Universitat Autònoma de Barcelona

GATE ASSIGNMENT OPTIMIZATION AT AIRPORTS

Thesis submitted for the degree on Aeronautical Management

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Abstract

The assignment of airport gates is a critical operational challenge that directly affects both efficiency and passenger experience. This work presents a computational optimization tool developed in Python that assigns flights to boarding gates by minimizing the total passenger-weighted walking distance inside the terminal. The model incorporates operational constraints including turnaround times, Schengen and non-Schengen gate compatibility, and temporal availability, and handles gate saturation through an automatic rescheduling mechanism. A greedy heuristic is adopted for its computational simplicity and adaptability to dynamic airport environments. The approach is applied to Girona–Costa Brava Airport as a case study, demonstrating its feasibility and practical applicability in a real operational context.

Keywords

Gate Assignment Problem; Greedy Heuristic; Passenger Walking Distance; Airport Operations; Schengen; Optimization

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1 Introduction

The Gate Assignment Problem (GAP) represents one of the most complex challenges in airport operations management. It consists of assigning each flight to an available gate within a specific time window while respecting multiple technical and operational constraints, such as gate availability, arrival and departure schedules, aircraft-gate compatibility, and turnaround times.

Proper gate assignment is essential to ensure overall airport efficiency, as it connects airside operations with the terminal and airline schedules. Correct planning reduces operational conflicts, minimizes delays, and contributes to maintaining the stability of the airport system, whereas inefficient assignment may cause congestion and chain delays, potentially compromising operational safety.

The literature has addressed this problem from different perspectives. Some studies have focused on maximizing operator preferences and managing schedule changes, using advanced algorithms to find good solutions under real constraints [1]. Previous research, such as the RAGA (Robust Airport Gate Assignment) model, has sought to maximize assignment robustness against real schedule uncertainty by means of a hybrid method combining tabu search and local search [2]. More recently, multi-objective models have been developed to reduce carbon emissions by maximizing the proportion of flights assigned to contact gates, minimizing fuel consumption during taxiing, and ensuring assignment stability, using genetic algorithms such as NSGA-II [3].

The objectives of the gate assignment problem can be classified into two main categories: the operational approach, which aims to minimize conflicts between flights, taxi delays, and operational costs; and the passenger-oriented approach, which seeks to improve the experience of travelers within the terminal by reducing walking distances, connection times, and the risk of missing flights. However, most of the literature has focused primarily on operational efficiency, while the impact on passenger experience has received comparatively less attention.

This work adopts a passenger-centered approach, placing the distance traveled inside the terminal as the main optimization criterion. The objective is to minimize the distance between the boarding gate and the arrivals exit, as well as the reverse direction for departing passengers, to improve traveler comfort without compromising the airport's operational feasibility.

To achieve this objective, a mathematical optimization model has been developed, which includes essential operational constraints such as aircraft-gate compatibility, time windows, and turnaround times. The model includes an objective function based on the distance traveled by passengers, weighted by the volume of travelers, which enables the impact of assignment decisions on passenger flow inside the terminal to be analyzed.

To contextualize the analysis, Girona–Costa Brava Airport has been selected as a case

study, as it allows approximate distances to be defined and the impact of the proposed model to be assessed in a representative manner.

The remainder of the paper is structured as follows. Section 2 presents the operational frameworks of the gate assignment problem. Section 3 formally describes the problem and its mathematical formulation. The methodology and optimisation approach are introduced in Section 4. In Section 5, the case study based on Girona–Costa Brava Airport is developed. The results obtained are presented and analyzed in Section 6. Finally, the main conclusions are outlined in Section 7.

2 | Operational Frameworks and Role of Gates

2.1 Airport Operational Environment

2.1.1 Actors within the Airport

Airports are highly dynamic environments where many operations take place simultaneously. These operations involve different actors who must coordinate efficiently to ensure flight safety and punctuality. The main stakeholders include:

- **Airlines:** They are the main users and customers of airports and represent a significant source of revenue. Therefore, airport service quality frameworks should be developed collaboratively to meet their needs. They provide air transport for passengers and/or cargo operating fleets of aircraft assigned according to routes and demand. Depending on the airline, they may operate scheduled or charter flights.
- **Ground handling companies:** They provide services at airports to support both passengers and airlines in flight operations. These services include baggage handling, assistance to passengers with special needs, coordination of aircraft arrivals and departures, as well as aircraft cleaning and maintenance.
- **Air Traffic Control (ATC):** This service is provided by ground-based controllers to ensure the safe, orderly, and efficient movement of aircraft both in the air and on the ground. It prevents collisions and provides mandatory instructions or flight information to pilots.
- **Airport operator:** Responsible for managing the airport as an infrastructure, including terminals, gates, services, and coordination with airlines. Its main focus is the overall operation and efficiency of the airport.
- **Passengers:** They are a key element of the airport system, as all operations are ultimately oriented towards transporting them safely, efficiently, and comfortably.

2.1.2 Airport Areas

From a functional point of view, an airport is divided into two main areas: **landside** and **airside**.

The **landside** is the area accessible to passengers before boarding or after arrival. It includes facilities such as check-in counters, security controls, commercial areas, baggage claim, and boarding gates.

On the other hand, the **airside** is the restricted area where aircraft operations take place. Its main component is the movement area, which includes:

- **Apron:** A defined area where aircraft are parked for passenger boarding and disembarkation, loading and unloading cargo, refuelling, parking, or maintenance. It also includes apron taxiways, access routes to stands, and service roads, as shown in Figure 1.

