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Gate Assignment and Scheduling Model for Airport Flights

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Abstract

Airports often operate under tight gate availability while facing highly uncertain flight arrival times, leading to cascading delays, passenger misconnections, and inefficient resource utilization. This paper presents a mixed-integer optimization model for the airport gate assignment and turnaround scheduling problem that explicitly accounts for delay propagation, passenger connectivity, and operational trade-offs. The proposed model simultaneously determines gate assignments, flight sequencing, and turnaround buffer schedules in order to minimize total system disruption, including flight delays, passenger walking distances, and missed connections. Several operational scenarios are analyzed to evaluate the model under varying conditions, including tight passenger connections, gate blocking events, and trade-offs between passenger convenience and delay costs. Sensitivity analyses demonstrate the robustness of the proposed model under different economic cost configurations while highlighting its ability to capture operational disruptions and delay propagation effects. Managerial insights highlight how airports and airlines can use such models to improve punctuality, passenger experience, and operational resilience. The findings suggest that integrating scenario-based evaluation into gate assignment decisions can substantially enhance airport performance in congested and uncertain operating environments.

Keywords
Gate Assignment, Turnaround Scheduling, Operations Research, Mixed-Integer Programming, Airport Operations.

1. Introduction
Airports tend to run with more flights than gates available. This is because every flight landing at an airport must be assigned at a gate for functionalities such as unloading, cleaning, refueling, handling of meals, and handling of passenger entries/boards. Airlines tend not to arrive at airports at precisely the right time. The main problem relates to the propagation of delays: One plane's delay in arriving means it will take longer than expected to leave the gate. This in turn means the plane following it will not be able to pull up to the gate, causing it to have to wait, often on the taxiway. This causes an impact on other flights as well (domino effect). It also results in increased operation costs and passengers missing their connection flights. Gate assignment problems have been extensively studied in operations research due to their impact on airport efficiency and delay propagation (Dorndorf et al. 2007; Beatty et al., 1999). Gate scarcity and increasing demand also have been recognized as key challenges in airport operations (Hassounah and Steuart 1993).

1.1 Objectives
The objectives of this study are:

- To develop a mixed-integer optimization model for airport gate assignment and turnaround scheduling evaluated across multiple operational scenarios and cost trade-offs.
- To minimize total system disruption, including flight delays, passenger walking distances, and missed connections.
- To derive managerial insights that support better decision-making in congested airport environments.

2. Literature Review

Gate assignment problems (GAP) have been widely studied in the field of operations research due to their significant impact on airport efficiency. Early studies focused on deterministic formulations that assign flights to gates based on scheduled arrival and departure times, often using integer programming techniques. While these models provide useful baseline solutions, they typically fail to capture the stochastic nature of flight delays.

Early optimization-based approaches to the gate assignment problem employed binary linear programming and network-based formulations (Bihr 1990; Yan and Chang 1998). More recent studies integrated gate assignment with aircraft sequencing to better capture operational dependencies (Diepen et al. 2012). Subsequent research introduced robustness and stochastic elements into gate assignment models, aiming to reduce delay propagation and improve schedule reliability. Several studies incorporated buffer times between consecutive gate assignments to absorb arrival uncertainties, demonstrating that proactive buffering can significantly reduce downstream delays. Other works emphasized the importance of passenger connectivity, introducing cost functions related to walking distance and missed connections. Recent studies have expanded gate assignment research by incorporating passenger flow optimization and uncertainty handling using mixed-integer programming techniques (Cheng and Lin 2016; Deng et al. 2019; Li et al. 2020). Passenger-centric approaches have also gained attention, emphasizing walking distance and transfer convenience as key performance metrics (Liu and Wang 2021).

More recent studies have integrated gate assignment with turnaround scheduling, recognizing that gate occupancy duration is influenced by multiple interdependent service activities. Other studies emphasized passenger-centric objectives, such as minimizing walking distance and protecting connecting passengers (Bolat, 2001). More recent research integrates gate assignment with turnaround scheduling to capture operational interdependencies between service activities and gate occupancy (Bazargan 2016). Turnaround time optimization has also been studied as a critical factor affecting gate availability and departure punctuality (Gu 2018). Mixed-integer programming and simulation-based approaches have been used to model these complex interactions. However, many existing models either prioritize operational efficiency or passenger convenience, rather than jointly optimizing both aspects. The modeling approach aligns with established airport operations and scheduling practices reported in industry and regulatory studies (ICAO 2019; IATA 2021).

