2024 ASI Symposium| Speaker: Peter Jackson

ASEAN Network Modeling and Translational Research

Co-authors: Benjamin Tan, Gengling Dai, Rakesh Nandi, Darryl Teo

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN | Aviation Studies Institute

Aviation Studies Institute

Overview

Aviation Studies Institute

- **Review of Collaborative Decision Making (CDM) Project**
- Overview of Network Capacity and Network Collaboration Projects
  - Dimensions: Network, Schedules, Routes, Trajectories, Capacities, and Information Regimes
  - Simulation Approaches and Insights
    - Global Optimization
    - Local Optimization
- The Airspace Design Game

Information Sharing & Collaborative Decision Making (CDM)

PI: Karthyek Murthy

Research Assistants: Lim Chee Chin, Ho Hui Qi

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN | Aviation Studies Institute

ASI
Aviation Studies Institute

Project Objective and Tool Developed

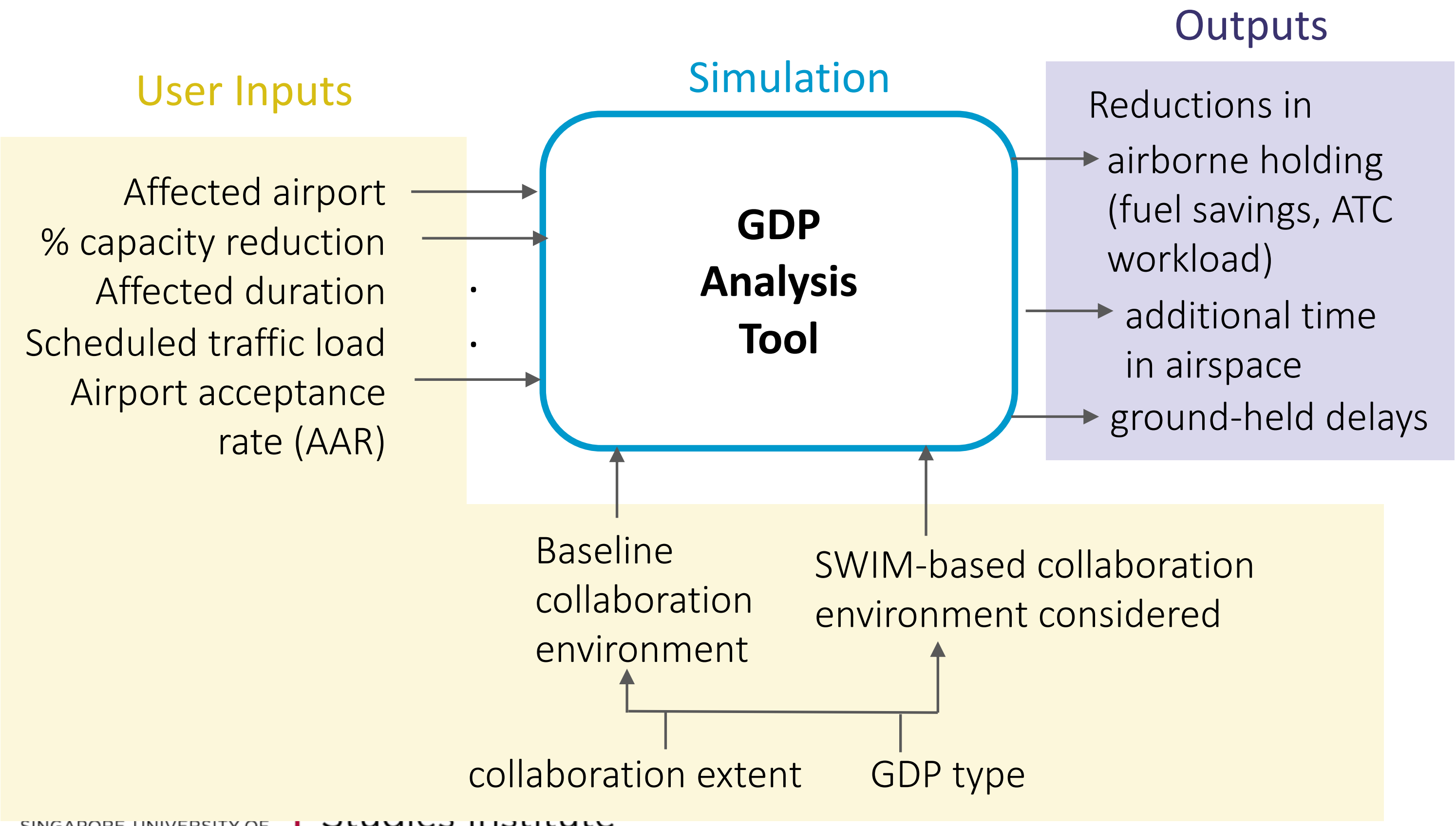
The picture can't be displayed.

To quantify the scale of airborne and ground delay savings that can be achieved with the improved predictability and decision-making possible with SWIM-coordinated Ground Delay Programs

The image part

rId2 was not found in the file.

Quantifying Delay Savings with SE Asia GDP Analysis Tool



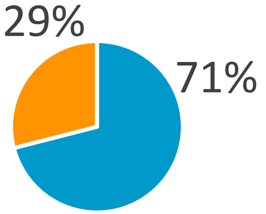
- Users can inform various capacity reduction scenarios and collaborative environments.
- Users gain an understanding of how increased participation in information sharing translates to decreased airborne holding and savings in fuel consumption, ATC workload, etc.
- Findings can then be used to promote the cooperation necessary for a harmonized ASEAN ATM.

Key Findings

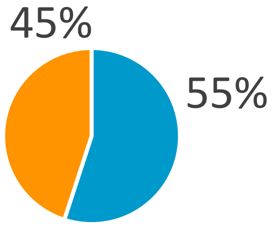
Main takeaways on benefits of SWIM based Ground Delay Program Management:

Cumulative airborne holding (**fuel savings**)

684 fewer minutes (52% of total minutes) for airborne flights when compared to existing multi-nodal arrangement



- Attainable with Static GDP
- Additional Improvement due to Dynamic GDP

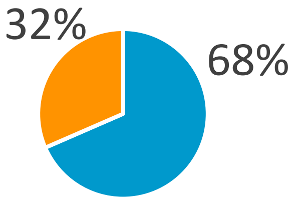


- Attainable with Level 3 Collaboration
- Additional Improvement due to Level 2&3 Collaboration

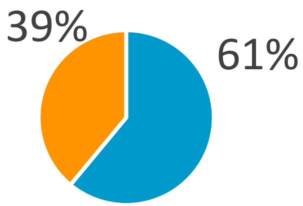
Avg. Additional time in airspace (per flight)

9 minutes fewer in airspace when compared to multi-nodal baseline

29 minutes fewer in airspace when compared to no GDP baseline



- Attainable with Static GDP
- Additional Improvement due to Dynamic GDP



- Attainable with Level 3 Collaboration
- Additional Improvement due to Level 2&3 Collaboration

Flights airborne per minute (**ATC workload**)

5 – 6 fewer flights airborne per minute when compared to multi-nodal

- The greater the airport's AAR and extent of GDP collaboration, the greater the reduction in ATC workload

Throughput efficiency

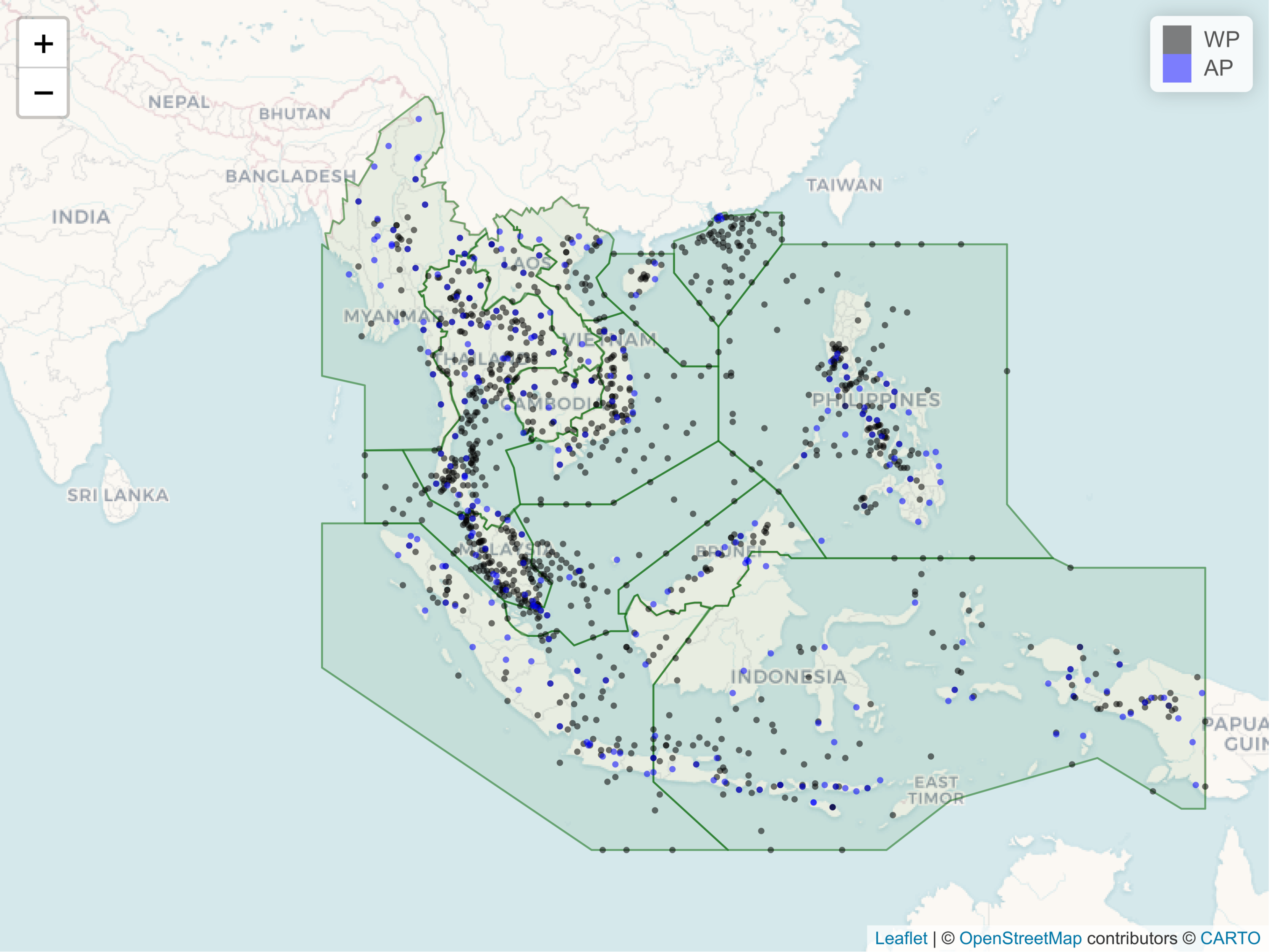
2 percentage points increase in throughput efficiency with dynamic GDP when compared to existing static GDP

