

Implications of Runway Direction Changes for Improved Arrival Management at Singapore Changi Airport

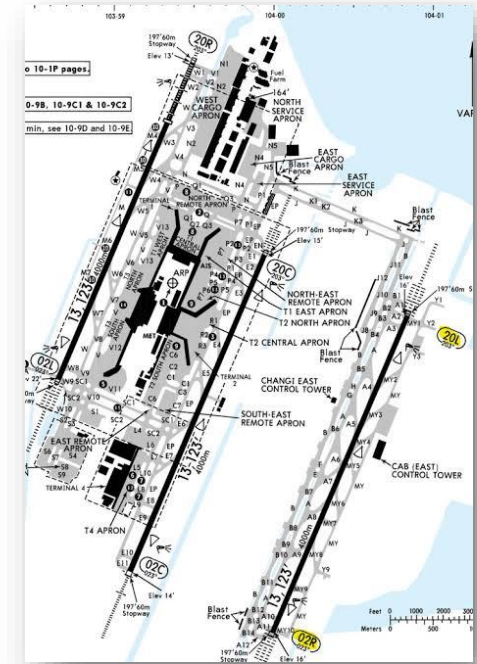
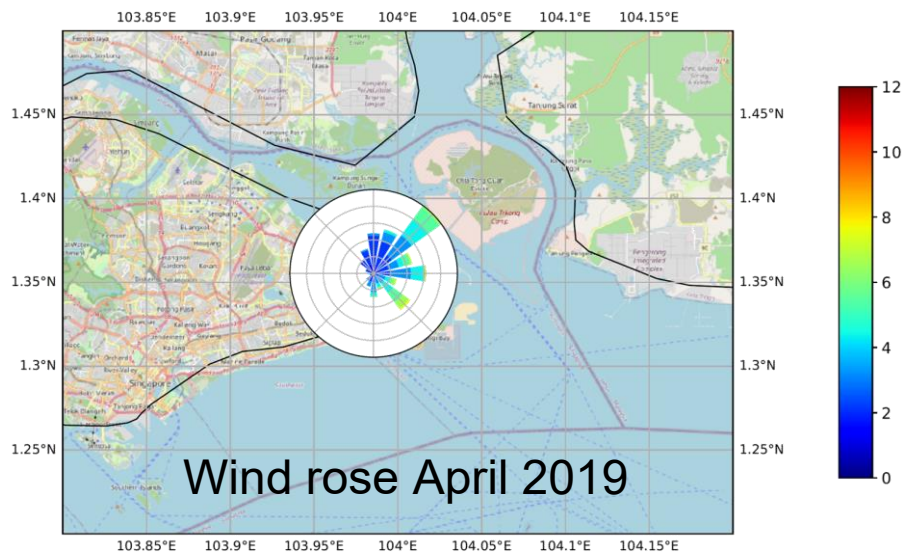
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Motivation & Long-Range ATFM concept

- Runway direction changes impact airport arrivals hourly capacity
 - LR-ATFM lever: meter at ~170 NM (near top-of-descent) via small cruise speed adjustments
 - Objective: keep airport arrival demand within weather-driven capacity
 - Outcome: fewer demand/capacity imbalances → fewer holdings, smoother arrival metering, less tactical re-sequencing



Changi Runway Layout

Proactively manage runway configuration changes is necessary to reduce disruptions at Changi Airport

ATFM = Air Traffic Flow Management

Motivation & Long-Range ATFM concept

- Singapore ANSP controls a relatively small airspace
- AMAN can only impose limited amount of delays
- Imposing long-range airborne delays requires coordination with other ANSPs
- Efficient pre-conditioning of arrival flows is key for smooth operations at Changi Airport