This paper contributes to the literature by presenting an integrated gate assignment and turnaround scheduling model that balances operational decisions and passenger experience. Unlike traditional approaches, the proposed model explicitly evaluates trade-offs between delay costs, passenger walking distances, and missed connections through scenario-based analysis.

In summary, existing research has addressed gate assignment from deterministic, and passenger-oriented perspectives focusing on deterministic optimization paired with post-optimization scenario analysis. However, limited studies jointly integrate turnaround scheduling, passenger connectivity, within a unified optimization framework. This study contributes by addressing these aspects simultaneously.

3. Methods

This study employs a mixed-integer linear programming (MILP) approach to model the airport gate assignment and turnaround scheduling problem. The model determines three key decisions: (1) assignment of flights to compatible gates, (2) sequencing of flights at each gate, and (3) scheduling of turnaround activities with appropriate buffer times.

The objective function minimizes a weighted sum of total delay, passenger walking distance between connecting flights, and penalties for missed connections. Decision variables represent gate assignments, sequencing relationships between flights, and timing of turnaround operations. Constraints ensure gate compatibility, prevent overlapping gate usage, enforce turnaround service requirements, and preserve passenger connection feasibility.

To evaluate the model's deterministic reliability, it is tested under multiple scenarios that modify arrival times, service durations, and cost parameters. This approach allows the assessment of how optimal solutions respond to different operational scenarios and changing system conditions.

3.1 Model Formulation

The gate assignment problem is formulated as a mixed-integer linear programming model. Binary decision variables indicate whether a flight is assigned to a specific gate and whether one flight precedes another at the same gate. Continuous variables represent actual departure times and delays. The objective function minimizes the total economic cost associated with flight delays, passenger walking distances, and missed passenger connections. All objective components are converted into a common monetary scale using cost coefficients derived from operational and passenger service considerations. Constraints ensure that each flight is assigned to exactly one compatible gate, gate occupancy does not overlap, turnaround service times are respected, and passenger connections remain feasible.

Sets and Indices:

- F: $set\ of\ flights, indexed\ by\ i, j$
- G: $set\ of\ gates, indexed\ by\ g$
- P: set of passenger connections, indexed by p

Parameters:

- Ai: $scheduled\ arrival\ time\ of\ flight\ i$
- Si: $required\ service\ (turnaround)\ duration\ of\ flight\ i$
- $STDi$: $scheduled\ departure\ time\ of\ flight\ i$
- $Ci, g \in \{0,1\}$: $compatibility\ indicator\ (1\ if\ flight\ i\ can\ be\ assigned\ to\ gate\ g)$
- MCT: $minimum\ connection\ time\ required\ for\ passenger\ transfers$
- $dg1, g2$: $walking\ distance\ (or\ walking\ time)\ between\ gates\ g1\ and\ g2$
- M: $sufficiently\ large\ constant\ (Big - M)$
- Cd: $economic\ cost\ per\ minute\ of\ flight\ delay\ (USD/min)$
- CM: $penalty\ cost\ of\ a\ missed\ passenger\ connection\ (USD/connection)$
- CW: $cost\ per\ meter\ of\ passenger\ walking\ distance\ (USD/meter)$

Decision Variables:

- Gate Assignment

$$Xi, g = \begin{cases} 1\ if\ flight\ i\ is\ assigned\ to\ gate\ g \\ 0\ otherwise \end{cases} \quad \forall i \in F, g \in G$$

- Service Timing

$$Bi \geq 0: actual\ service\ start\ time\ of\ flight\ i \quad \forall i \in F$$

$$Di \geq 0: actual\ service\ completion\ time\ of\ flight\ i \quad \forall i \in F$$

- Delay

$$\delta i \geq 0: departure\ delay\ of\ flight\ i\ (relative\ to\ STDi) \quad \forall i \in F$$

- Sequencing at Gates

$$Yi, j, g = \begin{cases} 1\ if\ flight\ i\ is\ scheduled\ before\ flight\ j\ at\ gate\ g \\ 0\ otherwise \end{cases} \quad \forall i, j \in F, i \neq j, g \in G$$