Overview

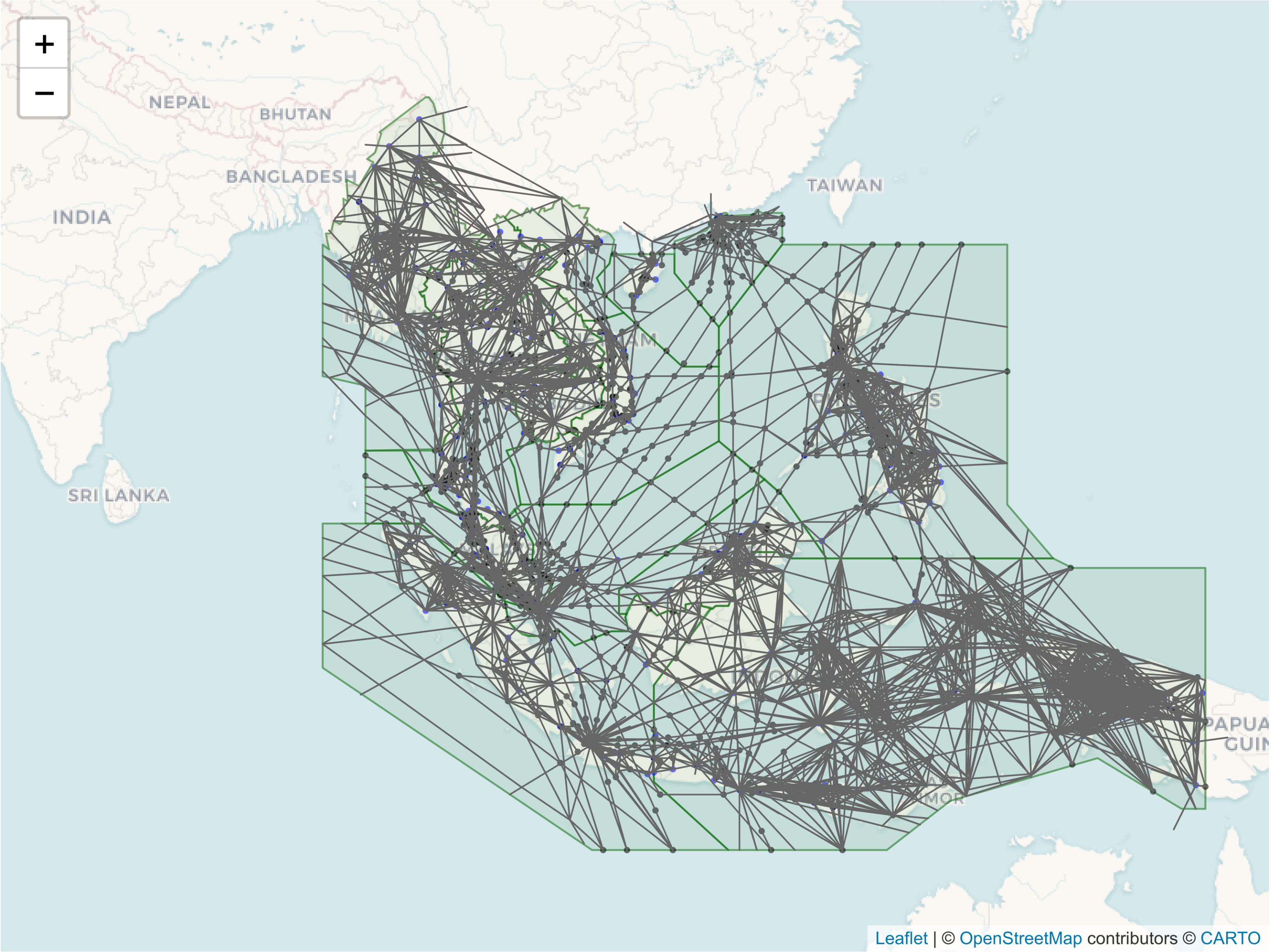
- Review of Collaborative Decision Making (CDM) Project
- **Overview of Network Capacity and Network Collaboration Projects**
  - **Dimensions: Network, Schedules, Routes, Trajectories, Capacities, and Information Regimes**
  - Simulation Approaches and Insights
    - Global Optimization
    - Local Optimization
- The Airspace Design Game

ASEAN(+Sanya & Hong Kong) Airports and Waypoints

298 airports, 14 FIRs, 63 ACCs



ASEAN(+Sanya & Hong Kong) Route Network



Note the sparsity of the network over the South China Sea

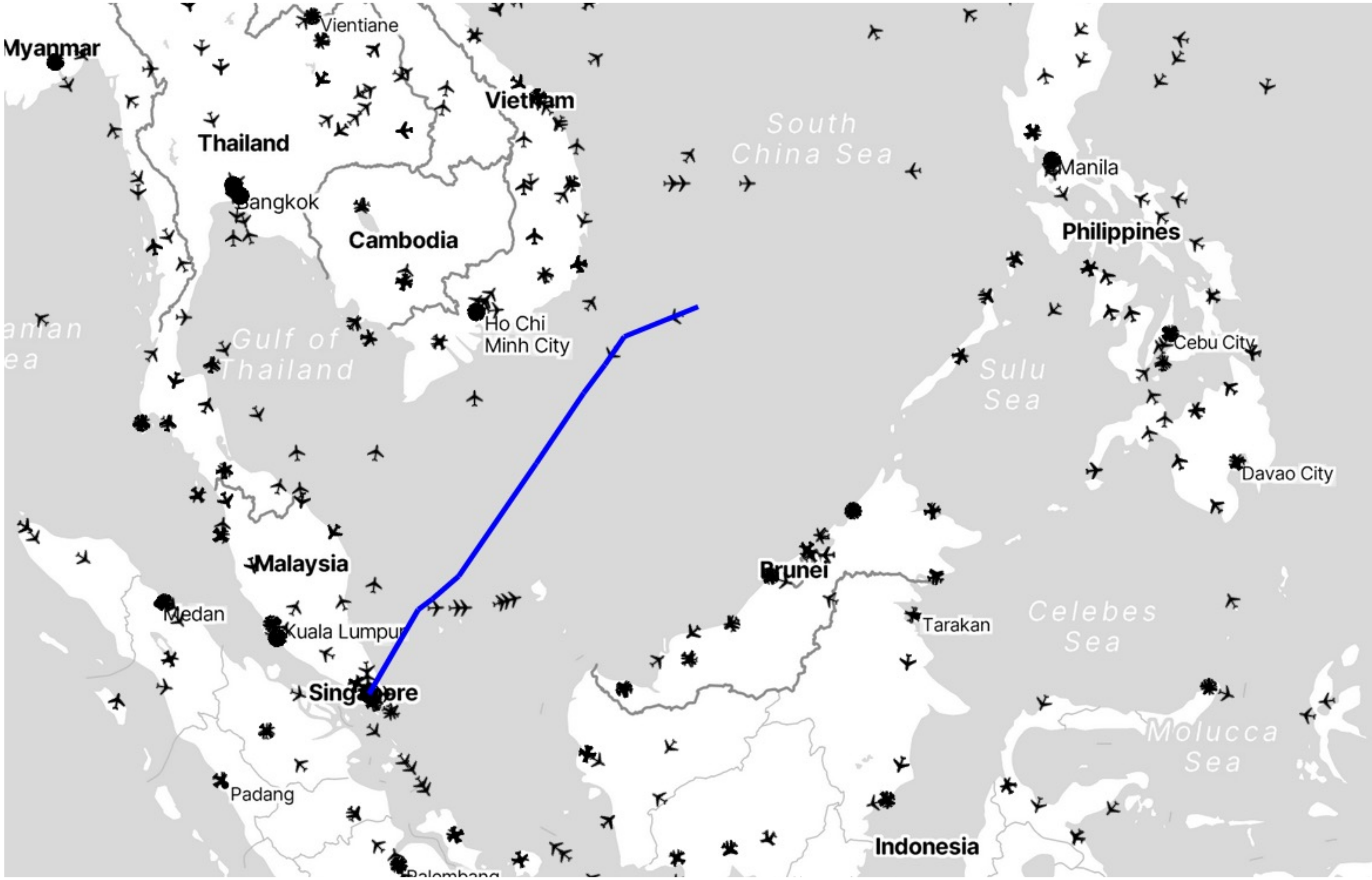
Flight Schedules (OAG)

ASI Aviation Studies Institute

~10,000 flights per day

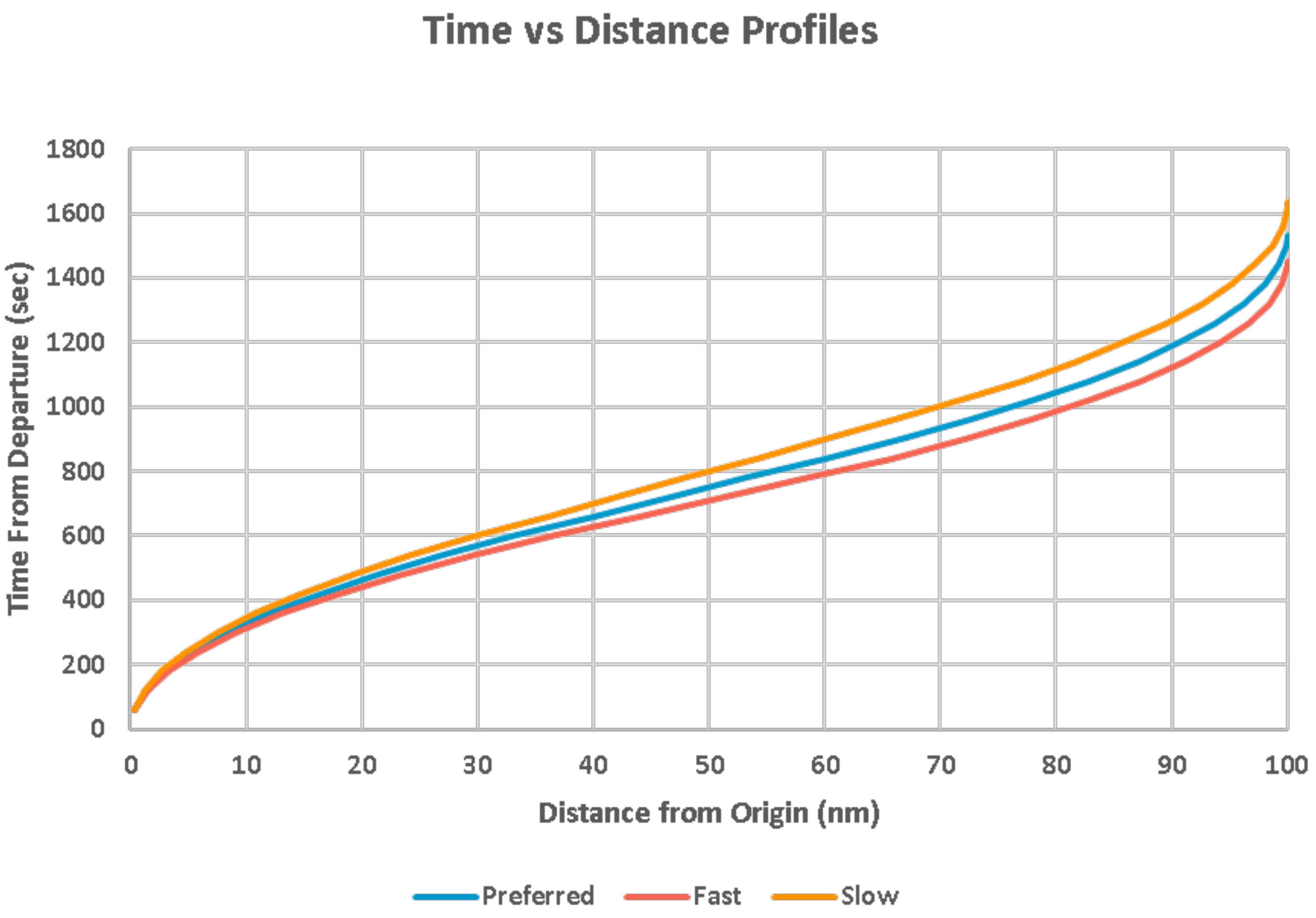
AirlineCode	FlightNumber	fnia	DepIATA	ArrIATA	DepCountry	ArrCountry	SchedDepUtc	SchedArrUtc	TailNumber	AircraftType
3U	610	3U610	SVO	CTU	RU	CN	10/8/2019 17:20	11/8/2019 0:55	B5945	330
3U	8713	3U8713	CTU	HFE	CN	CN	11/8/2019 12:10	11/8/2019 14:25	B5945	330
3U	8924	3U8924	NKG	CTU	CN	CN	12/8/2019 3:45	12/8/2019 6:20	B5945	321
3U	8925	3U8925	CTU	HKT	CN	TH	16/8/2019 12:45	16/8/2019 16:25	B5945	321
3U	8926	3U8926	HKT	CTU	TH	CN	16/8/2019 17:25	16/8/2019 21:20	B5945	321
3U	8645	3U8645	CTU	CAN	CN	CN	12/8/2019 7:30	12/8/2019 9:55	B5945	330
3U	8646	3U8646	CAN	CTU	CN	CN	13/8/2019 1:40	13/8/2019 4:10	B5945	330
3U	609	3U609	CTU	SVO	CN	RU	13/8/2019 7:15	13/8/2019 15:25	B5945	330
3U	610	3U610	SVO	CTU	RU	CN	13/8/2019 17:20	14/8/2019 0:55	B5945	330
3U	8647	3U8647	CTU	PVG	CN	CN	17/8/2019 9:25	17/8/2019 12:15	B5945	330
3U	8645	3U8645	CAN	SPN	CN	MP	12/8/2019 12:10	12/8/2019 17:10	B5945	A333
3U	8646	3U8646	SPN	CAN	MP	CN	12/8/2019 18:20	12/8/2019 23:35	B5945	A333
3U	8965	3U8965	CTU	PVG	CN	CN	14/8/2019 7:35	14/8/2019 10:30	B5945	359
3U	8966	3U8966	PVG	CTU	CN	CN	14/8/2019 11:45	14/8/2019 15:15	B5945	359
3U	8923	3U8923	CTU	NKG	CN	CN	15/8/2019 0:10	15/8/2019 2:30	B5945	359
3U	8961	3U8961	CTU	PVG	CN	CN	16/8/2019 23:40	17/8/2019 2:30	B5945	359
3U	8647	3U8647	PVG	SPN	CN	MP	17/8/2019 14:30	17/8/2019 18:30	B5945	A333
3U	8648	3U8648	SPN	PVG	MP	CN	17/8/2019 20:10	18/8/2019 0:45	B5945	A333
3U	8173	3U8173	CTU	NKG	CN	CN	18/8/2019 8:50	18/8/2019 11:25	B5945	330
3U	8271	3U8271	CTU	CPH	CN	DK	18/8/2019 18:00	19/8/2019 4:10	B5945	330
3U	8272	3U8272	CPH	CTU	DK	CN	19/8/2019 11:30	19/8/2019 21:00	B5945	330
3U	603	3U603	CTU	DXB	CN	AE	21/8/2019 7:05	21/8/2019 14:25	B5945	330
3U	604	3U604	DXB	CTU	AE	CN	21/8/2019 16:55	21/8/2019 23:45	B5945	330
3U	8295	3U8295	CTU	PRG	CN	CZ	23/8/2019 18:15	24/8/2019 4:50	B5945	330
3U	8296	3U8296	PRG	CTU	CZ	CN	24/8/2019 13:00	24/8/2019 22:25	B5945	330
3U	8945	3U8945	INC	DXB	CN	AE	20/8/2019 3:55	20/8/2019 12:10	B5945	330
3U	8946	3U8946	DXB	INC	AE	CN	20/8/2019 14:10	20/8/2019 21:15	B5945	330
3U	8648	3U8648	SPN	PVG	MP	CN	10/8/2019 20:10	11/8/2019 0:45	NULL	A333
3U	8657	3U8657	CTU	LXA	CN	CN	10/8/2019 22:10	11/8/2019 0:35	NULL	330