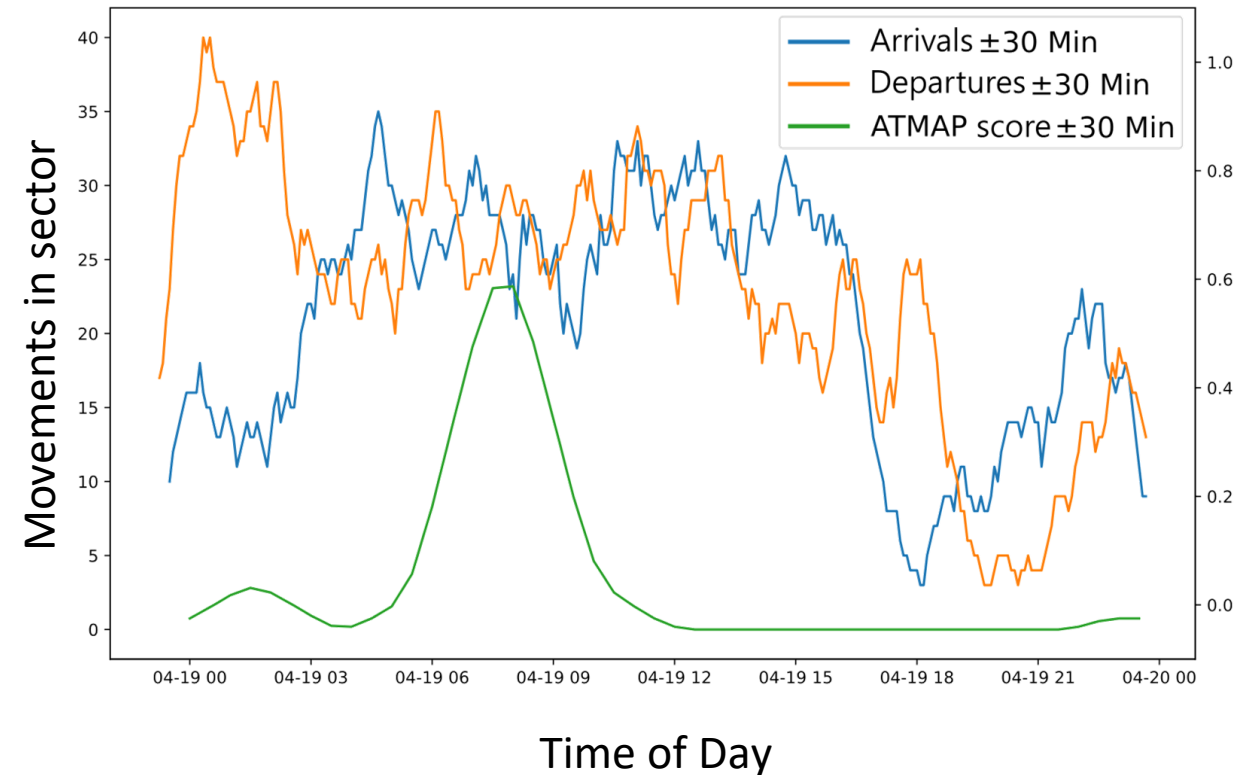


Singapore Flight Information Region (FIR)

Long-Range ATFM needs accurate forecast of runway configuration changes for strategic planning

Data Preprocessing

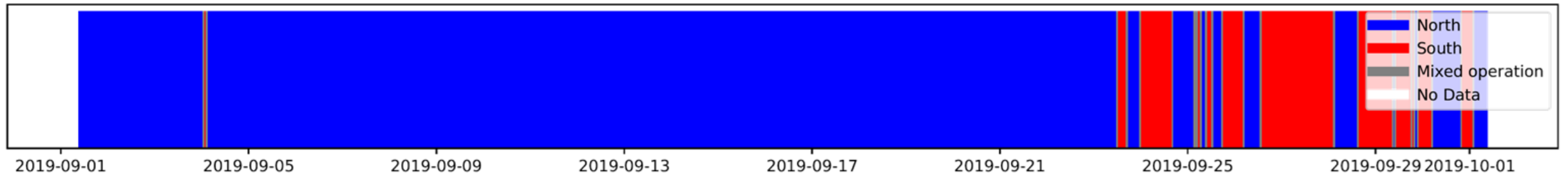
- Inputs: METAR → ATMAP scores (Visibility, Wind, Precipitations, etc.); ADS-B tracks; schedules/actuals (Actual Time Arrival/Departure)
 - Temporal update: 5-minutes; rolling-hour counts at 170 NM sector ring
 - ATMAP smoothing: 5-sample weighted moving average + centered 60-min mean