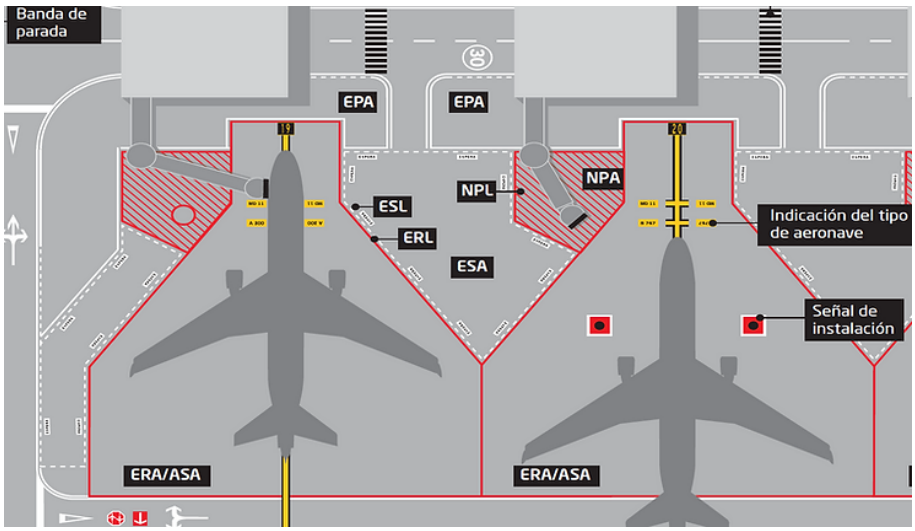

Figure 1: Technical configuration of an aircraft parking position [4]

- **Maneuvering area:** The part of the airport used for takeoff, landing, and taxiing of aircraft, excluding the apron.
- **Runway:** A defined rectangular surface prepared for the takeoff and landing of aircraft, as shown in Figure 2.



Figure 2: Castellón Airport runway [5].

- **Taxiways:** Defined paths used for the taxiing of aircraft, connecting different parts of the airport, as illustrated in Figure 3.

- **Exit taxiway:** Connects directly to a runway.
- **Parallel taxiway:** A main taxiway running parallel to a runway.
- **Rapid exit taxiway:** A taxiway connected to a runway at an acute angle, designed to allow landing aircraft to leave the runway at higher speeds, reducing runway occupancy time.

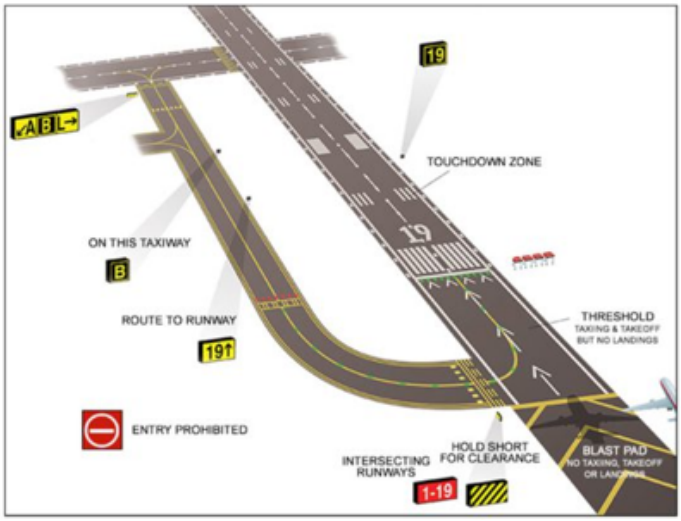

Figure 3: Airport Runway and Taxiway Markings Diagram [6].

Operations in the airside are highly complex due to what is known as **co-activity**, which refers to the fact that multiple activities are carried out simultaneously by different agents in the same space and within short time periods. During the turnaround process, tasks such as passenger boarding and disembarkation, baggage handling, refueling, catering, cleaning, and technical checks take place. This high level of interaction increases operational risks, making strict safety procedures and constant supervision essential.

2.2 The Gate as a Critical Resource

Boarding gates constitute a key element within airport operations, acting as a connection point between the landside and the air side. A gate is understood as the assigned position within the terminal from which passengers access the aircraft for departing flights or disembark upon arrival. Its assignment is directly linked to the aircraft's parking position on the apron, which makes gates a fundamental coordination element between passenger flows and aircraft operations.

In operational terms, boarding gates not only facilitate passenger transit but also directly influence airport efficiency. Proper assignment allows turnaround times to be optimized, operational conflicts to be reduced, and passenger experience to be improved, whereas inefficient management may generate delays, apron congestion, and longer walking distances inside the terminal.

Depending on their configuration and location, two main types of boarding gates can be distinguished: **contact gates** and **remote gates** (the latter including walk-boarding operations) [7].

Contact gates are those directly connected to the terminal by means of a Passenger Boarding Bridge (PBB). This type of gate offers a higher level of passenger service, as it reduces walking distances and provides a sheltered environment for weather conditions, in addition to facilitating and speeding up boarding and disembarkation operations.

By contrast, **remote gates** correspond to parking positions located away from the terminal. In these cases, access to the aircraft is provided by buses or, at some airports, on foot across the apron. This type of operation generally implies a lower level of passenger comfort and may increase process times, although it offers greater operational flexibility in position management.

At airport terminals, there are also shared gates, a system whereby passengers from different flights can access their respective aircraft through walkways that depart from the same physical point, generally a corridor that subsequently branches off. On one side, access to an aircraft is provided through the boarding bridge; on the other side, passengers are directed to internal transport buses that take them to aircraft parked at remote positions. Accordingly, different gate codes are assigned to each access point. This system aims to maximize the available space in the terminal and to manage passenger flow towards different aircraft efficiently.

From a strategic perspective, the combination and management of these gate types is crucial for airport capacity and operational efficiency. While contact gates improve service quality and reduce connection times, remote gates allow operational capacity to be increased at a lower cost, especially in situations of high demand or infrastructure limitations.

Minimizing passenger walking distance directly contributes to improving user experience, one of the main Key Performance Indicators (KPIs) in airport management according to IATA standards [8].

2.3 The Aircraft Turnaround Process

Aircraft turnaround is the time interval between the arrival of a flight and the departure of the next one. During this period, the aircraft must remain on the ground for the time needed to complete all required operations: passenger disembarkation, baggage unloading and loading, cleaning, refueling, catering services, crew change, and the subsequent boarding of passengers for the next flight. Proper gate assignments are critical for the efficiency of this process. The main stages of this process are summarized in Figure 4.

Airlines schedule flights with sufficient time to complete the turnaround correctly or, if applicable, to carry out maintenance activities.