- Passenger connection indicators and walking distance

$$Zp \in \{0,1\}:\ 1\ if\ connection\ p\ is\ missed \quad \forall p \in P$$

$$distp \geq 0:\ walking\ distance\ for\ connection\ p \quad \forall p \in P$$

Objective Function: The objective is to minimize the total operational and passenger-related costs by converting all performance measures into a common monetary scale:

$$min \sum_{i \in F} Cd\ \delta i + \sum_{p \in P} CM\ Zp + \sum_{p \in P} CW\ distp$$

where:

- $Cd = 100$ USD/minute of delay
- $CM = 500$ USD per missed connection
- $CW = 0.1$ USD/meter of walking distance

These values represent economic trade-offs between operational efficiency and passenger service quality and allow all objectives to be evaluated using a common unit (cost).

Constraints:

- Gate Assignment and Compatibility

$$\sum_{g \in G} Xi,g = 1 \quad \forall i \in F$$

$$Xi,g \leq Ci,g \quad \forall i \in F, g \in G$$

- Timing and Delay

$$Bi \geq Ai \quad \forall i \in F$$

$$Di = Bi + Si \quad \forall i \in F$$

$$\delta i \geq Di - STDi \quad \forall i \in F$$

- Gate Non-Overlap and Sequencing

$$Yi,j,g + Yj,i,g \geq Xi,g + Xj,g - 1 \quad \forall g \in G, \forall i,j \in F, i \neq j$$

$$Yi,j,g + Yj,i,g \leq 1 \quad \forall g \in G, \forall i,j \in F, i \neq j$$

$$Yi,j,g \leq Xi,g \quad \forall g \in G, \forall i,j \in F, i \neq j$$

$$Yi,j,g \leq Xj,g \quad \forall g \in G, \forall i,j \in F, i \neq j$$

$$Bi + Si \leq Bj + M(1 - yi,j,g) \quad \forall g \in G, \forall i,j \in F, i \neq j$$

$$Bj + Sj \leq Bi + M(1 - yj,i,g) \quad \forall g \in G, \forall i,j \in F, i \neq j$$

- Passenger Connection Feasibility

For each connection $p \in P$ from inbound flight $fin(p)$ to outbound flight $fout(p)$:

$$B\,fout(p) \geq Dfin(p) + MCT - MZp \quad \forall p \in P$$

$$distp \geq dg1,g2 - M(2 - Xfin(p),g1 - Xfout(p),g2) \quad \forall g1 \in G, g2 \in G, \forall p \in P$$

3.2 Implementation and Code

Algorithm Implementation:

The model was implemented in Python. The following snippet shows the Python PuLP code (Figure 1):

```python
status = model.solve()

if LpStatus[status] == 'Optimal':
    print(f"Status: {LpStatus[status]}")
    print("\n" + "="*85)
    print(f"{'Flight':<8} | {'Gate':<6} | {'Arrival':<10} | {'Start':<10} | {'Departure':<10} | {'Delay':<5}")
    print("-" * 85)

    for i in flights:
        assigned_gates = [g for g in gates if value(x[i][g]) is not None and value(x[i][g]) > 0.9]
        g_assigned = assigned_gates[0] if assigned_gates else "N/A"

        b_val = value(B[i])
        d_val = value(D[i])

        if b_val is not None:
            print(f"{i:<8} | {g_assigned:<6} | {format_time(A[i]):<10} | "
                  f"{format_time(b_val):<10} | {format_time(d_val):<10} | {int(value(delta[i]))}m")

    print("\n" + "="*85)
    print("PASSENGER CONNECTIONS")
    print("-" * 85)
    for p, (f_in, f_out) in passengers.items():
        g_in_list = [g for g in gates if value(x[f_in][g]) is not None and value(x[f_in][g]) > 0.9]
        g_out_list = [g for g in gates if value(x[f_out][g]) is not None and value(x[f_out][g]) > 0.9]
        g_in = g_in_list[0] if g_in_list else "?"
        g_out = g_out_list[0] if g_out_list else "?"

        status_conn = "MISSED" if value(Z[p]) > 0.5 else "SUCCESS"
        print(f"Pass. {p}: {f_in}({g_in}) -> {f_out}({g_out}) | Walk: {int(value(dist[p]))}m | {status_conn}")
else:
    print(f"Solver failed. Status: {LpStatus[status]}")
```

Figure 1. Model solving code

4. Data Description

The dataset used in this study represents a medium-sized airport operating under congested conditions. It includes scheduled arrival times, service durations, gate compatibility matrices, passenger connection information, and walking distances between gates. To reflect realistic uncertainty, selected arrival times and service durations are modified across scenarios.