Route Planning

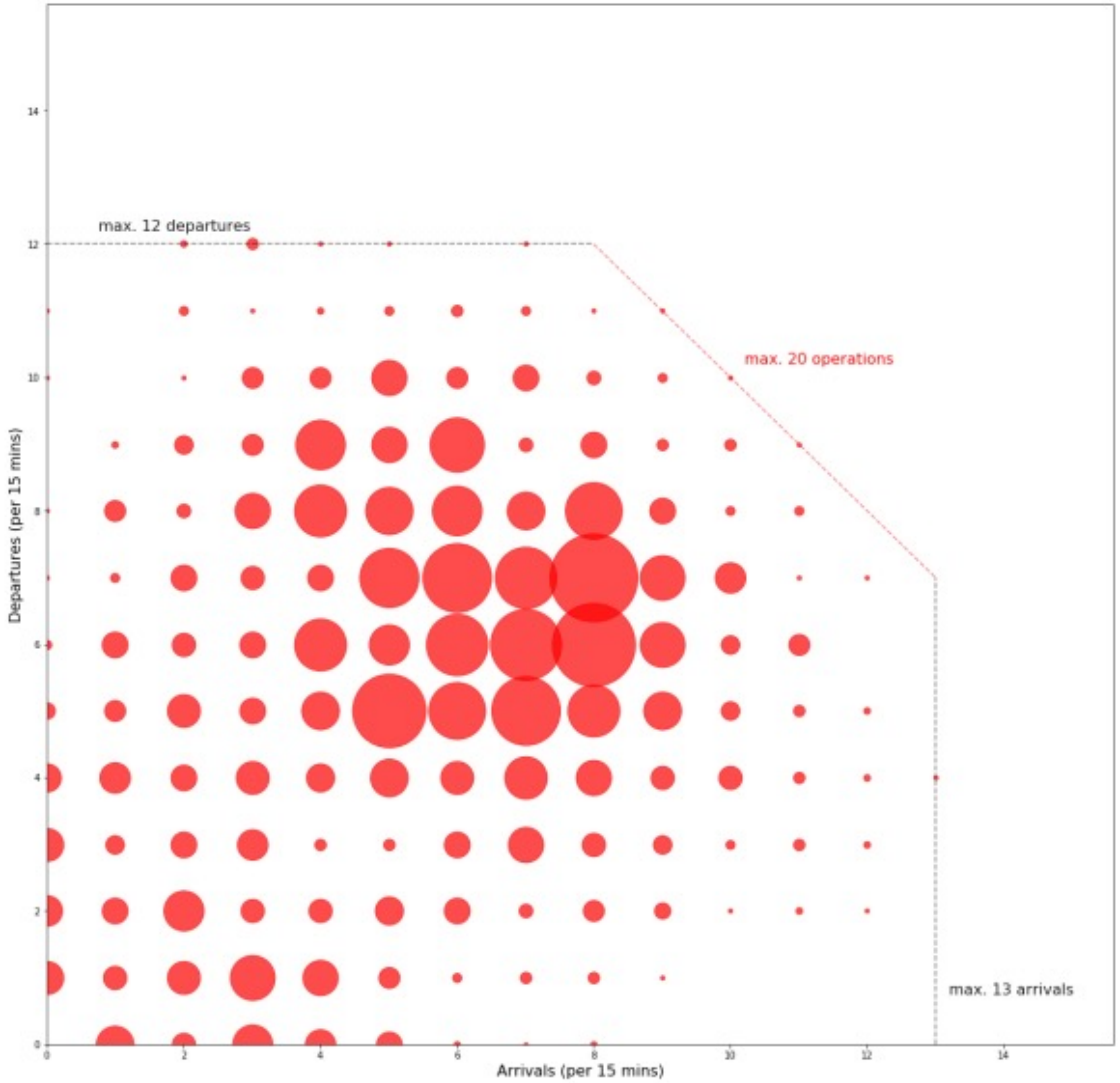


Speed Profiles by Equipment Type

Cruising Altitude	30000	ft
Cruising Speed	400	nm/hr
Rate of Ascent	50	ft/sec
Rate of Descent	45	ft/sec
TotalDistance	100	nm
SecondsPerHour	3600	



Capacity Envelopes



Default Capacities by Airport

ASI Aviation Studies Institute

icao	ArrivalsHourly	DeparturesHourly	OperationsHourly
WADD	32	32	52
VVDN	24	24	40
WALL	24	36	40
WIHH	24	20	40
VTCC	24	20	36
VTSP	20	24	36
WAJJ	20	24	36
RPVM	24	24	32
VDPP	20	20	32
VDSV	24	20	32
VYYY	32	28	32
WAHH	24	20	32

Default Waypoint Capacities

Waypoint	Traversals Hourly
AGOBA	80
AGOSA	80
AGPOP	80
AGPOR	80
AGSAM	80
AGSIS	80
AGSON	80
AGTEL	80
AGUNG	80
AGUSI	80
AGWAT	80

Custom Airport Capacity Events (Overrides)

Aviation Studies Institute

Capacity Overrides

Override List | Airport Overrides | Waypoint Overrides

`The current selected subscenarioid is 1`

Override Airport Capacity Envelopes

Refresh

Save Changes to Database

subscenarioic	icao	priority	name	ArrivalsHourl	DeparturesH	OperationsHc	DayStart	DayEnd	DailyHourSta	DailyMinuteS	DailyHourEnc	DailyM
1	WSSS	2		10.00	10.00	20.00	1	1	3	0	3	59

FF-ICE ‘Information Regime’

Select Regime for Editing

Refresh List of Regimes

Select Regime

Base case (default)

Information Regime Details

Refresh | Save Changes to Database

regimeid	firicao	releaselevel
1	RPHI	R0
1	UNKNOWN	R1
1	VDPP	R0
1	VHHK	R0
1	VLVT	R0
1	VTBB	R0
1	VVTS	R0
1	VVVV	R0
1	VYYF	R0
1	WAAF	R0
1	WBFC	R0
1	WIIF	R0
1	WMFC	R0
1	WSJC	R0
1	ZJSA	R0

In the Base Case regime, all FIRs operate at Release Level R0 (no sharing)

Select Regime for Editing

Refresh List of Regimes

Select Regime

All R1

Information Regime Details

Refresh | Save Changes to Database

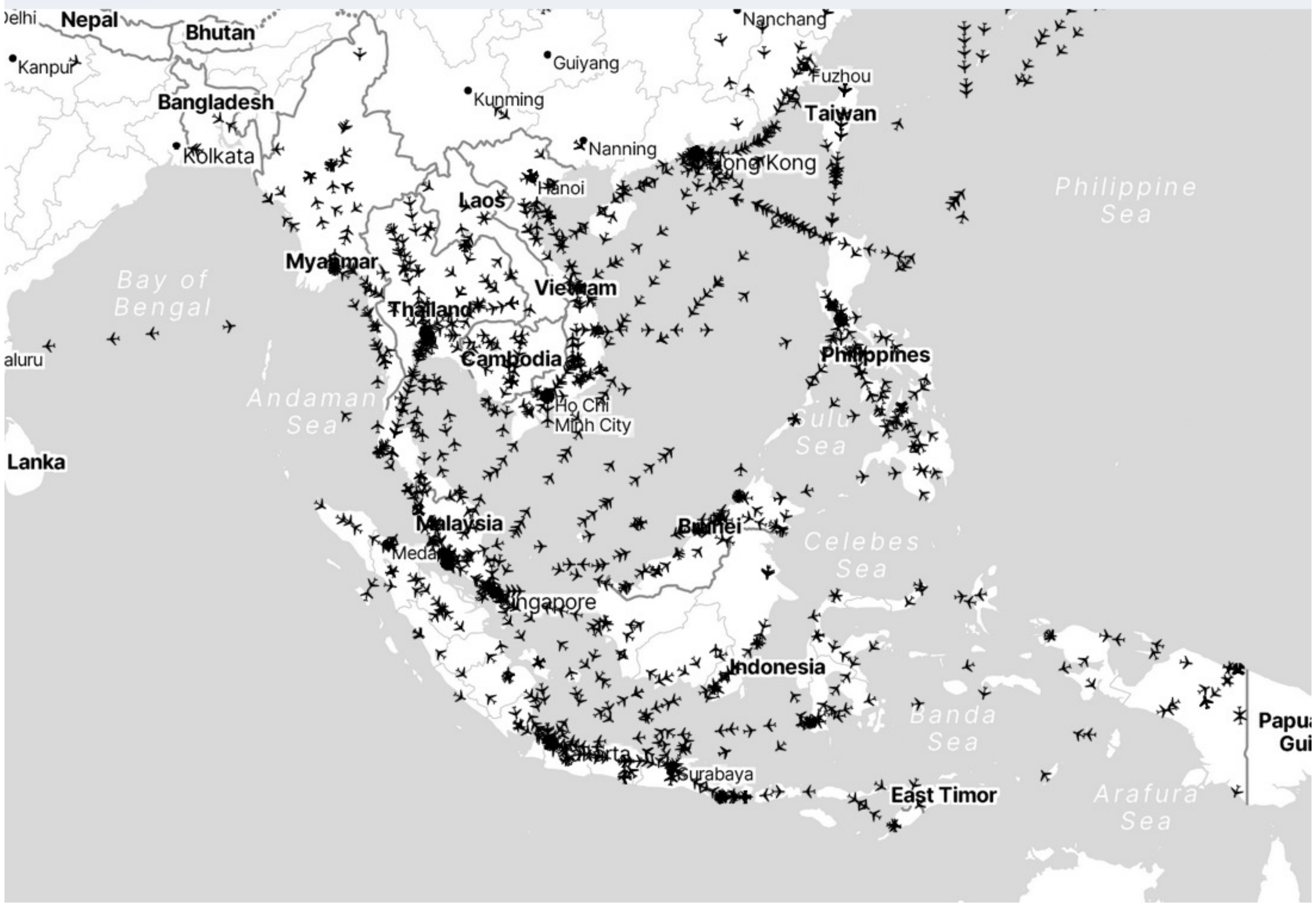
regimeid	firicao	releaselevel
3	RPHI	R1
3	UNKNOWN	R1
3	VDPP	R1
3	VHHK	R1
3	VLVT	R1
3	VTBB	R1
3	VVTS	R1
3	VVVV	R1
3	VYYF	R1
3	WAAF	R1
3	WBFC	R1
3	WIIF	R1
3	WMFC	R1
3	WSJC	R1
3	ZJSA	R1

In the ‘All R1’ regime, all FIRs operate at Release Level R1 (updated departure times)

