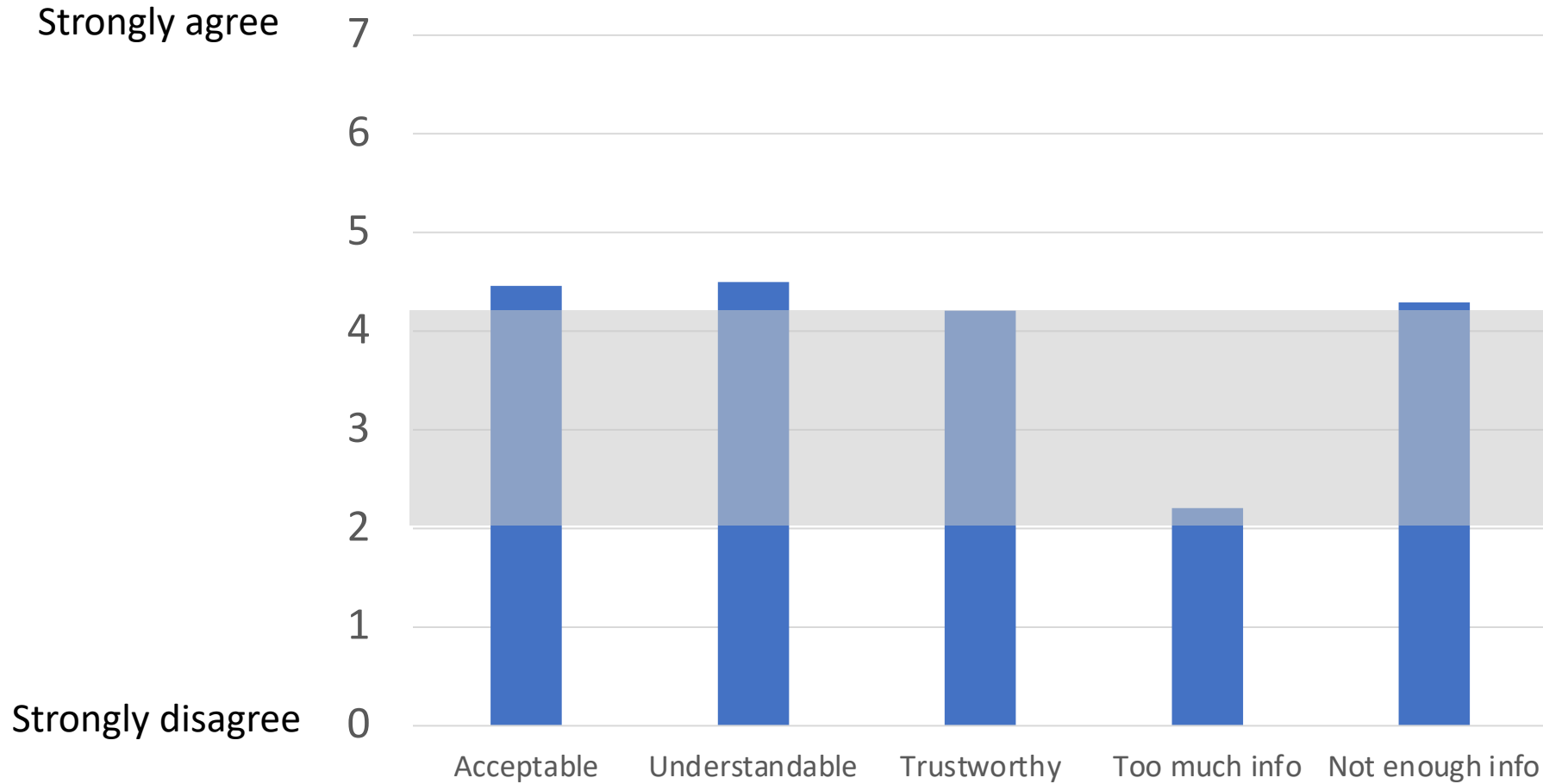


Metrics

1. The trial-planner solutions were acceptable.
2. The trial-planner solutions were understandable.
3. The trial-planner solutions were trustworthy.
4. The trial-planner displayed too much information.
5. The trial-planner did not display enough information.



Results: Average Ratings Evaluation Scales





Limitations

- Route selection was mandated
- Not enough time to select and execute routes
- Selected routes were not displayed visually
- Route selection factors were not visually displayed
- Quality of decision-making was not evaluated



Future Work: Trial Planner Version 2023

- Engage trial planner over a map display
- Highlight route selections over the map
- Show relevant decision factors over the map
- Employ decision making metrics in evaluation
- Explore different scenarios
 - Longer operations over SF/Bay Area and Norfolk, VA *to add variation to the decision factors
 - Missed approach routes



Backup



Methods (Continued)

- Video and audio recordings
- 9 unique subjective questionnaires across 12 runs
 - NASA-TLX [7]
 - Situation Awareness Rating Technique (SART) [10]
 - Perceived Risk [12]
 - Human-Automation Trust [8]
 - Trial Planner UX Survey
 - Post-Scenario review

END OF DAY

- Human-Automation Trust [8] (again)
- Post Study System Usability Questionnaire [9]
- Safety and Risk Perceptions of Automation [3]
- FMI Usability Questionnaire