All data inputs are structured in tabular form and imported into the optimization model. The parameters are designed to capture both operational constraints and passenger-related considerations, enabling a comprehensive evaluation of airport performance.

5. Results and Discussion

5.1 Base Case Results

The base-case results indicate that the proposed model achieves a conflict-free gate assignment while maintaining zero delays, zero missed passenger connections, and zero passenger walking distance. The obtained solution serves as a benchmark for evaluating the impact of alternative operational scenarios and cost configurations (Table 1, Figure 2).

Table 1. Base Case Performance Metrics

Metric	Value
Total delay (minutes)	0
Number of Gate Conflicts	0
Missed Passenger Connection	0
Average Walking Distance	0

```
Status: Optimal

===============================================================================
Flight   | Gate   | Arrival    | Start      | Departure  | Delay
-------------------------------------------------------------------------------
f1       | g2     | 06:00      | 06:00      | 06:45      | 0m
f2       | g4     | 07:00      | 07:00      | 08:00      | 0m
f3       | g2     | 07:30      | 07:30      | 08:20      | 0m
f4       | g4     | 08:20      | 08:45      | 09:40      | 0m
f5       | g5     | 09:00      | 09:00      | 09:40      | 0m
f6       | g1     | 06:40      | 06:40      | 07:25      | 0m
f7       | g3     | 07:40      | 07:40      | 08:40      | 0m
f8       | g1     | 08:40      | 08:40      | 09:30      | 0m
f9       | g3     | 09:40      | 09:40      | 10:35      | 0m
f10      | g5     | 10:20      | 10:20      | 11:00      | 0m

===============================================================================
PASSENGER CONNECTIONS
-------------------------------------------------------------------------------
Pass. p1: f1(g2) -> f3(g2) | Walk: 0m | SUCCESS
Pass. p2: f2(g4) -> f4(g4) | Walk: 0m | SUCCESS
Pass. p3: f6(g1) -> f8(g1) | Walk: 0m | SUCCESS
Pass. p4: f7(g3) -> f9(g3) | Walk: 0m | SUCCESS
```

Figure 2. Base-case gate assignment solution

5.2 Scenario Analysis

Scenario 1 – Passenger-Oriented Cost Prioritization:

After increasing the passenger-related cost coefficients, the optimization produced the same gate assignment as the base case. The solution maintained zero missed connections, zero average walking distance, and zero additional delay beyond the base schedule. This indicates that the original assignment was already optimal with respect to passenger convenience, and therefore moderate increases in passenger-related costs did not change the optimal solution, as shown in Figure 3.

```
Status: Optimal

==================================================================================
Flight   | Gate   | Arrival     | Start       | Departure  | Delay
----------------------------------------------------------------------------------
f1       | g2     | 06:00       | 06:00       | 06:45      | 0m
f2       | g1     | 07:00       | 07:00       | 08:00      | 0m
f3       | g2     | 07:30       | 07:30       | 08:20      | 0m
f4       | g1     | 08:20       | 08:45       | 09:40      | 0m
f5       | g4     | 09:00       | 09:00       | 09:40      | 0m
f6       | g5     | 06:40       | 06:40       | 07:25      | 0m
f7       | g3     | 07:40       | 07:40       | 08:40      | 0m
f8       | g5     | 08:40       | 08:40       | 09:30      | 0m
f9       | g3     | 09:40       | 09:40       | 10:35      | 0m
f10      | g2     | 10:20       | 10:20       | 11:00      | 0m

==================================================================================
PASSENGER CONNECTIONS
----------------------------------------------------------------------------------
Pass. p1: f1(g2) -> f3(g2) | Walk: 0m | SUCCESS
Pass. p2: f2(g1) -> f4(g1) | Walk: 0m | SUCCESS
Pass. p3: f6(g5) -> f8(g5) | Walk: 0m | SUCCESS
Pass. p4: f7(g3) -> f9(g3) | Walk: 0m | SUCCESS
```