Historical weather and flight data analyzed to evaluate airport capacity performance

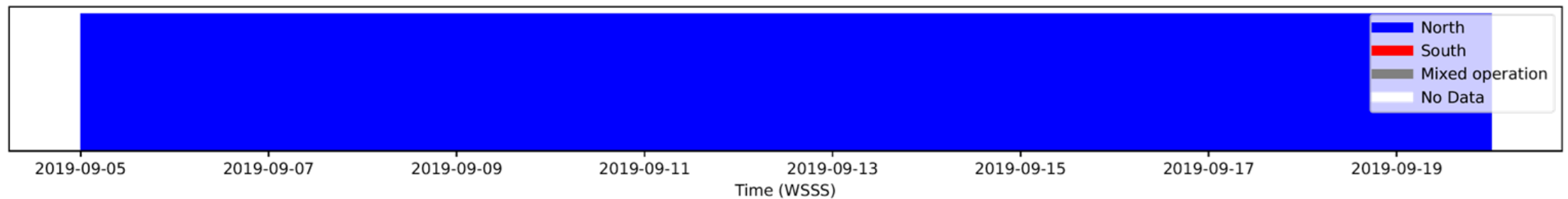
Operating Direction Detection

- Low-altitude filter: <4,000 ft and <50 km to avoid heading ambiguity
- Sliding-window classification → North / South / Mixed / No-data
- Captures day-level changes and month-level seasonality



Reference Capacity (Baseline Operations)

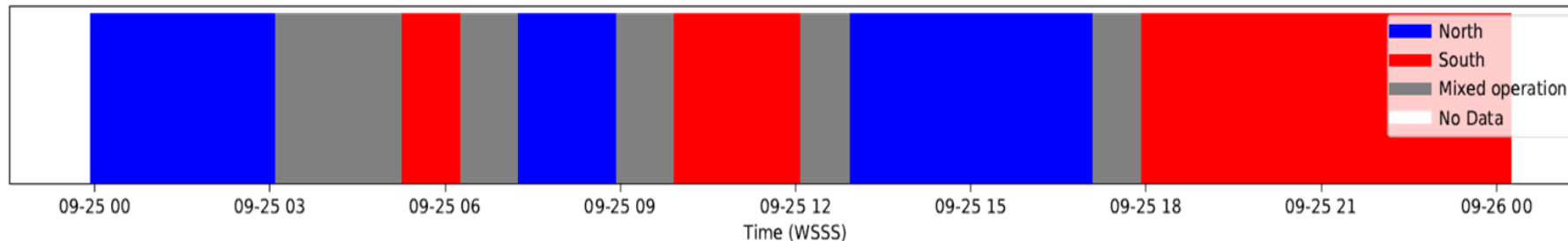
- Stable window: 5–20 Sep 2019 (North ops) → direction-clean baseline
- Method: 90th-percentile rolling-hour entries per 5-min time stamp
- Outcome: ~20–30 movements/h plateau, with routine evening trough