Overview

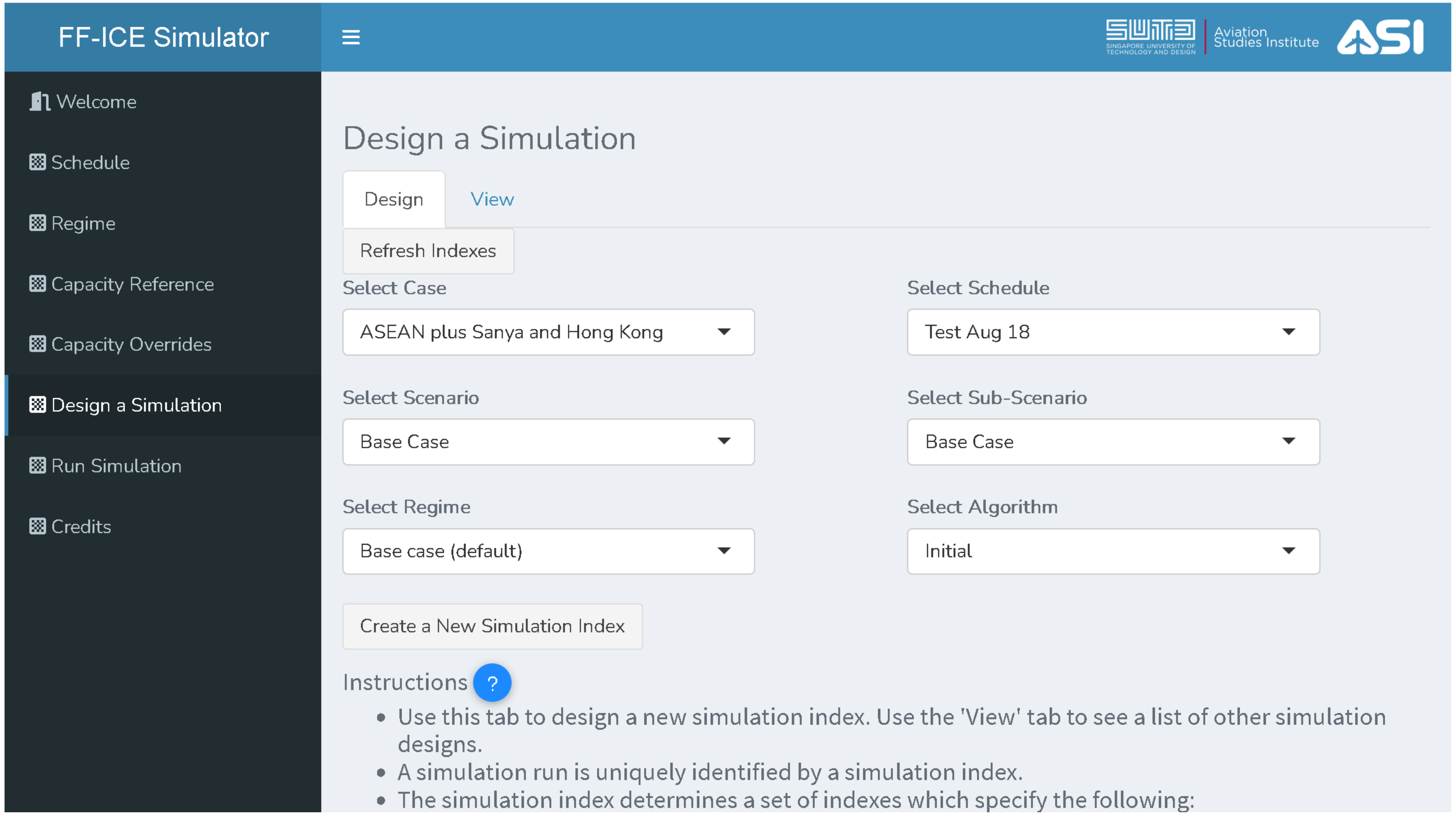
- Review of Collaborative Decision Making (CDM) Project
- Overview of Network Capacity and Network Collaboration Projects
  - Dimensions: Network, Schedules, Routes, Trajectories, Capacities, and Information Regimes
  - **Simulation Approaches and Insights**
    - Global Optimization
    - Local Optimization
- The Airspace Design Game

Simulate Flight Flow Throughout ASEAN+



Designer: Design a Simulation

- A simulation is defined by a combination of:
  - Case (network)
  - Flight schedule
  - Capacity scenario
  - Override sub-scenario
  - Information regime
  - Algorithm choice
- A simulation index (“simid”) is used to uniquely identify the simulation definition
- This will allow the analyst to compare simulation runs by simulation index



Performance Metrics

- **Cancelled Flights**: capacity constraints are impossible to meet

- **Arrival Delays**: measured relative to Scheduled Departure Time + Preferred Flight Tim
  - Scheduled Arrival Time includes an airline buffer, which we ignore

- **Fuel Efficiency**: Deviations from Preferred Flight Time (speed-up or slow-down)

- **Ground Holding Delays** *vs* **Airborne Holding Delays**

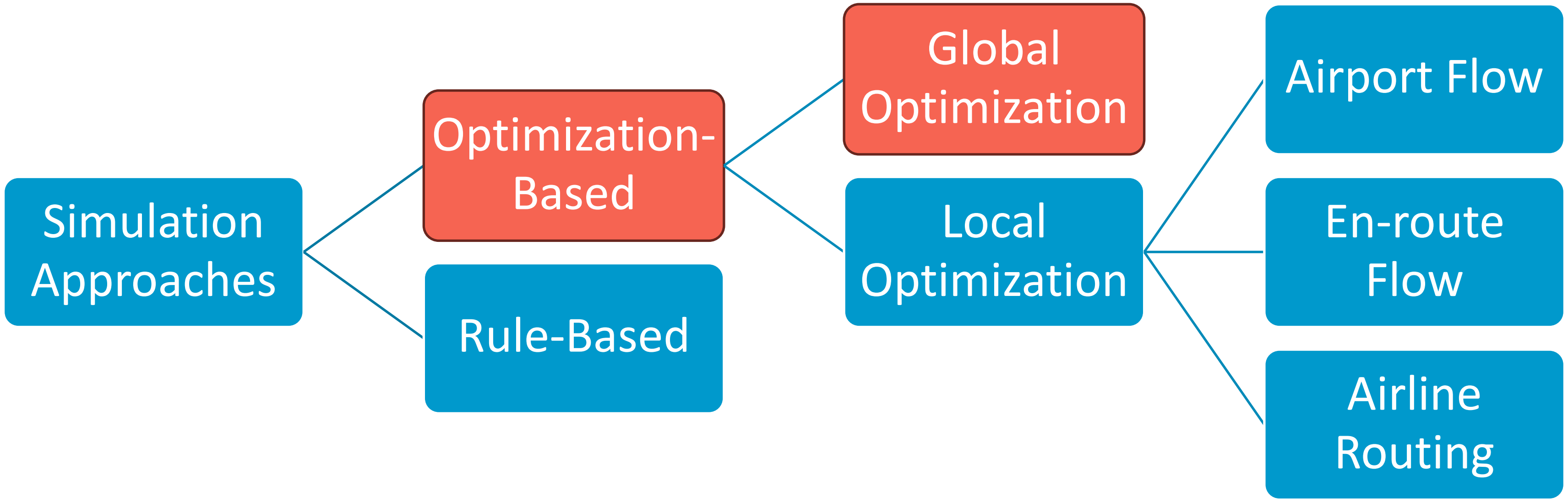
“vecteezy_refuel-vector-icon-design” vecteezy.com

“vecteezy_realistic-airplane-vector-design-illustration-isolated-on-white-background” vecteezy.com “vecteezy_flight-timings-vector-icon-design” vecteezy.com “vecteezy_cancelled-stamp-rubber-with-grunge-style-on-white-background” vecteezy.com

Overview

- Review of Collaborative Decision Making (CDM) Project
- Overview of Network Capacity and Network Collaboration Projects
  - Dimensions: Network, Schedules, Routes, Trajectories, Capacities, and Information Regimes
  - Simulation Approaches and Insights
    - **Global Optimization**
    - Local Optimization
- The Airspace Design Game

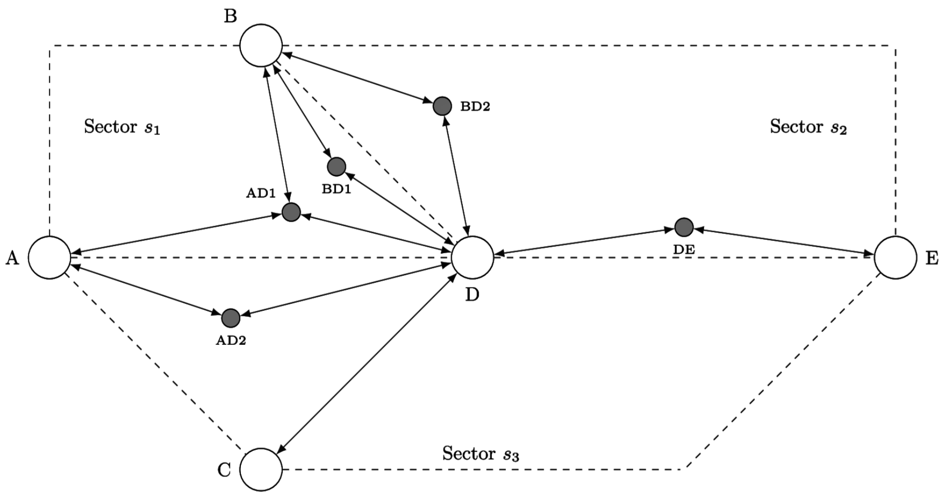
Methodology



Global Optimization

Aviation Studies Institute

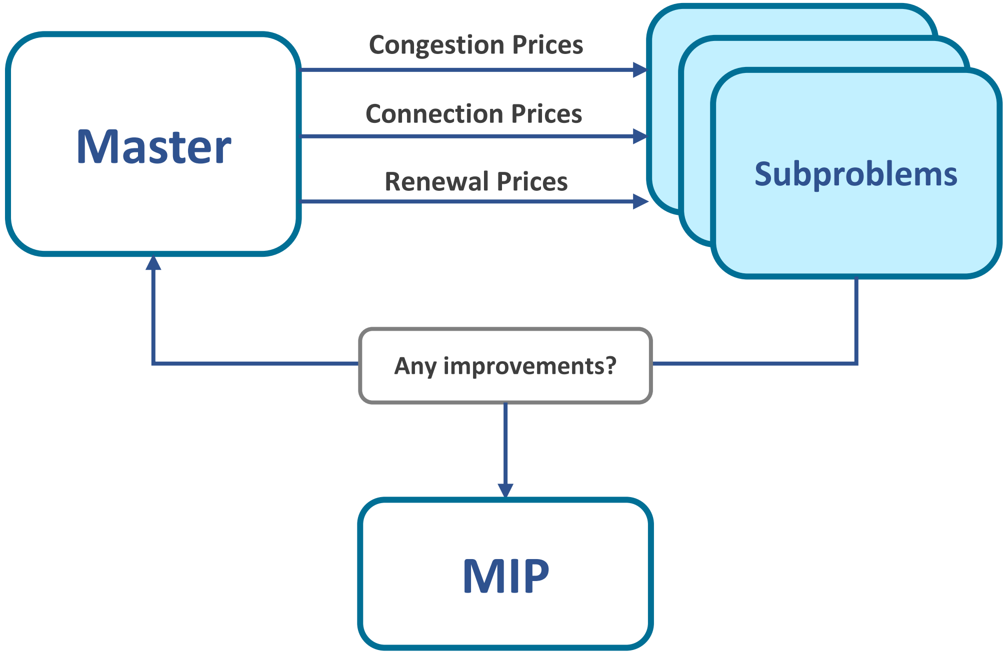
- Based on ATFM model from (Balakrishnan and Chandran, 2014; Tan, 2021)
- Each flight is viewed as a trajectory through **a space-time network**.
- **An ideal central controller** with perfect knowledge of all constraints decides on aircraft trajectories (departure times and speeds) for all aircraft in the region.
- The central controller attempts to **minimize a system-wide objective** (minimal delays) but ensures all **flow and capacity constraints** are met.
- **Use as an ideal**: the best that could be accomplished if everyone worked together for a common purpose.