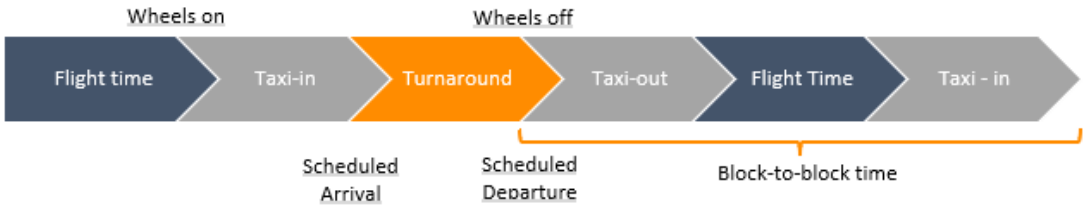

Figure 4: Turnaround process

This process begins once the aircraft lands (wheels-on) and taxis to its parking position (stand). From that moment on, ground operations start disembarkation, aircraft services, and preparation for the next flight. Once these tasks are completed, boarding begins, and after the doors are closed, the aircraft proceeds to taxi-out towards the runway for takeoff.

A relevant concept is blocking time, which corresponds to the total time from when the aircraft departs from the origin gate until it comes to a stop at the destination gate. Both block time and turnaround are key indicators in operational planning, as they directly influence punctuality and operational efficiency. Likewise, buffer time is an additional margin incorporated into the schedule to absorb possible unexpected delays.

In aviation, it is often said that ”an aircraft is not generating revenue while it is on the ground”, a statement that reflects the opportunity cost associated with ground time. While the aircraft is not operating flights, it does not generate revenue, but it continues to incur costs such as airport fees or leasing charges. For this reason, turnaround optimization is particularly critical on short-haul flights, where this time represents a higher proportion of the total operation.

The duration of this process varies depending on the aircraft type, the airline's operational model (for example, low-cost or traditional), flight duration, or unforeseen operational incidents.

2.4 Passenger Flow and Impact of Gate Assignment

Passengers, as central actors in the airport system, directly experience the consequences of gate assignments. Within the terminal, their movements respond to three main flows: departure, arrival, and connection. It is important to consider that one arrival and one departure are counted as two independent movements of the same passenger.

On a departing flight, the passenger starts from the check-in area, goes through security control, and moves to the assigned boarding gate. On a flight arriving, the route runs from the gate to the baggage claim area and then to the terminal exit. For connecting passengers, the journey involves moving between the arrival gate of one flight and the boarding gate of the next. On short layovers, passengers do not leave the airport and simply change gates; on long layovers, they may exit and re-enter, following the same route as arriving passengers and, depending on the country, may need to collect their luggage and check it in again.

On international flights, especially those with origin or destination outside the Schengen Area or the European Union, passengers must undergo passport control. This procedure, generally located before the baggage claim area and the terminal exit (for arrivals) or after security control (for departures), adds an additional distance to the passenger's route.

To provide context on which countries belong to the Schengen Area, the following table lists the member states, classified into EU and non-EU member countries [9]:

EU Countries	Non-EU Countries
Austria, Belgium, Bulgaria, Croatia, Cyprus*, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden	Iceland, Liechtenstein, Norway, Switzerland

In the case of Girona-Costa Brava Airport, which flights to both Schengen and non-Schengen destinations, this additional distance must be considered when assessing the impact of gate assignment on passenger experience.

The assignment of each flight to a specific gate therefore determines the distance that its passengers will have to travel. An assignment that places a flight at a gate far from control points or transfer zones significantly increases walking distance, with the negative repercussions this entails in terms of comfort, connection time, and overall passenger satisfaction. This effect is particularly critical at airports with large terminals or suboptimal gate layouts. For connecting passengers who need to change terminals, many airports provide free internal transport services (buses, trains). Nevertheless, careful gate assignment can reduce internal transit times and improve passenger experience, even without modifying the existing infrastructure.

It is worth noting that this study does not consider transferring passengers when calculating walking distances. This decision is based on the multiple factors that may affect their walking routes, such as the possibility of changing terminals, the need to re-check luggage, or the existence of multiple connecting flights within a single itinerary. Since the scenario under analysis is limited to a single terminal, the study focuses exclusively on origin-destination passengers, who constitute most travelers at regional airports of this type.

3 The Gate Assignment Problem

3.1 Objective Function: Passenger-Weighted Walking Distance

The gate assignment problem considered in this study consists of assigning each flight to one available and compatible gate, while minimizing the total walking distance of arriving and departing passengers inside the terminal. The mathematical presentation of the problem can be set as follows [10]:

Let the set of gates be denoted by Let the set of gates be denoted by

$$G = \{g_1, g_2, \ldots, g_i, \ldots, g_n\}$$

where g_i represents the i-th gate and n is the total number of available gates.

Walking distances for arriving passengers are represented by

$$A = \{a_1, a_2, \ldots, a_i, \ldots, a_n\}$$

where a_i is the walking distance from gate g_i to the baggage claim area.

Similarly, walking distances for departing passengers are denoted by

$$D = \{d_1, d_2, \ldots, d_i, \ldots, d_n\}$$

where d_i is the walking distance from the check-in/security area to gate g_i.

For the analysed period, let the set of flights be denoted by

$$F = \{f_1, f_2, \ldots, f_j, \ldots, f_m\}$$

where f_j represents the j-th flight and m is the total number of flights considered in the analysis.

