Research Summary: Runway Assignment Optimisation Model (IST)

Based on Güven et al. (2024), *The Aeronautical Journal*

1 Problem Definition & Motivation

This study addresses the **Runway Assignment Problem (RSP)** at Istanbul Airport (IST), characterized by its complex layout of five parallel runways. The primary objective is to minimise total fuel consumption during taxi and waiting operations.

Gap & Motivation: Traditional literature often relies on generic aircraft weight categories (Heavy/Medium/Light) for fuel estimation. This paper fills a gap by utilizing **engine-specific fuel flow rates** for 47 different aircraft types derived from the ICAO Engine Emission Databank. The goal is to optimize the assignment and sequencing of arrival/departure traffic to minimize environmental impact compared to the First-Come-First-Served (FCFS) logic.

2 Model Formulation

The problem is modelled as a deterministic **Mixed Integer Linear Programming (MILP)**.

2.1 Indices, Sets, and Parameters

- **Sets:** $I = \{1, \ldots, n\}$ (Aircraft); J (Runways: 34L/R, 35L/R, 36); K (Parking positions).
- **Parameters:**
  - $ox_i \in \{1, 2\}$: Operation type (1 = Arrival, 2 = Departure).
  - $g_i \in K$: The specific parking position (gate) assigned to aircraft i (fixed parameter).
  - $ra_{i,j} \in \{0, 1\}$: Feasibility parameter (1 if aircraft i can technically use runway j).
  - $dpr_{j_1,j_2} \in \{0, 1\}$: Dependency matrix (1 if runways are the same or parallel-dependent).
  - $taxiin_{j,k}/taxiout_{j,k}$: Taxi duration (min) for runway j and gate k.
  - f_i: **Fuel flow rate** (kg/min) specific to aircraft i's engine type.
  - sep_{i_1,i_2}: Required wake turbulence separation (seconds) if i_1 precedes i_2.

2.2 Decision Variables

- $x_{i,j} \in \{0, 1\}$: 1 if aircraft i is assigned to runway j; 0 otherwise.
- $e_{1,i_1,i_2} \in \{0, 1\}$: Sequencing binary; 1 if aircraft i_1 uses the runway before aircraft i_2.
- $rut_i \geq 0$: Runway Use Time (instant aircraft i touches down or lines up).
- $aw_i, gw_i \geq 0$: Airborne waiting time (arrivals) and Ground waiting time (departures).

2.3 Objective Function and Representative Constraints

The objective minimises total fuel (Z), derived from taxi duration (lookup based on assigned runway j and fixed gate g_i) and variable waiting times.

$$\min Z = \sum_{i \in I} f_i \cdot \left[(aw_i + gw_i) + \sum_{j \in J} x_{i,j} \cdot (taxiin_{j,g_i} \cdot \mathbf{1}_{\{ox_i=1\}} + taxiout_{j,g_i} \cdot \mathbf{1}_{\{ox_i=2\}}) \right] \quad (1)$$

Assignment Constraint: Each aircraft must be assigned to exactly one feasible runway.

$$\sum_{j \in J, ra_{i,j}=1} x_{i,j} = 1 \quad \forall i \in I \quad (2)$$

Separation Logic (Big-M): Ensures separation (sep) between aircraft i_1, i_2 if they are assigned to dependent runways ($dpr_{j_1,j_2} = 1$) and i_1 is sequenced first ($e = 1$).

$$rut_{i_2} - rut_{i_1} \geq sep_{i_1,i_2} - M(1 - e_{1,i_1,i_2}) - M(2 - x_{i_1,j_1} - x_{i_2,j_2}) \quad (3)$$

(Note: Valid $\forall i_1, i_2 \in I, \forall j_1, j_2 \in J$ where $dpr_{j_1,j_2} = 1$)

3 Solution Approach

The authors utilized exact solution methods (MILP) to compare the "Proposed Mathematical Model (PMM)" against the historical "Fixed Runway Assignment Approach (FRAA)."

Project Implementation Strategy: While the authors likely used GAMS/CPLEX, this implementation will utilize the **Gurobi Optimizer** (via Python) to solve the MILP formulation to optimality given the reduced problem size.

4 Data & Computational Experiments

Paper's Data: The study analysed 8 scenarios from September 2021 IST data, each covering a 6-hour window with 413–478 aircraft, using 47 distinct aircraft types.

Project Data (Synthetic): Due to the unavailability of proprietary IST radar data, a **synthetic dataset** will be generated for the implementation phase:

- **Scenario Scope:** A **1-hour operation window** to manage computational complexity.
- **Traffic Volume: 50 aircraft** (approx. 25 arrivals / 25 departures).
- **Parameters:** Random generation of aircraft types (Heavy/Medium/Light mapped to proxy fuel flows) and gate assignments based on the IST North Configuration layout.

5 Critique & Contribution

Novelty: The paper's main contribution is replacing generic weight-class assumptions with high-fidelity, engine-specific fuel data. It explicitly models the unique dependencies of IST's 5-runway system. The PMM reduced total fuel consumption by **6.6% to 14.4%**.

Critique: The model assumes deterministic taxi times, ignoring ground traffic stochasticity. Since solving for $n = 400+$ requires significant resources, the scaled-down synthetic approach ($n = 50$) is appropriate for testing model validity within a term project scope.