Global Optimization: Parallel Processing

Solution through decomposition:

- Master program: select trajectories that optimize the system-wide objective
    - Solved over a restricted subset of available aircraft trajectories
    - Constraint 'prices' are stored at each solve
- Subproblems: generate new, improved aircraft trajectories (with **parallel processing**)
    - Each aircraft trajectory is solved over a granular space-time network
    - Determines the exact routings and schedules of flights
    - Accounts for the 'prices' associated with network congestion, passenger connections, renewing trajectories
- Once the master problem is solved (within tolerance):
    - Integer constraints are enforced
    - Systemically-optimal solution is the returned MIP solution on the restricted integer master program



Observations from Global Optimization

- **Airport shutdowns result in delay propagation**
  - Primarily through ‘tail flight connections’
  - But… airport shutdowns are mitigated by en route speed-up

- **Storm scenarios result in re-routing**
  - Mitigated by en route speed-up
  - New routes reveal how sparse is the ASEAN+ network

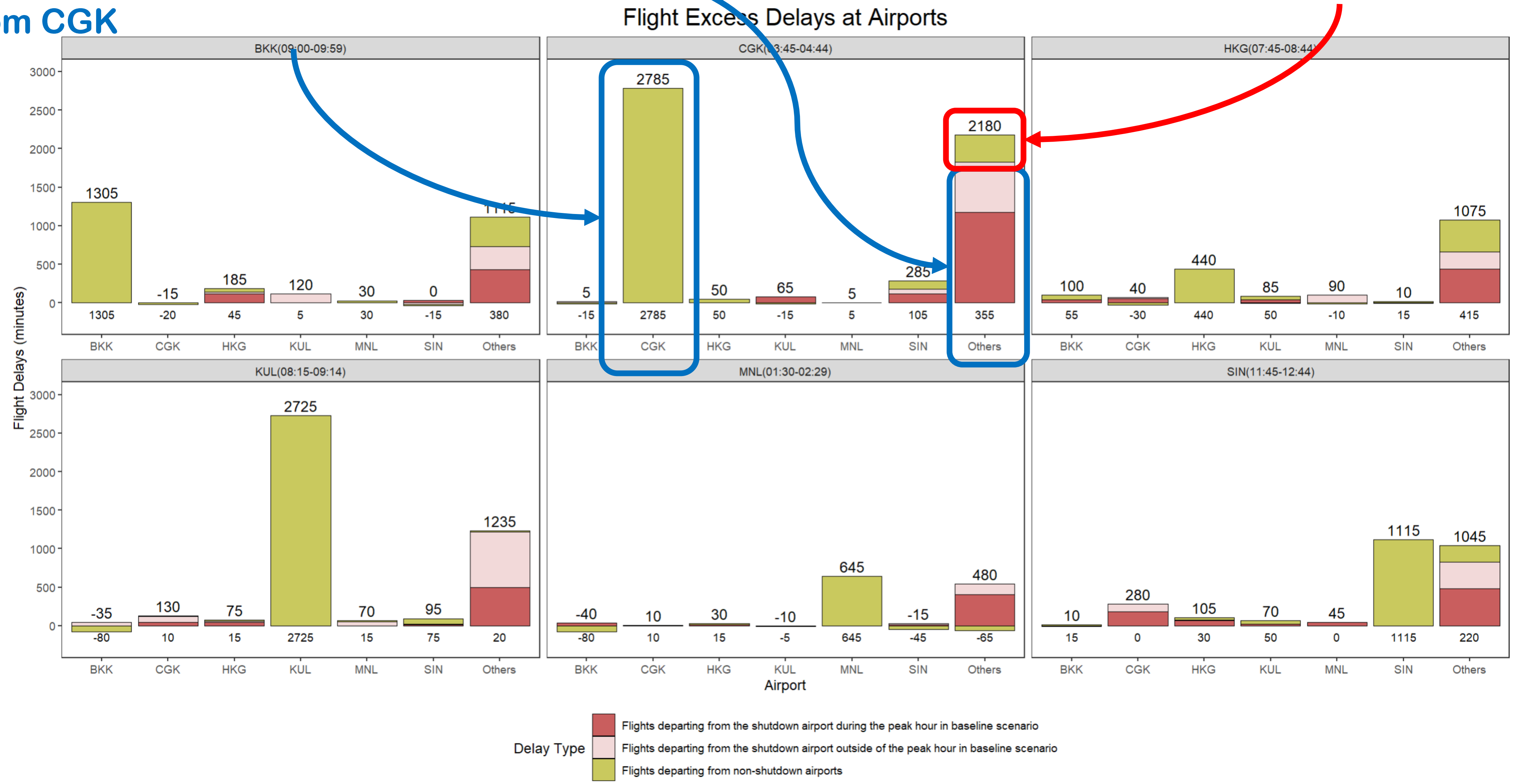
- **Giving priority for connecting flights has disparate impacts**
  - Hubbing airlines delay departures of collector flights
  - If ATC prioritizes connections too much, then non-hubbing airlines suffer

Delay Propagation

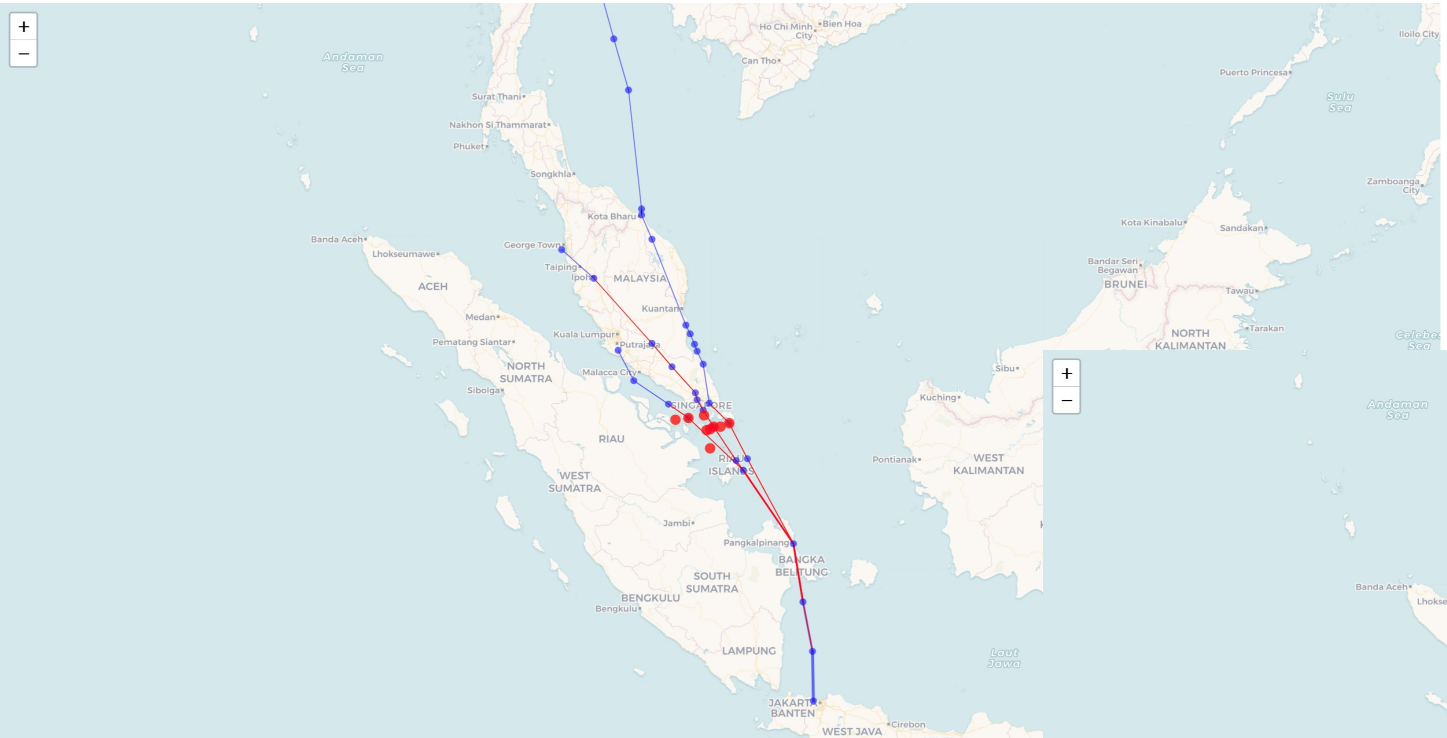
Aviation Studies Institute

CGK shutdown mostly affects arrivals at CGK and at airports *directly* served from CGK

But the delays also propagate to other airports not served directly from CGK



Southbound Flights through Blue Zone



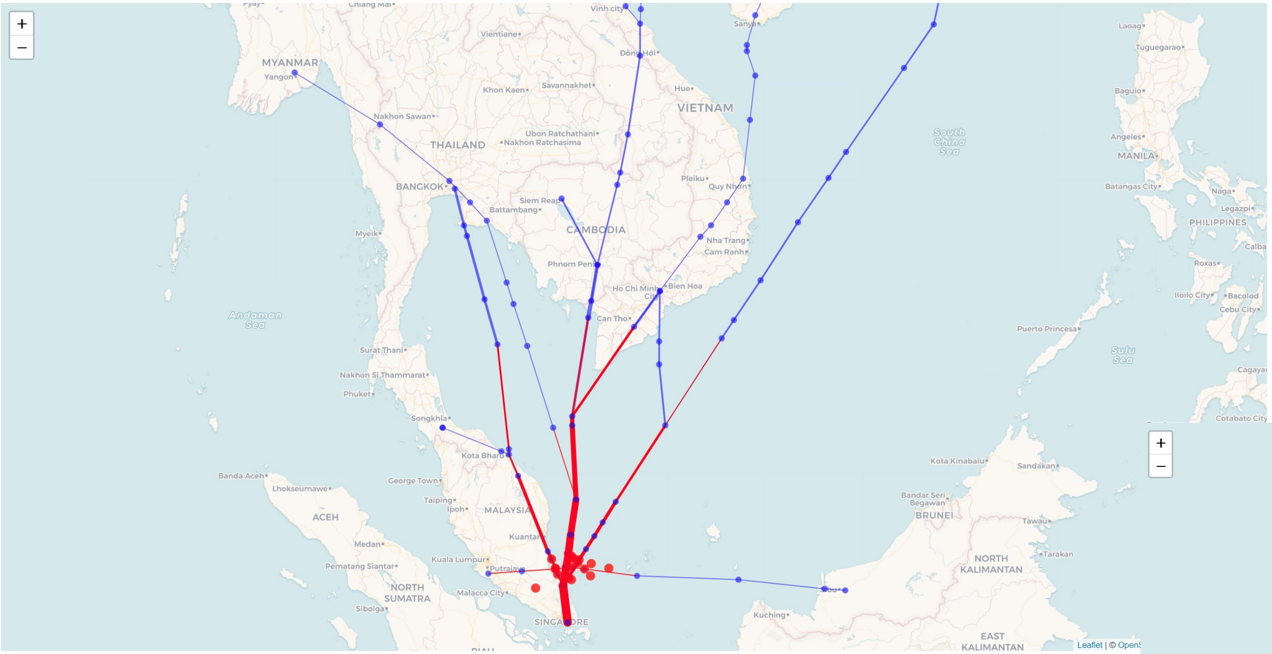
Baseline (no storm)

Optimized solution is mixture of speed changes (to avoid time of storm) and re-routing

Storm

Northbound through Orange Zone

ASI Aviation Studies Institute



Baseline

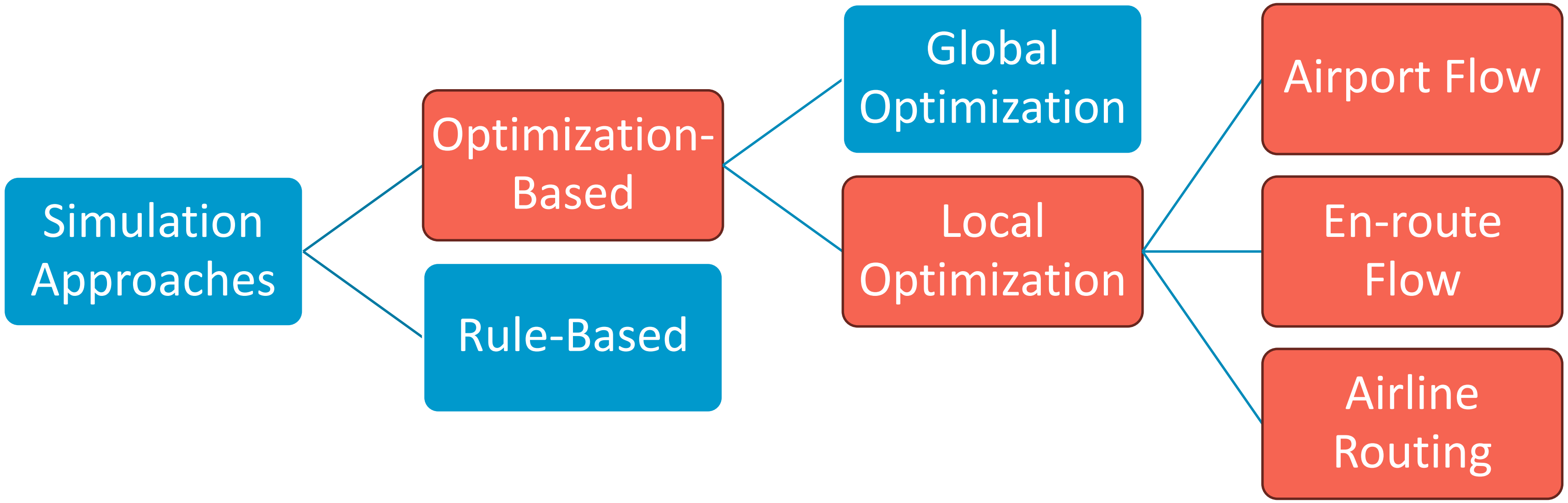
Storm

South China Sea route network is sparse. Optimization is forced into backtracking solution to avoid storm. In practice, controllers would request free route directly north from LUSMO