The set of flight arrival times is given by

$$T^{arr} = \{t_1^{arr}, t_2^{arr}, \ldots, t_j^{arr}, \ldots, t_m^{arr}\}$$

and the set of flight departure times is denoted by

$$T^{dep} = \{t_1^{dep}, t_2^{dep}, \ldots, t_j^{dep}, \ldots, t_m^{dep}\}$$

The number of arriving passengers is represented by

$$P^{arr} = \{p_1^{arr}, p_2^{arr}, \ldots, p_j^{arr}, \ldots, p_m^{arr}\}$$

while the number of departing passengers is represented by

$$P^{dep} = \{p_1^{dep}, p_2^{dep}, \ldots, p_j^{dep}, \ldots, p_m^{dep}\}$$

A binary decision variable y_{ij} is introduced as follows:

$$y_{ij} = \begin{cases} 1, & \text{if gate } g_i \text{ is assigned to flight } f_j \\ 0, & \text{otherwise} \end{cases}$$

The objective is to minimise the total passenger-weighted walking distance:

$$\min Z = \sum_{j=1}^{m} \sum_{i=1}^{n} y_{ij} \left(p_j^{arr} \cdot a_i + p_j^{dep} \cdot d_i \right)$$

In this expression, the first term represents the total walking distance of arriving passengers from the assigned gate to the baggage claim area, while the second term represents the total walking distance of departing passengers from the check-in/security area to the assigned gate.

This formulation gives greater importance to flights with a larger number of passengers. Therefore, assigning a distant gate to a flight with many passengers has a greater impact on the objective function than assigning the same gate to a flight with fewer passengers.

3.2 Problem Constraints

The first constraint ensures that each flight is assigned to exactly one gate:

$$\sum_{i=1}^{n} y_{ij} = 1, \quad j = 1, 2, \ldots, m$$

The second constraint prevents two flights from occupying the same gate at the same time. A minimum turnaround time must be respected between consecutive flights assigned to the same gate. If flight f_k is assigned to gate g_i, the gate cannot be reassigned to the next flight f_l until the turnaround process has been completed:

$$t_k^{dep} + \tau_k < t_l^{arr}, \quad \text{if } y_{ik} = 1 \text{ and } y_{il} = 1,\ k < l$$

where τ_k is the minimum turnaround time required for the aircraft of flight f_k.

The binary nature of the assignment variable is defined as:

$$y_{ij} \in \{0, 1\}, \quad i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m$$

In addition, not every flight can be assigned to every gate. A compatibility parameter c_{ij} is introduced:

$$c_{ij} = \begin{cases} 1, & \text{if flight } f_j \text{ can be assigned to gate } g_i \\ 0, & \text{otherwise} \end{cases}$$

The compatibility constraint is then written as:

$$y_{ij} \leq c_{ij}, \quad i = 1,2,\ldots,n;\ j = 1,2,\ldots,m$$

This constraint ensures that a flight can only be assigned to a compatible gate. In this study, compatibility includes operational restrictions such as Schengen and non Schengen requirements, passport-control availability, and possible aircraft-gate limitations. In particular, since not all gates are equipped with passport control facilities, and aircraft cannot be repositioned between gates once assigned, both the arriving and departing flights sharing a gate must belong to the same operational category, either both Schengen or both non-Schengen. This restriction is formally incorporated into the compatibility parameter c_{ij}, which takes a value of 0 whenever a gate-flight combination violates this condition.

3.3 Practical Challenges

In addition to the constraints mentioned above, the gate assignment problem presents high computational complexity. This complexity arises from its *combinatorial nature*: since each flight can be assigned to any of the available gates, the number of possible combinations grows exponentially with the number of flights and available gates. For example, in a small scenario with 5 flights and 3 available gates, there are $3^5 = 243$ possible assignments.

Although this figure is modest, it already demonstrates the impracticality of exhaustive manual assignment.

Another factor that increases the difficulty of the problem is the inherent uncertainty present in the airport environment. Actual flight schedules often deviate from planned ones due to delays caused by weather conditions, air traffic congestion, aircraft technical failures, or ground operations. This variability can cause an assignment that is considered optimal at the planning stage to become infeasible or highly inefficient during actual operations, since a delayed flight may occupy a gate that had been reserved for another, triggering a chain reaction. It should be noted that, in this study, this uncertainty will not be considered explicitly, as the model uses fixed time intervals that do not vary. External disruptions that cause delays are unpredictable and manifest during daily operations, and their inclusion falls beyond the scope of this study.

3.4 Handling of Gate Saturation

The only variation that will be considered in this study is the situation in which all available gates for a given flight are occupied at the time of assignment. In this scenario, the model allows the flight to be assigned to the first gate that becomes available, thus avoiding flight cancellation when the user does not wish this outcome. This flexibility is essential, since requiring a flight to be removed every time a gate is unavailable would make the process inefficient and overly restrictive and would fail to reflect the real operational situations that occur in airport management.

3.5 Multi-Objective Nature of the Problem

In addition to constraints and uncertainty, the gate assignment problem often requires managing multiple and potentially conflicting objectives. Operational efficiency (minimizing taxi times and costs), passenger comfort (reducing walking distances), robustness (ability to absorb unexpected events), and sustainability (reducing emissions) are objectives that may come into conflict with one another. For example, assigning a flight to a contact gate close to the exit may improve passenger experience, but may increase aircraft taxi time or reduce operational flexibility. In general, it is not possible to optimize all these objectives simultaneously, which makes it necessary to establish priorities. This trade-off was highlighted by the Multiobjective Gate Assignment Model Considering Carbon Emissions study [3], where three objectives, the proportion of flights assigned to contact gates, fuel consumption during taxiing, and assignment robustness were shown to conflict with each other, requiring a multi-objective algorithm such as NSGA-II to find balanced solutions.

For all these reasons, manual gate assignment or the use of simple rules such as assigning each flight to the first available gate, prove insufficient to manage the real complexity of the problem. These approaches cannot simultaneously account for temporal and physical constraints, uncertainty, or conflicts between objectives. Consequently, the use of mathematical optimization models becomes necessary in order to find quality solutions, evaluate different scenarios, and justify decisions based on objective criteria. The following chapter presents the computational methodology implemented to solve the gate assignment problem in accordance with the formulation described above.

4 | Methodology and Computational Implementation

4.1 General Computational Approach

The methodology proposed in this study is based on a hybrid computational approach, which combines the use of Microsoft Excel for data storage and management with the Python programming language for processing and optimization. This structure allows for the separation of input data from computational logic, thus facilitating the modification of scenarios and providing greater flexibility to the model.

Excel is used as the main database, owing to its accessibility, simplicity, and ease of visualization. All operational information relating to flights, boarding gates, passenger volumes, distances inside the terminal, and operational parameters is organized into different structured spreadsheets. This organization enables quick modifications to schedules or airport configurations without the need to alter the program code.