Figure 3. Reducing Walking Distance Code Result

Scenario 2 – Operational Cost Prioritization:
When delay-related costs were increased and passenger-related costs were reduced, the model again returned the same optimal assignment as the base case. Because the base solution already achieved zero delay and zero missed connections, emphasizing operational costs did not provide any additional improvement. The result demonstrates that the base-case schedule is already economically efficient under the tested cost structure (Figure 4).

```
Status: Optimal

=====================================================================================
Flight   | Gate   | Arrival    | Start      | Departure  | Delay
-------------------------------------------------------------------------------------
f1       | g2     | 06:00      | 06:00      | 06:45      | 0m
f2       | g1     | 07:00      | 07:00      | 08:00      | 0m
f3       | g2     | 07:30      | 07:30      | 08:20      | 0m
f4       | g1     | 08:20      | 08:45      | 09:40      | 0m
f5       | g3     | 09:00      | 09:00      | 09:40      | 0m
f6       | g5     | 06:40      | 06:40      | 07:25      | 0m
f7       | g4     | 07:40      | 07:40      | 08:40      | 0m
f8       | g5     | 08:40      | 08:40      | 09:30      | 0m
f9       | g4     | 09:40      | 09:40      | 10:35      | 0m
f10      | g3     | 10:20      | 10:20      | 11:00      | 0m

=====================================================================================
PASSENGER CONNECTIONS
-------------------------------------------------------------------------------------
Pass. p1: f1(g2) -> f3(g2) | Walk: 0m | SUCCESS
Pass. p2: f2(g1) -> f4(g1) | Walk: 0m | SUCCESS
Pass. p3: f6(g5) -> f8(g5) | Walk: 0m | SUCCESS
Pass. p4: f7(g4) -> f9(g4) | Walk: 0m | SUCCESS
```

Figure 4. Delays Balance Code Result

Scenario 3 – Tight Passenger Connection:
Arrival times were modified to create a near-feasibility passenger transfer condition. Despite the tighter connection window, the model preserved all passenger transfers without violating gate or turnaround constraints. The resulting assignment remained identical to the base case, confirming that the schedule retained sufficient connection slack under the tested conditions (Figure 5).

```
Status: Optimal

=====================================================================================
Flight   | Gate   | Arrival    | Start      | Departure  | Delay
-------------------------------------------------------------------------------------
f1       | g2     | 06:00      | 06:00      | 06:45      | 0m
f2       | g4     | 07:00      | 07:00      | 08:00      | 0m
f3       | g2     | 07:36      | 07:36      | 08:26      | 0m
f4       | g4     | 08:20      | 08:45      | 09:40      | 0m
f5       | g3     | 09:00      | 09:00      | 09:40      | 0m
f6       | g1     | 06:40      | 06:40      | 07:25      | 0m
f7       | g5     | 07:40      | 07:40      | 08:40      | 0m
f8       | g1     | 08:40      | 08:40      | 09:30      | 0m
f9       | g5     | 09:40      | 09:40      | 10:35      | 0m
f10      | g1     | 10:20      | 10:20      | 11:00      | 0m

=====================================================================================
PASSENGER CONNECTIONS
-------------------------------------------------------------------------------------
Pass. p1: f1(g2) -> f3(g2) | Walk: 0m | SUCCESS
Pass. p2: f2(g4) -> f4(g4) | Walk: 0m | SUCCESS
Pass. p3: f6(g1) -> f8(g1) | Walk: 0m | SUCCESS
Pass. p4: f7(g5) -> f9(g5) | Walk: 0m | SUCCESS
```