Overview

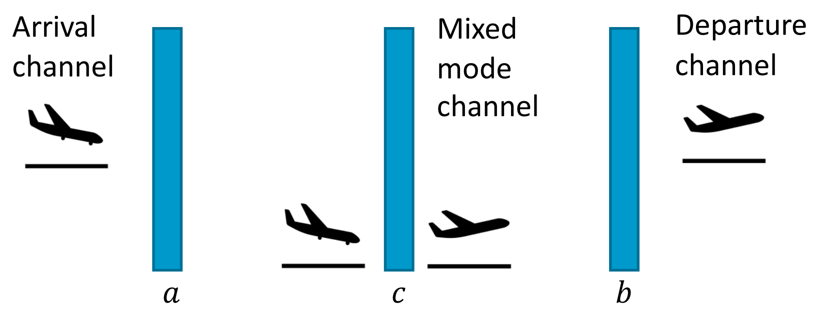
- Review of Collaborative Decision Making (CDM) Project
- Overview of Network Capacity and Network Collaboration Projects
  - Dimensions: Network, Schedules, Routes, Trajectories, Capacities, and Information Regimes
  - Simulation Approaches and Insights
    - Global Optimization
    - **Local Optimization**
- The Airspace Design Game

Methodology



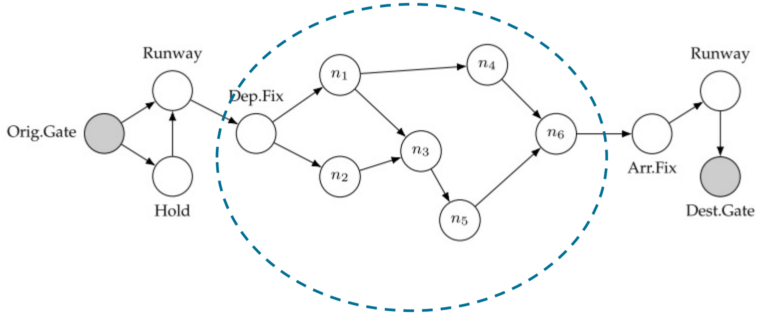
Local Optimization

Airport Flow Manager



- One airport at a time
- Given current state of all visible aircraft
- Schedule channel time of each flight
- Enforce separation constraints in each channel consistent with capacity envelope
- Minimize squared error from schedule

En Route Flow Manager



- One sector (or FIR) at a time
- Given current location of all visible aircraft
- Given current flight path of each aircraft
- Schedule TTO of each flight at each waypoint/channel in sector
- Enforce separation constraints
- Minimize squared error from schedule

Iterate

Adaptive Routing (Airline)

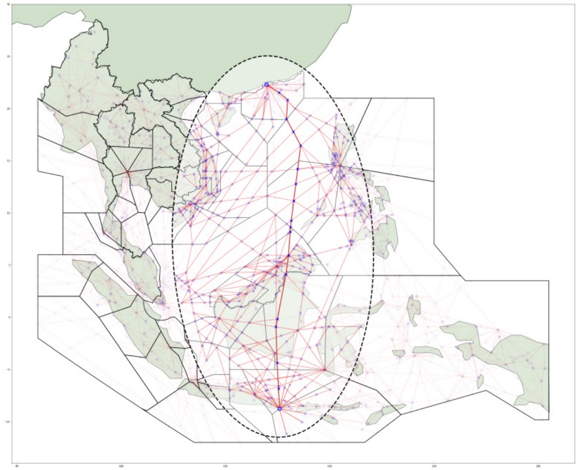


FIGURE 4.12: *The rerouting network for a southward-bound HKG-DPS flight, with its corresponding rerouting ellipse. The nominal (shortest) route is marked in dark red.*

- One flight at a time
- Forecast delays at waypoints
- Choose flight path with least total time

Implementation of 'Information Regimes'

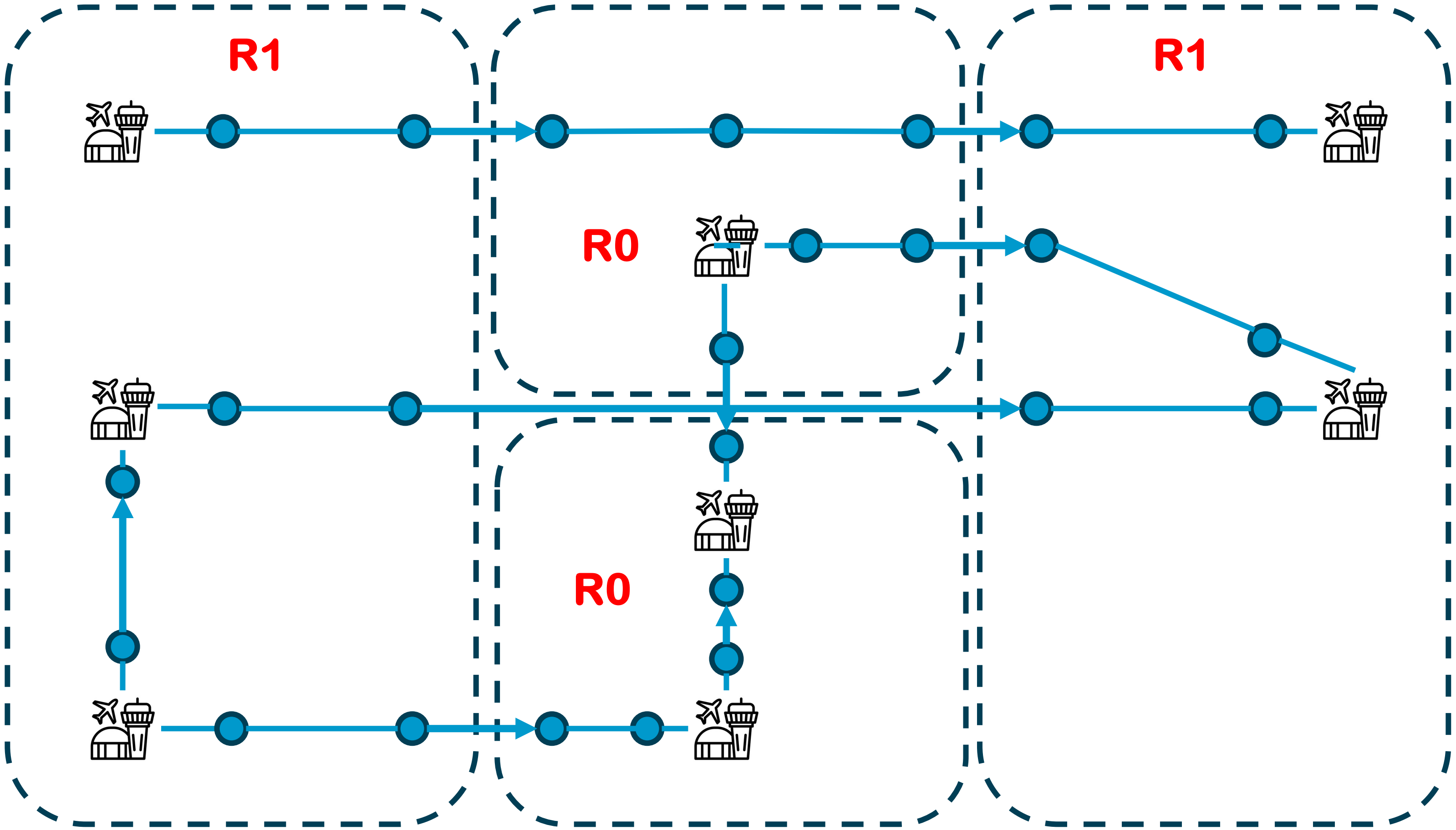
- An information regime defines:
  - **What flights are "visible" for each FIR** to manage arrivals, departures, and en route
    - A flight may be "visible" and available for planning even if it has not yet reached the FIR
  - **What information is available** about a flight to any FIR, depending on release level
    - The original flight plan, or,
    - The flight plan updated by departure and en route changes, and, perhaps,
    - Desired delays from the arrival airport (CTOT's)

- For each flight in the simulation, and each leg of the flight plan **we maintain the following information**
  - The **R0 TTO**: the target time over waypoint (or airport channel) under the original flight schedule (available to all FIR under release level R0)
  - The **R1 TTO**: the target time over waypoint (or airport channel) updated by departure times and en route changes
  - The **R1 BackTTO**: the target time over waypoint (or airport channel) back calculated from the desired arrival time at the destination airport