Python, on the other hand, is used as the main language to implement the optimization model. The program is responsible for reading and validating input data, preprocessing information, generating compatibility matrices between flights and gates, and executing the optimization algorithm to obtain the final gate assignment. In addition, the program calculates the total distance walked by passengers, weighted by the number of travelers associated with each flight.

The combination of Excel and Python offers several advantages. Firstly, it simplifies the interaction between operational data and the optimization model. Secondly, it allows the model to be scalable and adaptable to different airport scenarios. Thirdly, it facilitates a clear separation between the operational definition of the problem and the computational implementation of the solution.

4.2 Data Input: Excel Workbook

The input data required for the model are stored in an Excel file named `AirportData.xlsx`. This file is structured into four worksheets, each containing specific information for the program's execution.

4.2.1 DISTANCES Worksheet

This worksheet contains information regarding the distances that passengers will have to walk inside the terminal for each boarding gate. The fields included are:

- **Gate:** boarding gate identifier.
- **Check-in distance:** distance (in meters) from the check-in area to the gate, applicable to departing passengers.
- **Baggage distance:** distance (in meters) from the gate to the baggage claim area, applicable to arriving passengers.
- **Passport Gate (True/False):** indicates whether the gate is equipped with passport control facilities (for non-Schengen flights).

This worksheet is essential for calculating the total weighted distance, as it provides the values of d_i (distance from check-in) and a_i (distance to baggage claim) for each gate. It also indicates an additional constraint, where not every flight can be assigned to every gate; rather, the assignment depends on whether the flight originates from a Schengen country or not. If the flight originates from a Schengen country, passengers do not need to go through passport control, which would alter walking distance and time, although this circumstance is not taken into account in the present study.

4.2.2 FLIGHTS Worksheet

This worksheet contains the operational information for each flight. Each row represents an independent flight. The fields included are:

- **Arrival time:** scheduled arrival time of the flight (format HH:MM:SS).
- **Origin:** IATA code of the departure airport.
- **Passengers arriving:** number of passengers arriving on this flight.
- **Destination:** IATA code of the destination airport.
- **Passengers departing:** number of passengers departing on this flight.
- **Airline:** name of the operating airline.
- **Aircraft type:** aircraft model.

The data in this worksheet makes it possible to determine passenger demand for each flight, as well as gate compatibility based on the airline and the airport of origin.

4.2.3 TURNAROUND Worksheet

This worksheet contains the turnaround times required to complete the process depending on the airline, aircraft type, and capacity. The fields included are:

- **Airline:** name of the airline.
- **Aircraft:** aircraft model.
- **Capacity:** maximum passenger capacity of the aircraft.

- **Time:** minimum turnaround time (in minutes) required for all necessary services to be carried out.

This worksheet is essential for managing operational constraints, as it determines how long a gate will remain occupied after a flight arrives before it can be reused.

4.2.4 DESTINATIONS Worksheet

This worksheet contains a compatibility matrix between destination/origin airports and airlines. A value of 1 indicates that the airline operates flights to or from that airport, while a value of 0 indicates that it does not. This information is used solely to validate that the flights entered in the FLIGHTS worksheet are consistent with the routes operated by each airline.

- **Airports:** IATA code of the set of airports served by the airlines.
- **Airlines:** columns for each airline with Boolean values (1 = operates, 0 = does not operate).

This information is used solely to validate that the flights entered in the `FLIGHTS` worksheet are consistent with the routes operated by each airline, thereby avoiding input data errors.

4.3 Python Program Structure

4.3.1 Data Loading and Initialization

In this phase, the different worksheets of the Excel file are read using the `pandas` library, which allows the information to be imported and structured efficiently. Data corresponding to flights, airports, distances, gate configurations, and turnaround times are loaded into DataFrames to facilitate subsequent processing. To simplify the code and avoid repetition, specific variables are created for each dataset, enabling clearer and more efficient validation through error detection. DataFrames are used for tabular manipulation, dictionaries represent complex entities such as boarding gates with their attributes, and lists manage flight sequences and individual fields. This organisation facilitates access to information, its processing, and the subsequent system simulation.

Regarding design decisions, it is worth noting that the program works exclusively based on the column names defined in the Excel file, such as `'Arrival time'`, `'Origin'`, `'Airline'`, `'Check-in distance'`, and `'Passport Gate (True/False)'`, among others. This means that if the user modifies these names without also updating the code, the program may not run correctly or may not recognise the information contained therein. This dependence on column names constitutes a conscious design decision, as it maintains data integrity and ensures that each field is always interpreted correctly.

However, this approach presents a notable advantage: the program works regardless of the position or order of the columns within the spreadsheet. As long as the column names remain unchanged, the system automatically locates the necessary information, whether it is in column A, column F, or any other location. This flexibility facilitates the

introduction of new data, reduces errors arising from reorganizing columns, and makes the program more robust and adaptable to different editing styles.

Once processed, the data is transformed and stored in different structures according to their nature and subsequent use within the system.

4.3.2 Data Validation

Format Checking

Format errors refer to inconsistencies that arise when entering data into the Excel file, when the value entered does not comply with the expected structure, type, or format for that column. This type of validation ensures that the data are syntactically correct before being processed.

- `find_empty_cells`: checks for the presence of empty cells within the dataset.
- `check_duplicate_gates`: verifies that each gate identifier is unique.
- `check_digits`: validates that the values in columns required to be numeric contain only digits.
- `check_passport_gate`: verifies that the values in the passport control field are valid Boolean indicators (TRUE/FALSE).
- `check_time`: checks that time values follow the established format HH:MM:SS.
- `check_routes`: validates that the route matrix contains only binary values (0 or 1).