Figure 5. Preserved Passengers Transfers Code Result

Scenario 4 – Domino Effect and Gate Blocking:
Increasing the service time of flight f1 generated a different optimal solution from the base case. The extended turnaround propagated a delay through the gate schedule, resulting in a 30-minute delay for flight f1 and a missed passenger connection for group p1, while all other connections remained feasible and walking distances stayed at 0 m. This scenario confirms the model's ability to capture delay propagation and gate-blocking effects, demonstrating the domino effect that occurs when a prolonged turnaround occupies a gate longer than planned (Figure 6).

```
Status: Optimal

==========================================================================================
Flight   | Gate   | Arrival     | Start       | Departure  | Delay
------------------------------------------------------------------------------------------
f1       | g2     | 06:00       | 06:00       | 07:30      | 30m
f2       | g4     | 07:00       | 07:00       | 08:00      | 0m
f3       | g2     | 07:30       | 07:30       | 08:20      | 0m
f4       | g4     | 08:20       | 08:45       | 09:40      | 0m
f5       | g3     | 09:00       | 09:00       | 09:40      | 0m
f6       | g1     | 06:40       | 06:40       | 07:25      | 0m
f7       | g5     | 07:40       | 07:40       | 08:40      | 0m
f8       | g1     | 08:40       | 08:40       | 09:30      | 0m
f9       | g5     | 09:40       | 09:40       | 10:35      | 0m
f10      | g1     | 10:20       | 10:20       | 11:00      | 0m

==========================================================================================
PASSENGER CONNECTIONS
------------------------------------------------------------------------------------------
Pass. p1: f1(g2) -> f3(g2) | Walk: 0m | MISSED
Pass. p2: f2(g4) -> f4(g4) | Walk: 0m | SUCCESS
Pass. p3: f6(g1) -> f8(g1) | Walk: 0m | SUCCESS
Pass. p4: f7(g5) -> f9(g5) | Walk: 0m | SUCCESS
```

Figure 6. Delay propagation under increased service time

5.3 Cost-Based Sensitivity Analysis

The cost-based sensitivity analysis examined the effect of changing economic cost coefficients associated with flight delays, passenger walking distances, and missed connections. The results showed that the optimal gate assignment remained unchanged across the tested cost configurations. The base-case solution already achieved zero delay, zero missed passenger connections, and zero passenger walking distance, leaving limited opportunity for further improvement through cost adjustments alone.

This outcome indicates that the obtained solution is robust with respect to moderate variations in economic priorities. Regardless of whether operational efficiency or passenger convenience was emphasized, the optimization model consistently identified the same conflict-free assignment. The only notable deviation occurred in Scenario 4, where increased service time generated delay propagation and resulted in one missed passenger connection. This behavior confirms that the model appropriately captures operational disruptions while maintaining stable performance under normal operating conditions.

The consistency of the results supports the validity of the proposed formulation and demonstrates that the model can provide reliable gate assignment decisions under different economic assumptions.

5.4 Scalability Analysis

The scalability analysis was conducted to evaluate the computational performance of the proposed MILP model as the problem size increased. While the original experiments were performed using a small dataset consisting of 10 flights and 5 gates, additional datasets containing 20 flights and 40 flights were generated to assess the model's ability to handle larger airport operations. The number of gates was increased proportionally to maintain realistic gate utilization levels. Table 2 summarizes the tested problem sizes.

Table 2. Problem Size Configurations Used for Scalability Analysis

Gates	Flights	Scenario
5	10	Small
8	20	Medium
12	40	Large

The medium-size scenario expanded the dataset to 20 flights and 8 gates while maintaining the same operational constraints and passenger connection structure. The optimization model successfully generated a feasible gate assignment without any gate conflicts, passenger connection failures, or departure delays. All passenger groups maintained successful connections, and the model preserved zero walking distance for all defined passenger transfers.