Illustrated Flight Plans Through Release Levels

ASI Aviation Studies Institute

- R1→R0 →R1
- R0 →R1
- R1 →R1
- R0 →R0
- R1 →R0
- R0⟲
- R1⟲

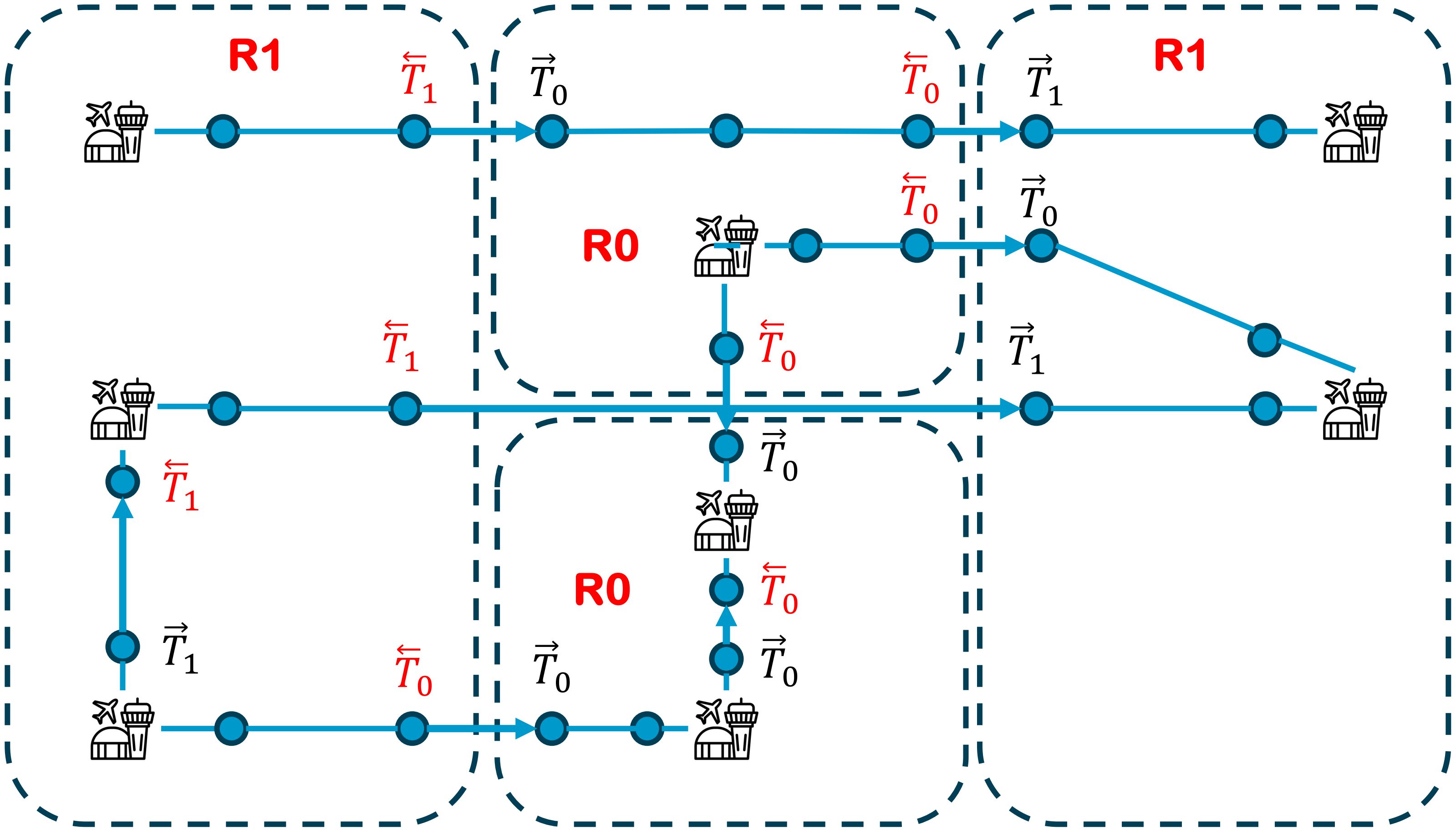


https://www.vecteezy.com/vector-art/10751900-airport-icon-design

Visible Information by FIR and Flight Plan

- R1→R0 →R1
- R0 →R1
- R1 →R1
- R0 →R0
- R1 →R0
- R0⭮
- R1⭮

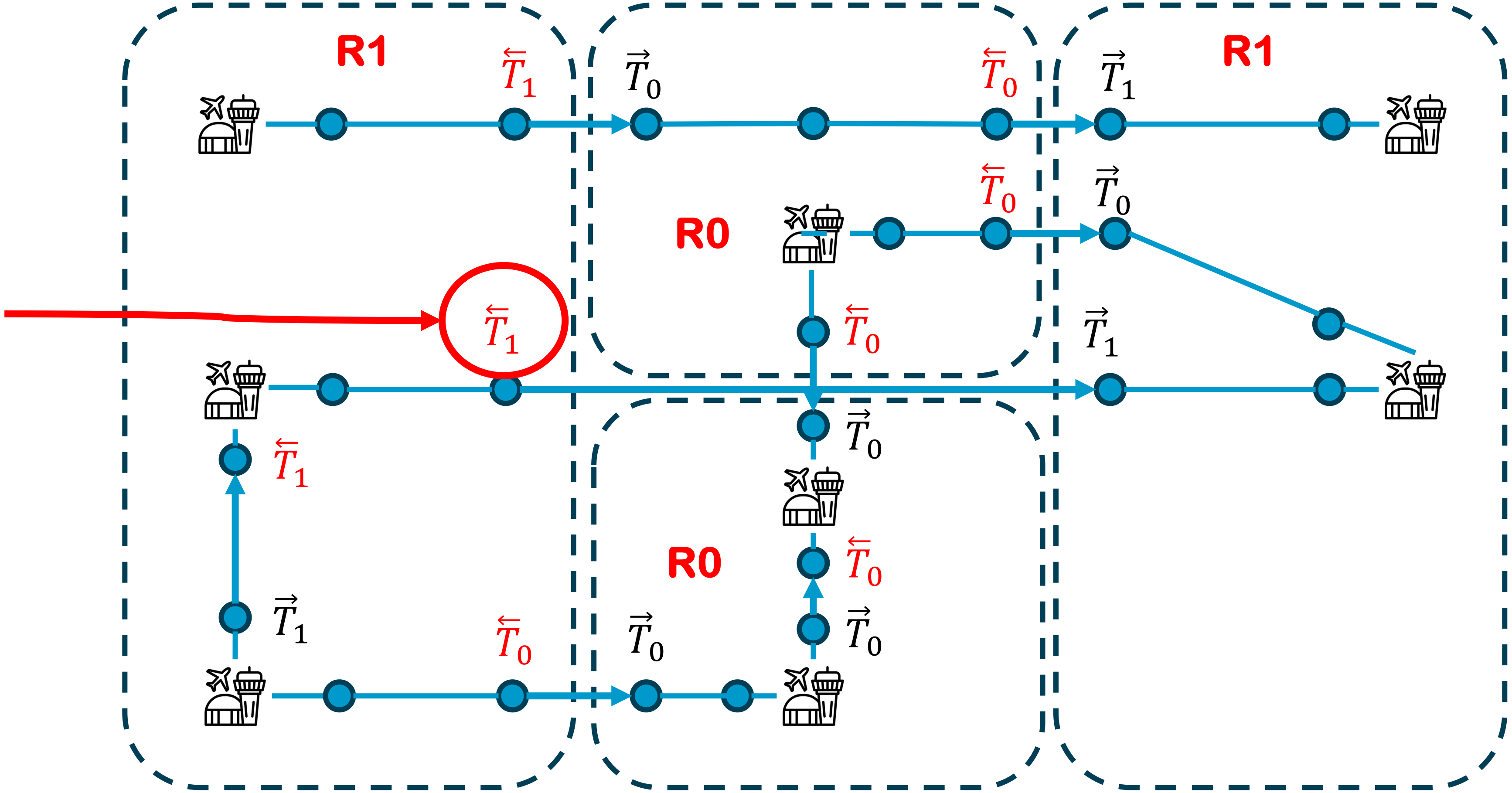
- Notation:
- $\vec{T}_0$ TTO forward R0
- $\vec{T}_1$ TTO forward R1
- $\overleftarrow{T}_0$ TTO backward R0
- $\overleftarrow{T}_1$ TTO backward R1



https://www.vecteezy.com/vector-art/10751900-airport-icon-design

How To Read the Diagram: 1

When planning for this flight, this FIR knows the back TTO at the exit waypoint, based on the destination airport's target arrival time: it will adjust departure and en route times to meet this target as best it can. In this way, delays at the *destination* airport can result in cooperative ground delays at the *origin* airport.



Compare Simulations

FF-ICE Simulator

- Welcome
- Select Index
- Compare Simulations
- Credits

Compare Simulation Runs

Compare simulation runs based on matching completed flights.

Select Simulation Index ('simid'): 9

Select Simulation Index ('simid'): 10

Compare

Choose two different simulation indices and then click 'Compare'.

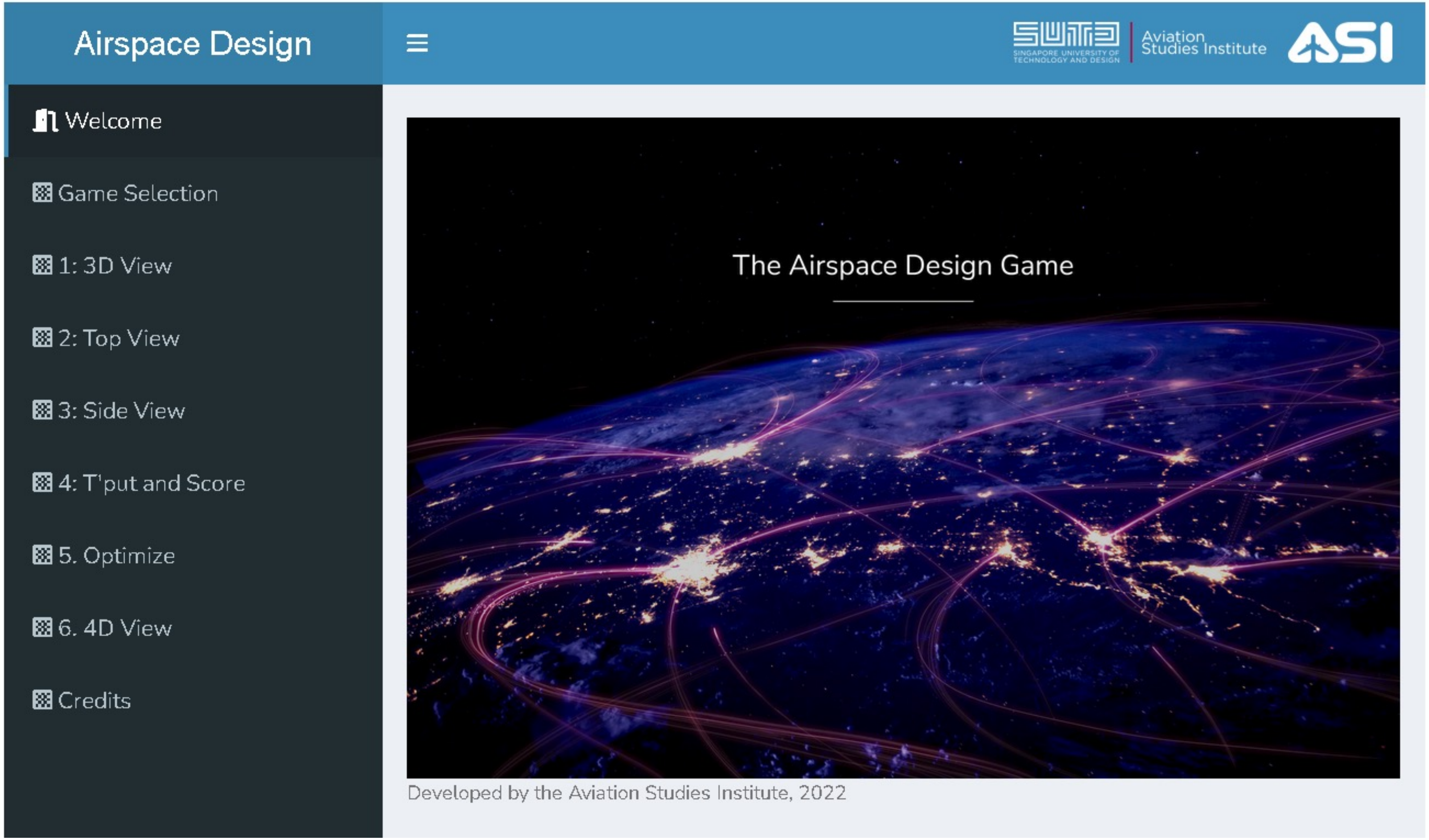
Simid	Avg Preferred Flight Time	Avg Actual Flight Time	Avg Airborne Slowdown	Avg Airborne Speedup	Avg Actual Ground Delay Time	Conditional Avg Airborne Slowdown	Conditional Avg Airborne Speedup
9	133.78	137.31	3.78	0.25	4.57	13.17	1.30
10	133.78	138.90	5.59	0.46	11.31	9.70	1.30

Our R1 collaborative ground delay rules do result in longer ground delays and less airborne holding or slowdown

Overview

- Review of Collaborative Decision Making (CDM) Project
- Overview of Network Capacity and Network Collaboration Projects
  - Dimensions: Network, Schedules, Routes, Trajectories, Capacities, and Information Regimes
  - Simulation Approaches and Insights
    - Global Optimization
    - Local Optimization
- **The Airspace Design Game**