Consistency Checking

Consistency errors arise when, despite the correct data format having been ensured, logical inconsistencies are detected between different sets of information. The validation functions include:

- `check_airports`: verifies that the IATA codes of the airports exist within the reference database [11] and determines whether the origin or destination airport is located within the Schengen Area.
- `check_cities`: validates that both the origin and destination airports exist within the list of airports in use and that the route is coherent with respect to the Schengen or non-Schengen classification.
- `check_airline`: checks that the airlines referenced in the flights worksheet exist within the destinations matrix.
- `check_aircraft_operation`: verifies for each flight that the airline operates the aircraft type specified and that the stated capacity is not exceeded by the number of passengers.
- `check_airline_route`: checks that each airline has permission to operate both the origin and the destination specified.

Validation Flowchart

Figure 5 presents the complete validation flowchart, illustrating the sequential process through which input data is checked before the optimization algorithm is executed. The diagram shows how the system first performs format checks and, if these are passed, proceeds to consistency checks. If any error is detected at either stage, the system returns a descriptive error message and halts execution, otherwise, the data is considered valid and the optimization phase begins.

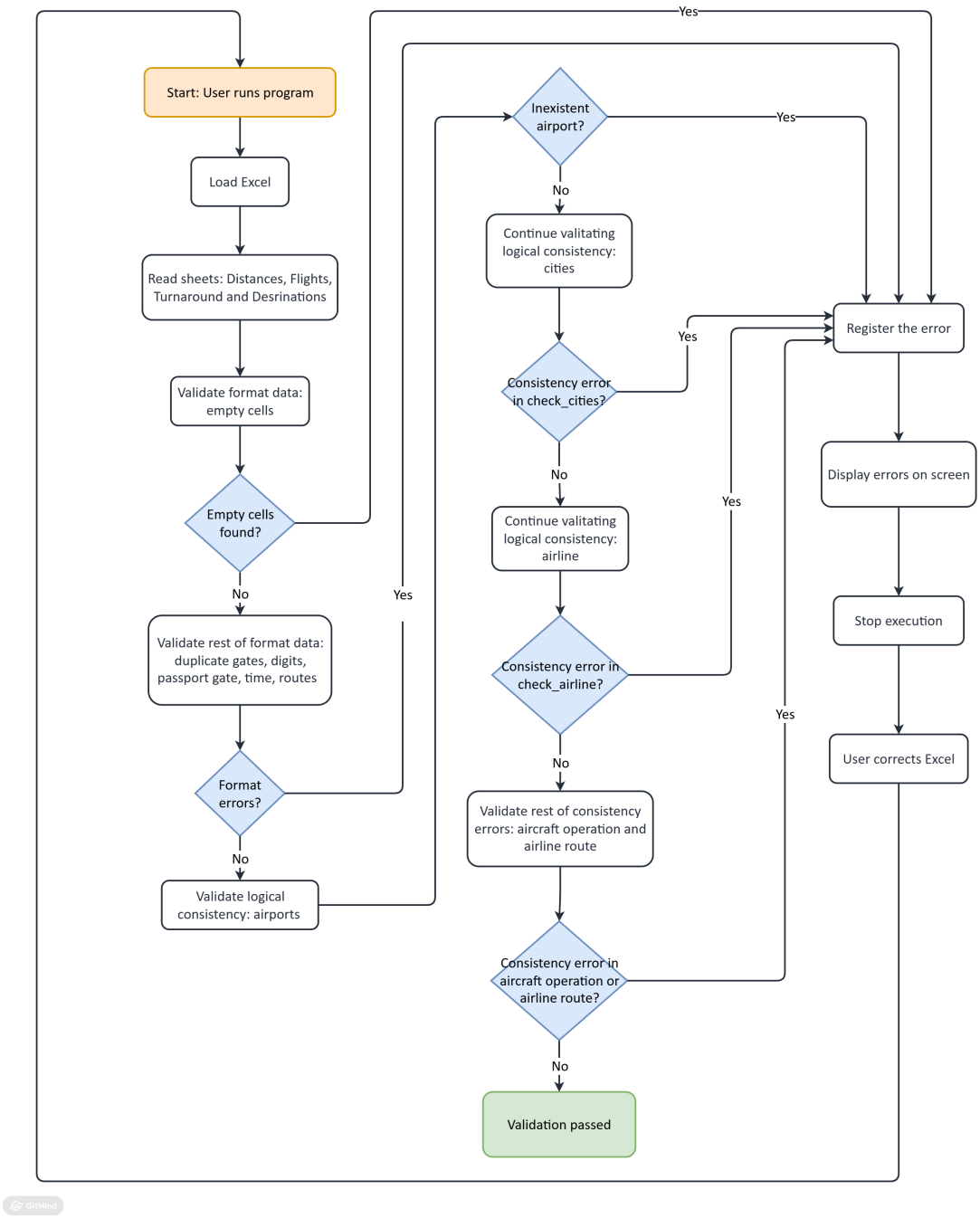

Figure 5: Flight Data Validation Flowchart.

4.3.3 Optimization Algorithm: Heuristic for Gate Assignment

Once the data has been validated and structured, the optimization phase begins, in which the assignment of each flight to a boarding gate is determined. The main objective of this stage is to reduce the total walking distance of passengers inside the terminal and to ensure coherent gate occupancy based on temporal availability, while respecting the operational constraints derived from turnaround times and Schengen/non-Schengen compatibility.

Input Data Processing

Before applying the optimisation algorithm, it is necessary to prepare the input data to ensure that the assignment process proceeds coherently and efficiently. This preparation phase is essential for guaranteeing the integrity of the execution and the traceability of the results obtained.

- **Chronological sorting of flights.** Flights are sorted according to their arrival time, which ensures that the algorithm processes flights in the correct temporal sequence and in the actual order in which aircraft arrive at the airport. In cases where two or more flights share the same arrival time, they are sorted according to the order in which the user entered them in the Excel file.
- **Assignment of internal identifiers.** Internal identifiers are assigned to each flight to facilitate their management and traceability. These identifiers allow quick access to the attributes of each flight and maintain the traceability of assignment decisions. The use of internal identifiers also simplifies the debugging of the code and subsequent analysis of the results.
- **Definition of flight–gate compatibility.** Compatibility based on operational constraints, such as terminal type or Schengen and non-Schengen requirements, is implicitly defined. Gates are classified into two independent dictionaries: `schengen_gates` and `non_schengen_gates`.
- **Pre-calculation of distances associated with each gate.** The distances linked to each gate are calculated in advance, considering the walking costs of both arriving and departing passengers.