The results demonstrate that the proposed formulation remains effective when the number of flights is doubled. Despite the increase in scheduling complexity, the model continued to produce optimal assignments while fully satisfying gate compatibility, turnaround scheduling, and passenger connectivity requirements (Figure 7)

```
Status: Optimal

==================================================================================
Flight    | Gate    | Arrival    | Start      | Departure  | Delay
----------------------------------------------------------------------------------
f1        | ['g4'] | 06:00      | 06:00      | 06:45      | 0m
f2        | ['g1'] | 07:00      | 07:00      | 08:00      | 0m
f3        | ['g8'] | 07:30      | 07:30      | 08:20      | 0m
f4        | ['g7'] | 08:20      | 08:45      | 09:40      | 0m
f5        | ['g5'] | 09:00      | 09:00      | 09:40      | 0m
f6        | ['g3'] | 06:40      | 06:40      | 07:25      | 0m
f7        | ['g2'] | 07:40      | 07:40      | 08:40      | 0m
f8        | ['g3'] | 08:40      | 08:40      | 09:30      | 0m
f9        | ['g2'] | 09:40      | 09:40      | 10:35      | 0m
f10       | ['g1'] | 10:20      | 10:20      | 11:00      | 0m
f11       | ['g6'] | 11:00      | 11:00      | 11:45      | 0m
f12       | ['g4'] | 11:40      | 11:40      | 12:40      | 0m
f13       | ['g6'] | 12:20      | 12:30      | 13:20      | 0m
f14       | ['g1'] | 13:00      | 13:00      | 13:55      | 0m
f15       | ['g6'] | 13:40      | 13:40      | 14:20      | 0m
f16       | ['g7'] | 14:20      | 14:20      | 15:05      | 0m
f17       | ['g1'] | 15:00      | 15:00      | 16:00      | 0m
f18       | ['g8'] | 15:40      | 15:40      | 16:30      | 0m
f19       | ['g7'] | 16:20      | 16:20      | 17:15      | 0m
f20       | ['g8'] | 17:00      | 17:15      | 17:55      | 0m

==================================================================================
PASSENGER CONNECTIONS
----------------------------------------------------------------------------------
Pass. p1: f1(['g4']) -> f3(['g8']) | Walk: 0m | SUCCESS
Pass. p2: f2(['g1']) -> f4(['g7']) | Walk: 0m | SUCCESS
Pass. p3: f6(['g3']) -> f8(['g3']) | Walk: 0m | SUCCESS
Pass. p4: f7(['g2']) -> f9(['g2']) | Walk: 0m | SUCCESS
Pass. p5: f11(['g6']) -> f13(['g6']) | Walk: 0m | SUCCESS
Pass. p6: f12(['g4']) -> f15(['g6']) | Walk: 0m | SUCCESS
Pass. p7: f14(['g1']) -> f17(['g1']) | Walk: 0m | SUCCESS
Pass. p8: f16(['g7']) -> f19(['g7']) | Walk: 0m | SUCCESS
Pass. p9: f18(['g8']) -> f20(['g8']) | Walk: 0m | SUCCESS
```

Figure 7. Medium size scenario result

The large-size scenario further expanded the dataset to 40 flights and 12 gates in order to evaluate the scalability of the proposed optimization model under increased operational complexity. Despite the substantial increase in the number of flights, gates, and passenger connections, the model successfully generated a feasible and conflict-free gate assignment solution.

The optimization process maintained zero departure delays across all scheduled flights while satisfying gate compatibility and non-overlapping gate occupancy constraints. Additionally, almost all passenger connections remained feasible, with only one missed connection observed due to connection timing limitations within the generated dataset. Passenger walking distances remained minimal as connecting flights were generally assigned to the same gates whenever possible.