The Airspace Design Game

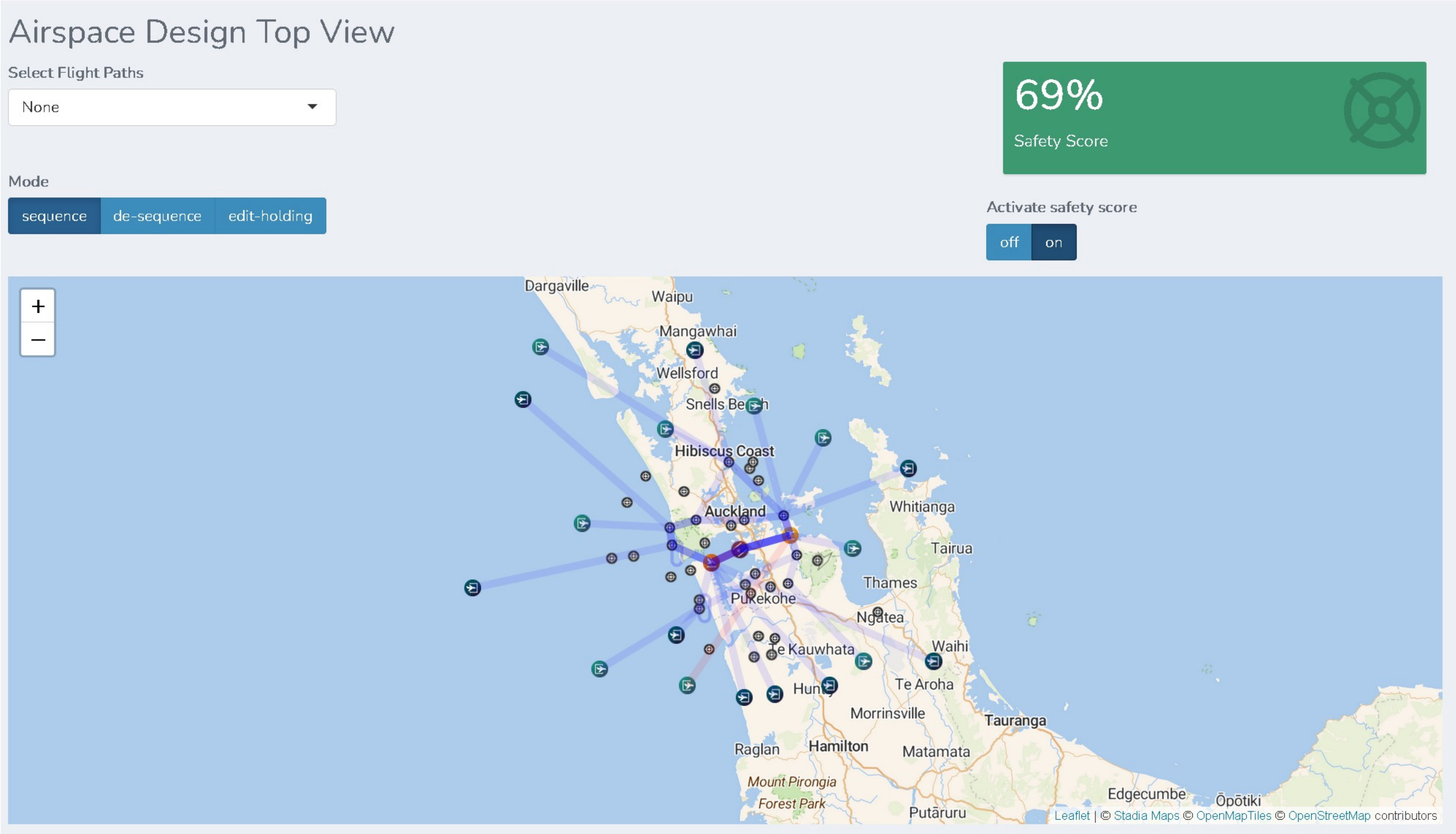


Objectives of Game Development

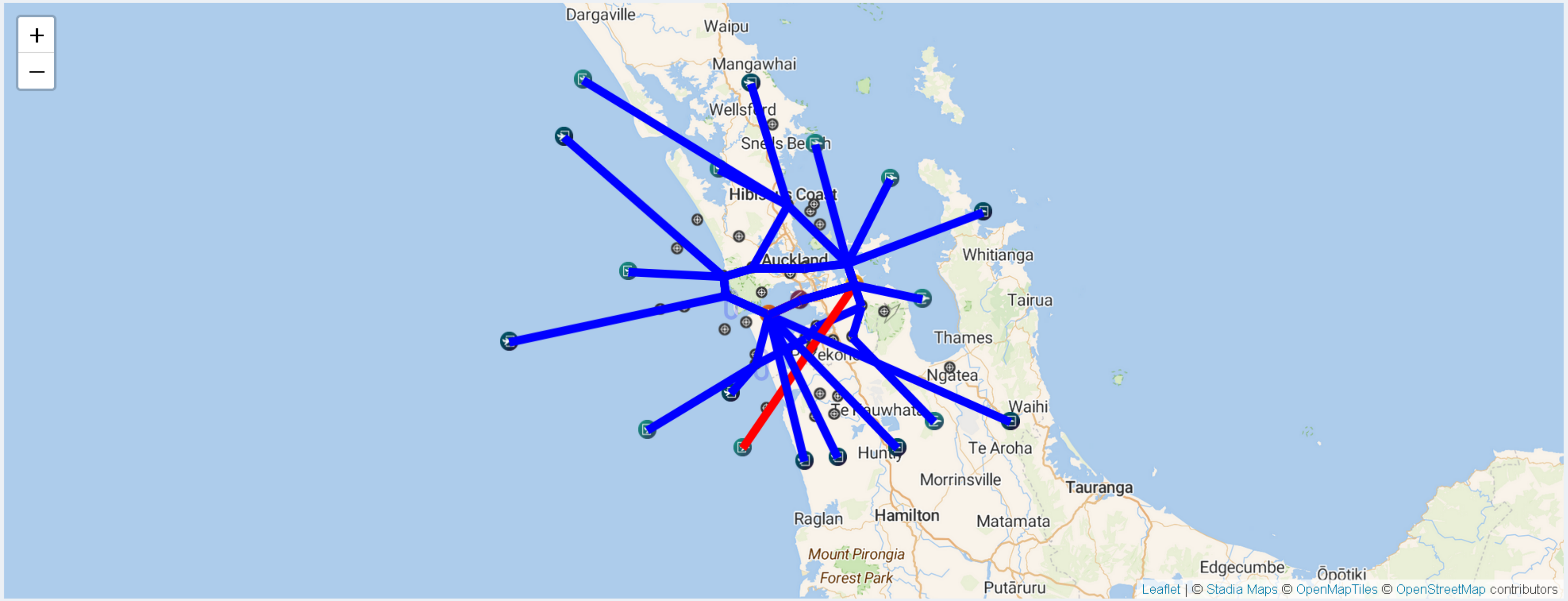
- Engage students in aviation system design challenge
  - Airspace design is a 3D problem
  - Safety issues come first
  - Fuel efficiency is a rising concern
  - Airports face a trade-off between throughput and timeliness
  - Airspace operation is a 4D problem

- Engage Subject Matter Experts in research problem formulation
  - What are the use cases for airspace design?
  - What are the safety issues?
  - What are the design constraints?
  - What are the appropriate metrics?

Start With Safety



Solve Safety Design Issues



Selected Design Issues

Flight path 'EMRAG to KAPAI' has bearing change (see red line) that is too extreme. Include another waypoint in the sequence to soften the turn.
Flight path 'NOBAR to IRSIP' has bearing change (see red line) that is too extreme. Include another waypoint in the sequence to soften the turn.
Flight path 'SKEPY to IRSIP' has bearing change (see red line) that is too extreme. Include another waypoint in the sequence to soften the turn.
Flight path 'DAVEE to IRSIP' is an arrival path. It must connect with a holding area.
Flight path 'NOBAR to IRSIP' is an arrival path. It must connect with a holding area.
Flight path 'PEPPE to IRSIP' is an arrival path. It must connect with a holding area.
Flight path 'SKEPY to IRSIP' is an arrival path. It must connect with a holding area.
Flight path 'TAZEY to IRSIP' is an arrival path. It must connect with a holding area.
Flight path 'APABO to IRSIP' enters a holding area at too sharp an angle. Consider changing the bearing of the holding area.
Flight path 'BASIV to IRSIP' enters a holding area at too sharp an angle. Consider changing the bearing of the holding area.
Flight path 'EAGIL to IRSIP' enters a holding area at too sharp an angle. Consider changing the bearing of the holding area.
Flight path 'NOBAR to IRSIP' crosses path 'EMRAG to IPDIN' at unspecified flight level. Change sequences to cross at a waypoint.
Flight path 'EMRAG to IPDIN' crosses path 'NOBAR to IRSIP' at unspecified flight level. Change sequences to cross at a waypoint.
Flight path 'EMRAG to TULMI' crosses path 'NOBAR to IRSIP' at unspecified flight level. Change sequences to cross at a waypoint.

Adjust Flight Levels for Fuel Efficiency

Airspace Design Side View

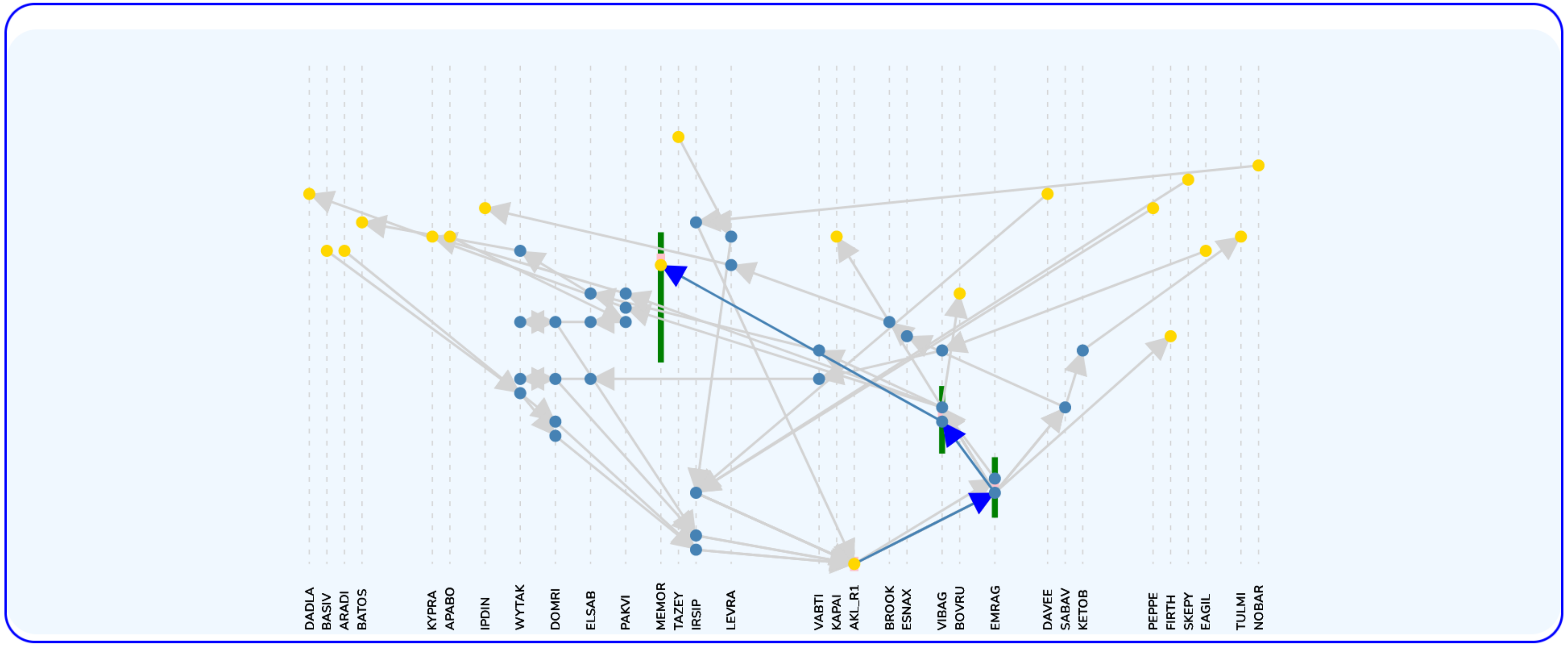
Select Flight Paths

EMRAG to MEMOR

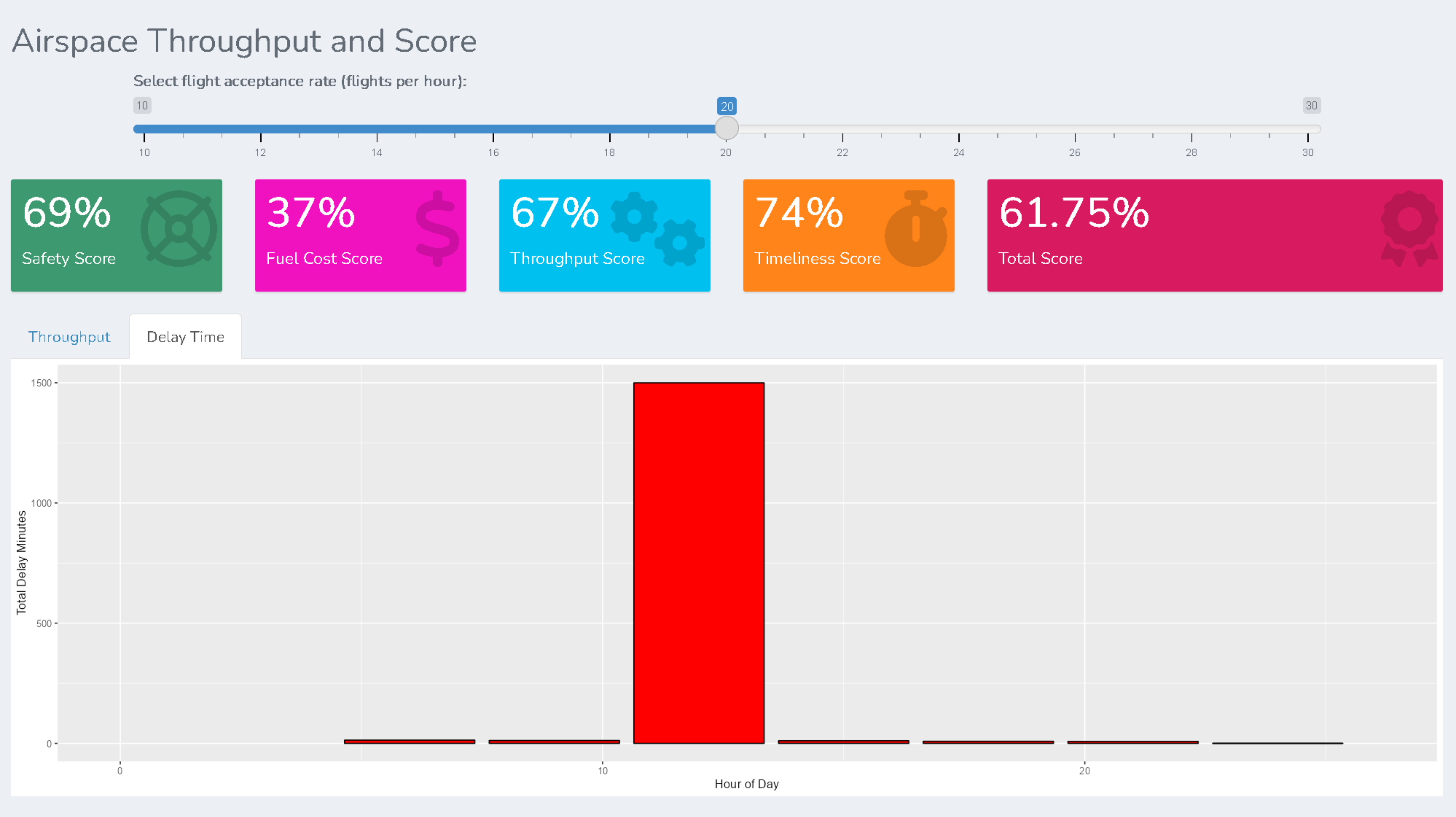
37%

Fuel Cost Score

Edit Flight Level Crossings



Tradeoff Throughput with Timeliness



View 3D Cesium Animation

Aviation Studies Institute

Thank You

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN
Aviation Studies Institute

Aviation Studies Institute