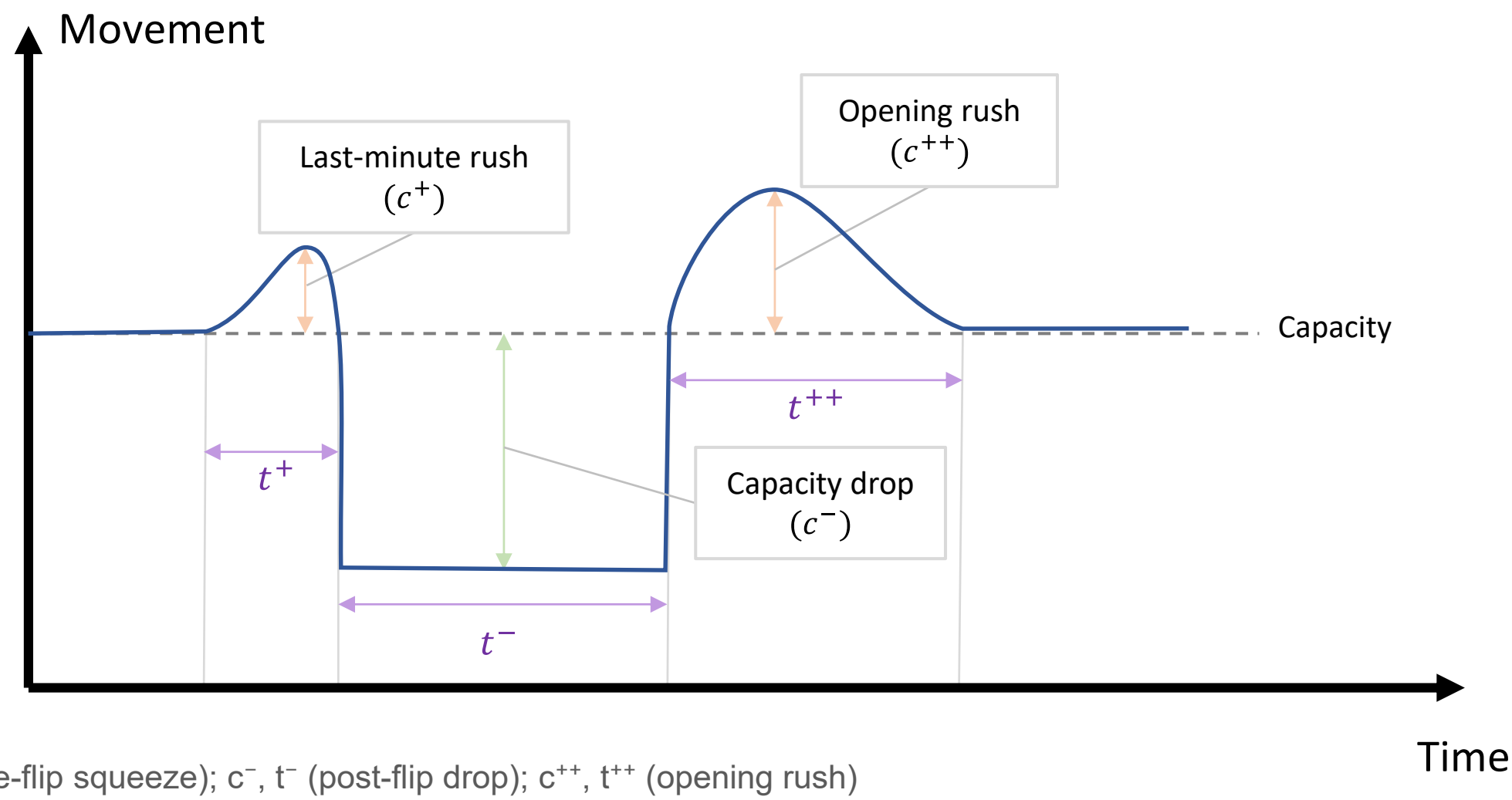
Clean configuration period used to identify reference hourly capacity at Changi Airport

Flip Day (25 Sep) vs Reference

- Ten direction transitions (02:20→...→17:10) across morning to late afternoon
- Throughput reduction begins ~10–15 min pre-flip; post-flip trough lasts 45–60 min (up to 90 with back-to-back flips)
- Mid-morning drawdowns milder (–3 to –6/h); brief compensating bump as sequence restabilizes



Runway Direction Change Notional Model



Runway-aware Metering: Optimization

- **Sets/Vars:** choose one option per flight (x_{ij}); overload slack ρ_t
- **Objective:** minimize total overload $\sum_{t \in T} M \rho_t$ over the horizon
- **Constraint:** in-sector entries should be less than the time-varying capacity U_t ;

assignment $\sum_j x_{ij} = 1$

$$\min \sum_{t \in T} M \rho_t$$

s.t.