The Greedy Optimisation Model

The algorithm used in this study is a greedy heuristic [12]. This type of algorithm is based on making locally optimal decisions at each iteration to obtain a computationally efficient global solution. In the context of the gate assignment problem, this means that each flight is assigned to the best available gate at the time it is processed, without reconsidering previous assignments.

Specifically, the algorithm selects for each flight the compatible gate that minimizes the passenger weighted distance weighted by traveler volume inside the terminal. Once an assignment has been made, it is not subsequently modified, even if future assignments could lead to a better overall combination. This is, therefore, a sequential and irreversible approach.

This type of algorithm is widely used in optimization problems because it makes decisions using only the information available at each step, which considerably simplifies the design and implementation of the model. However, as noted in Section 3.3, this approach does not guarantee the globally optimal solution, since local decisions may negatively affect future assignments. For this reason, the results obtained should be interpreted as a feasible and operationally practical solution, but not necessarily the global optimum.

The selection of this heuristic is justified mainly by its computational simplicity and ease of implementation, the reduction in computation time compared to exact methods, its suitability for a dynamic problem with multiple temporal constraints, and the possibility of developing a flexible tool that can be easily adapted to different airport scenarios.

Furthermore, this approach facilitates the traceability of the decisions made by the algorithm and simplifies future modifications to the model.

Although more advanced methods exist, such as genetic algorithms, simulated annealing [13], or tabu search [14], these require greater computational complexity and a more demanding calibration process.

Heuristic Algorithm Procedure

The gate assignment algorithm follows a sequential process based on the temporal availability of gates and the minimisation of passenger walking distance. The procedure can be summarised in the following steps:

1. **Flight sorting.** All flights are sorted chronologically according to their arrival time. In cases where two or more flights share the same arrival time, the original order entered by the user is preserved through stable sorting.

2. **Schengen or non-Schengen classification of the flight.** For each flight, the system determines whether the origin airport belongs to the Schengen or non-Schengen area using the airport's IATA code. This classification allows two independent sets of gates to be used:

    - Schengen gates (no passport control).
    - Non-Schengen gates (requires passport control).

3. **Gate availability check.** The algorithm iterates through all compatible gates of the corresponding type (Schengen or non-Schengen) and checks their status:

    - If the gate has no recorded occupancy, it has not yet been assigned any flight and is therefore available.
    - If the gate already has assigned flights, the departure time of the last assigned aircraft is retrieved:
        - If the departure time is earlier than the arrival time of the new flight, the gate is considered available.
        - Otherwise, the gate is considered occupied, and the time at which it will become free is recorded.

4. **Walking distance calculation.** For all available gates, the total passenger walking distance is calculated as the number of arriving passengers multiplied by the distance to the baggage claim area, plus the number of departing passengers multiplied by the distance to check-in.

5. **Selection of the best gate.** Once the walking distance has been calculated for all available gates, the algorithm selects the gate with the minimum walking distance.

6. **Assignment and occupancy update.** After selecting the best gate:

   - The aircraft departure time is calculated based on the corresponding turnaround time.
   - The gate occupancy record is updated.
   - The assigned flight and the accumulated total distance are stored.
   - The flight is marked as `Rescheduling = False`, indicating that it was assigned without requiring any time modification.

7. **Occupancy conflict management.** If all compatible gates are occupied, the algorithm identifies the first gate that will become free. In this case:

   - The user is prompted to reschedule the flight to a later time.
   - If the user accepts, the flight is automatically reassigned to the earliest available time. The flight is marked as `Rescheduling = True`, allowing it to be visually distinguished in the flight timeline chart.
   - If the user rejects the proposal, the flight is cancelled.

8. **Separation between Schengen and non-Schengen gates.** This entire procedure is carried out independently for Schengen and non-Schengen flights, since each category uses different gate dictionaries and therefore physically separate resources within the airport.

Pseudocode

Algorithm 1: Greedy Gate Assignment Heuristic

Input: Flights, gate sets (Schengen / non-Schengen), distances, turnaround times
Output: Gate assignment for each flight

Sort flights by `arrival_time` (stable);

foreach *flight i* **do**
    Determine whether origin is Schengen or non-Schengen;
    Select the corresponding gate set;
    `available_gates` $\leftarrow \emptyset$;
    `occupied_gates` $\leftarrow \emptyset$;

    foreach *gate j* **do**
        if gate j has no occupancy **then**
            Calculate `walking_distance`(j,i);
            Add j to `available_gates`;
        else
            Obtain `last_departure`;
            if $last_departure < arrival_time[i]$ **then**
                Calculate `walking_distance`(j,i);
                Add j to `available_gates`;
            else
                Add j to `occupied_gates`;
            end
        end
    end

    if `available_gates` $\neq \emptyset$ **then**
        Select gate with minimum `walking_distance`;
        Assign flight i to that gate;
        Calculate `turnaround_time`;
        Update occupancy and total distance;
        Mark flight as `Rescheduling` $\leftarrow$ `False`;
    else
        Select the gate that becomes free first from `occupied_gates`;
        Request rescheduling from user;
        if user accepts **then**
            Assign flight i to that gate;
            Calculate `turnaround_time`;
            Update occupancy and total distance;
            Mark flight as `Rescheduling` $\leftarrow$ `True`;
        else
            Cancel flight i;
        end
    end
end

4.3.4 Output Generation and Visualization

The output generation phase, once the execution of the gate assignment algorithm has been completed, allows for a more intuitive interpretation of system behavior, analysis of the occupancy of each boarding gate, and evaluation of the impact of the decisions made by the implemented heuristic. These visualizations have been developed to facilitate operational analysis of the model and to provide a graphical representation of the most relevant metrics, particularly passenger walking distance and flight scheduling.

Walking Distance Visualization

To evaluate the efficiency of gate assignment, the system generates a series of bar charts representing the total distance walked by passengers associated with each boarding gate.