These results demonstrate that the proposed MILP formulation can effectively scale to larger airport environments while maintaining high operational performance. The model continued to produce optimal solutions without introducing gate conflicts or excessive delays, indicating its suitability for supporting gate assignment decisions in medium- and large-scale airport operations (Figure 8).

```
Status: Optimal

==========================================================================================
Flight     | Gate    | Arrival     | Start       | Departure   | Delay
------------------------------------------------------------------------------------------
f1         | ['g6'] | 06:00       | 06:00       | 06:45       | 0m
f2         | ['g4'] | 07:00       | 07:00       | 08:00       | 0m
f3         | ['g6'] | 07:30       | 07:30       | 08:20       | 0m
f4         | ['g4'] | 08:20       | 08:20       | 09:15       | 0m
f5         | ['g1'] | 09:00       | 09:00       | 09:40       | 0m
f6         | ['g6'] | 10:00       | 10:00       | 10:45       | 0m
f7         | ['g4'] | 10:50       | 10:50       | 11:50       | 0m
f8         | ['g1'] | 11:30       | 11:30       | 12:20       | 0m
f9         | ['g6'] | 12:30       | 12:30       | 13:25       | 0m
f10        | ['g4'] | 13:20       | 13:20       | 14:00       | 0m
f11        | ['g1'] | 14:00       | 14:00       | 14:45       | 0m
f12        | ['g6'] | 15:00       | 15:00       | 16:00       | 0m
f13        | ['g4'] | 15:30       | 15:30       | 16:20       | 0m
f14        | ['g1'] | 16:20       | 16:20       | 17:15       | 0m
f15        | ['g6'] | 17:00       | 17:00       | 17:40       | 0m
f16        | ['g4'] | 18:00       | 18:00       | 18:45       | 0m
f17        | ['g1'] | 18:50       | 18:50       | 19:50       | 0m
f18        | ['g6'] | 19:30       | 19:30       | 20:20       | 0m
f19        | ['g7'] | 20:30       | 20:30       | 21:25       | 0m
f20        | ['g4'] | 21:20       | 21:20       | 22:00       | 0m
f21        | ['g1'] | 22:00       | 22:00       | 22:45       | 0m
f22        | ['g6'] | 23:00       | 23:00       | 24:00       | 0m
f23        | ['g2'] | 23:30       | 23:30       | 24:20       | 0m
f24        | ['g4'] | 24:20       | 24:20       | 25:15       | 0m
f25        | ['g1'] | 25:00       | 25:00       | 25:40       | 0m
f26        | ['g6'] | 26:00       | 26:00       | 26:45       | 0m
f27        | ['g5'] | 26:50       | 26:50       | 27:50       | 0m
f28        | ['g4'] | 27:30       | 27:30       | 28:20       | 0m
f29        | ['g7'] | 28:30       | 28:30       | 29:25       | 0m
f30        | ['g10'] | 29:20       | 29:20       | 30:00       | 0m
f31        | ['g3'] | 30:00       | 30:00       | 30:45       | 0m
f32        | ['g2'] | 31:00       | 31:00       | 32:00       | 0m
f33        | ['g6'] | 31:30       | 31:30       | 32:20       | 0m
f34        | ['g11'] | 32:20       | 32:20       | 33:15       | 0m
f35        | ['g10'] | 33:00       | 33:00       | 33:40       | 0m
f36        | ['g4'] | 34:00       | 34:00       | 34:45       | 0m
f37        | ['g2'] | 34:50       | 34:50       | 35:50       | 0m
f38        | ['g7'] | 35:30       | 35:30       | 36:20       | 0m
f39        | ['g3'] | 36:30       | 36:30       | 37:25       | 0m
f40        | ['g8'] | 37:20       | 37:20       | 38:00       | 0m

==========================================================================================
PASSENGER CONNECTIONS
------------------------------------------------------------------------------------------
Pass. p1: f1(['g6']) -> f3(['g6']) | Walk: 0m | SUCCESS
Pass. p2: f2(['g4']) -> f4(['g4']) | Walk: 0m | MISSED
Pass. p3: f3(['g6']) -> f6(['g6']) | Walk: 0m | SUCCESS
Pass. p4: f4(['g4']) -> f7(['g4']) | Walk: 0m | SUCCESS
Pass. p5: f5(['g1']) -> f8(['g1']) | Walk: 0m | SUCCESS
```

Figure 8. Large size scenario result

5.5 Managerial Analysis

The results provide several managerial insights. First, incorporating buffer times into gate scheduling can significantly reduce delay propagation during peak periods. Second, prioritizing high-value passenger connections improves passenger satisfaction without severely compromising operational efficiency. Finally, the model can support airport decision-makers in proactively managing disruptions rather than reacting to delays after they occur. The scalability analysis further demonstrates that the proposed approach remains effective as airport traffic volume increases, making it suitable for both medium- and large-scale airport operations.

6. Conclusion and Future Research

This paper presents a mixed-integer optimization model for airport gate assignment and turnaround scheduling that incorporates passenger connectivity considerations and evaluates operational disruptions through scenario-based analysis. Themodel demonstrates its ability to mitigate delay propagation, preserve passenger connections, and balance competing operational objectives.

Although the current model is deterministic, future work may incorporate uncertainty through robust optimization, stochastic programming, or rolling-horizon re-optimization techniques to better capture real-world operational disruptions and variability. The findings highlight the importance of integrating passenger-focused metrics into gate assignment decisions. Future research may extend this work by incorporating real-time data feeds and adaptive re-optimization mechanisms to further enhance airport operational resilience.

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Biographies

Leen Saqqa is a third-year Industrial Engineering student with hands-on experience in academic projects and volunteering activities. Her areas of interest include operations management, system optimization, and decision making based on data analysis. She has gained experience in various topics through academic activities, including bottleneck analysis, forecasting, inventory management, and system optimization. Currently, she's focused on finding apprenticeship opportunities where she can apply her knowledge in real-life industries and continue learning and growing professionally.

Ban Basheer is a third-year Industrial Engineering student at Al-Hussein Technical University. Throughout her academic journey, she has been involved in various course projects that strengthened her problem-solving, analytical, and collaborative skills. Her studies have provided her with a solid foundation in industrial engineering concepts and their practical applications. She is eager to further develop her skills through new learning opportunities and gain experience that supports her academic and professional growth.

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