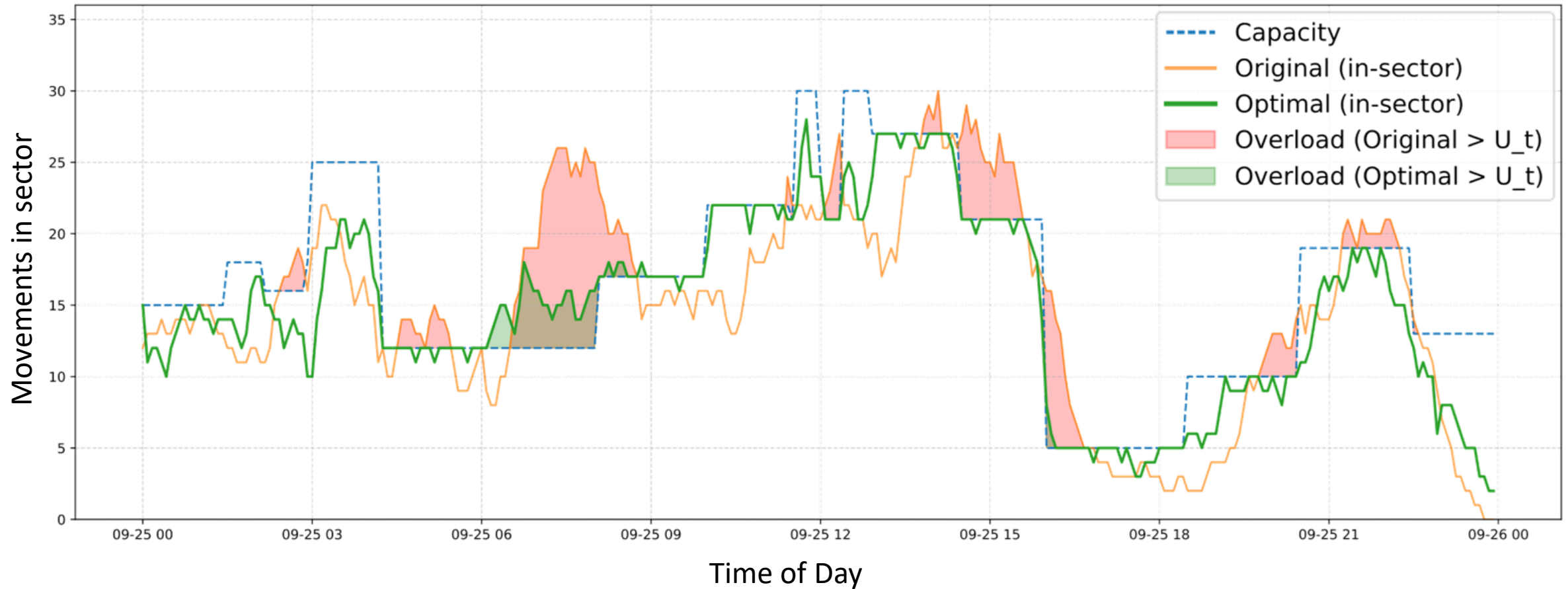
$$\sum_{i \in I} \sum_{j \in J_i} x_{ij} T_{ijt} - \rho_t \leq U_t \quad \forall t \in T$$

$$\sum_{j \in J_i} x_{ij} = 1 \quad \forall i \in I$$

$$x_{ij} \in \{0, 1\}, \rho_t \in \{0, 1, \dots, \infty\} \quad \forall i \in I, j \in J_i, t \in T$$

**Optimization to maintain
demand/capacity balancing at
the sector and airport level**

Results Original vs Optimized (September 25)

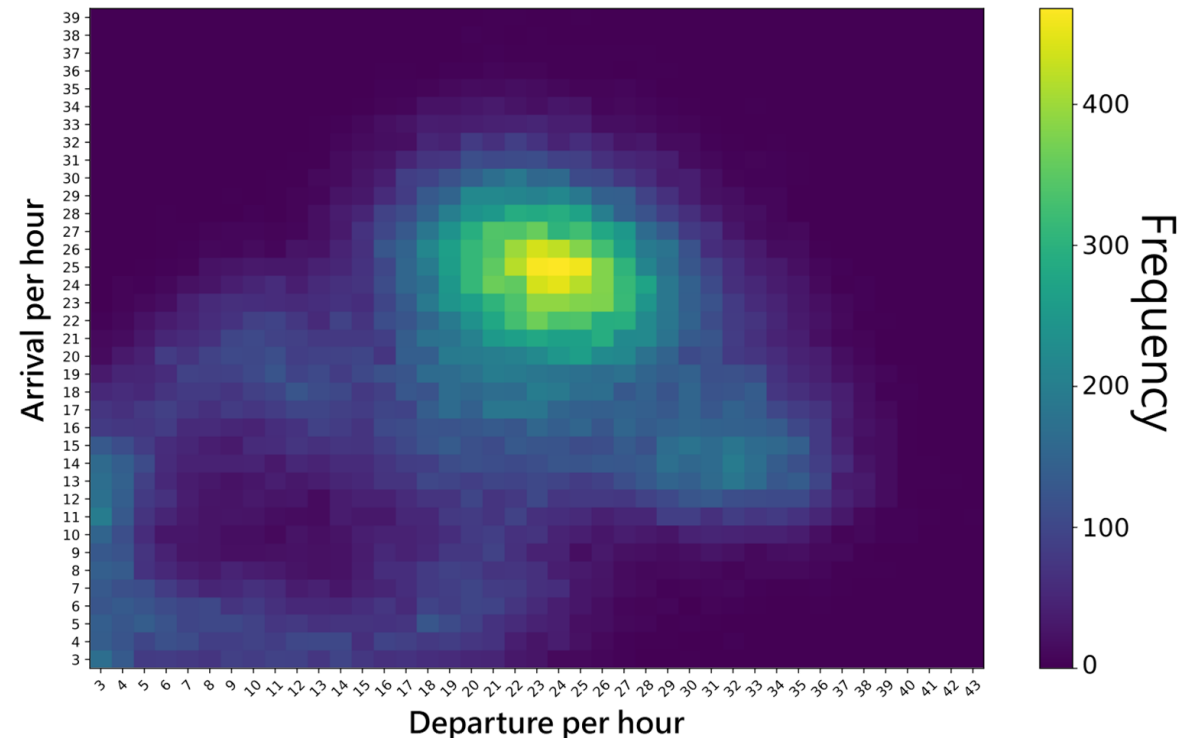


Overload: 2085 → 395 flight-min (−81%); max residual 6 at 06:45 (severe trough)

Operational Parameters Identification

- Use Normal-ops template + (c^+, t^+) , (c^-, t^-) , (c^{++}, t^{++}) deltas around forecast runway direction changes
- Pre-flip notch ($t^+ \approx 10\text{--}15$ min), post-flip drop ($t^- \approx 45\text{--}60$ min; deeper early a.m.), opening bump ($t^{++} \approx 20\text{--}30$ min mid-day)
- Direction-aware: stronger deltas during inter-monsoon convection; lighter in stable monsoon hours

Pareto frontiers obtained from the model
used to identify operational parameters



Feasibility & Acceptance

- Options predominantly require $\leq \pm 10$ -20 min shifts (per multiple flight hours), aligned with trial evidence
- Recommend limited advisories only (e.g., greater than 0.01 Mach) to limit cockpit workload
- Integration with AMAN near 170 NM ensures minimal tactical re-sequencing

Concept of operations to implement Long-Range ATFM still needs to be finalized

Limitations and Next Steps

- Reference built from North-ops; extend to South-ops seasonal template
- Flip-delta calibration can be refined with longer multi-year data and weather nowcasts
- Couple with AMAN simulations and airline cost indices for joint benefit analysis

Key Takeaways

- Capacity at Changi Airport is a runway-aware envelope, not a fixed ceiling
- Runway-aware LR-ATFM cuts overload by ~80% on a high-flip day while preserving arrival rushed
- Simple, direction-aware rules + modest in-cruise advisories deliver material benefits
- Implementation of the LR-ATFM concept still needs to be finalized