Two types of charts are generated. On the one hand, charts separated by gate type (Schengen or non-Schengen) produce independent visualisations. Each bar represents the total accumulated distance associated with a specific gate after flight assignment. This representation allows the user to:

- Identify which gates concentrate a greater operational load.
- Detect possible imbalances in the assignment.
- Compare the level of utilisation between different gates.

This facilitates operational decision-making: if an imbalance or an increase in demand is detected, the necessary adjustments can be made to suit the context, as in the case of the airport studied in the case study.

On the other hand, a global visualisation combining all Schengen and non-Schengen gates into a single representation is also available. To facilitate interpretation, a colour-coding system is used, whereby Schengen gates are displayed in green and non-Schengen gates in blue, allowing the user to obtain an overall view of system behaviour and to visually compare the distribution of distances between the two types of airport operations. For large-scale problems involving a greater number of gates, flights, and airlines, separate charts can provide a more detailed and insightful visualisation, enabling a deeper level of analysis.

Flight Timeline Visualisation

This visualisation constitutes a temporal representation of boarding gate occupancy throughout the day. Each flight is represented by a horizontal bar showing the time interval between the aircraft's arrival time and its departure time, calculated based on the turnaround time.

This representation allows the user to:

- Observe the temporal scheduling of flights.
- Analyse gate occupancy.
- Detect potential temporal conflicts or overlaps between operations.

To identify such conflicts, the system compares the time intervals of all assigned flights. Flights are represented using one of three colours depending on their scheduling status:

- Flights with no temporal overlap with other flights are shown in blue.
- Flights that overlap in time with at least one other flight, while remaining assigned to different gates, are shown in orange.
- Flights that have been rescheduled because no compatible gate was available at the time of assignment are shown in red.

This graphical representation facilitates the visual validation of the results obtained by the algorithm and allows potentially problematic situations in airport scheduling to be detected.

Objective of the Visualisation Stage

The visualisation phase not only improves the interpretability of the results but also constitutes a support tool for operational analysis and model validation. Through these representations, it is possible to identify occupancy patterns, evaluate assignment efficiency, and detect possible limitations of the implemented heuristic.

Furthermore, the generated visualisations allow the user to:

- Verify the algorithm's results by visually comparing the assignment obtained with the defined operational constraints (Schengen or non-Schengen, turnaround times, etc.).
- Facilitate the interpretation of results by different stakeholders involved in airport management.
- Identify recurring patterns: for example, gates that systematically show high occupancy or flights that tend to generate scheduling conflicts.
- Support decision-making by providing visual evidence that can help adjust future operational planning.

It is also worth noting that the output system is flexible and scalable. Depending on the user's needs, new graphical representations can be added or existing ones modified without affecting the internal logic of the optimisation algorithm, since these representations are generated from the occupancy records contained within the dictionaries in which all time intervals and flights are stored. This modularity facilitates the adaptation of the model to different airport scenarios and to specific analysis requirements.

5 | Case Study: Girona – Costa Brava Airport

5.1 Airport Description

The airport selected as the case study in this work is Girona-Costa Brava Airport, identified by the IATA code GRO. This is a Spanish airport owned by AENA, located in the municipality of Vilobí d'Onyar, approximately 13 km from the city of Girona and about 74 km from Barcelona. The airport primarily serves the Costa Brava region and the province of Girona, although it also acts as a complementary infrastructure for the Barcelona metropolitan area. An overview of the airport is shown in Figure 6.



Figure 6: Girona – Costa Brava Airport [15].

The airport mainly operates short and medium-haul commercial flights, with both domestic and international connections, especially to European destinations. Its activity is strongly linked to tourist traffic and low-cost carrier operations, with a particularly notable presence of Ryanair, which has established one of its main operational bases at the airport.

According to official data from AENA [16], during 2025 the airport recorded more than 2.1 million passengers and nearly 28.000 operations, representing an increase of 9,4% in passenger numbers and 15,2% in operations compared to the previous year. This growth reflects the airport's progressive consolidation within the Spanish airport network and its importance as a regional infrastructure.

The airport has a single passenger terminal spread across two floors, where the departures and arrivals areas are integrated within the same building. Security control is located

on the departures floor and provides access to the boarding area, from which the different gates are distributed towards the apron.

Currently, the terminal has a total of 15 boarding gates and divided between Schengen and non-Schengen operations, which makes it possible to examine constraints related to passenger control and gate compatibility.

The choice of Girona-Costa Brava Airport as a case study is justified for multiple reasons. Firstly, it is an airport with a sufficiently representative volume of operations to study the gate assignment problem, while featuring a relatively simplified operational structure, comprising a single terminal and a moderate number of boarding gates. This simplicity facilitates system modeling and the interpretation of the results obtained.

Furthermore, the coexistence of Schengen and non-Schengen flights makes this airport a suitable scenario for assessing the impact of gate assignments on the distance walked by passengers inside the terminal.

5.2 Airport Operational Characteristics

The airport presents a relatively compact but functional operational configuration, suitable for the analysis of boarding gate assignment and passenger flow management.

5.2.1 General Infrastructure

According to AENA [17], the main airport infrastructure consists of:

- 1 runway of 2.400 meters in length
- 50 aircraft parking positions
- 1 passenger terminal
- 1 cargo terminal

Passenger Terminal

The terminal has the following operational elements:

- 33 check-in desks
- 15 boarding gates
- 5–6 baggage claim carousels
- Commercial area
- Vehicle rental desks
- Airline and tour operator desks

Gate Distribution and Schengen / Non-Schengen Operation

Of the 15 boarding gates:

- Gates 1–7: Non-Schengen operations (with passport control when required)
- Gates 8–15: Schengen operations

During the high season, all available gates are used, while in the low season, operational usage is reduced. In the low-season situation, Gate 8 is occasionally used for charter flights or internal operational purposes. The gates most commonly in operation are 1, 3, 5, 9, 10, and 12, with the aim of optimizing resources and avoiding the simultaneous use of adjacent gates when not strictly necessary.

Furthermore, the terminal has a flexible separation between the Schengen and non-Schengen areas by means of a movable glass structure. This configuration allows the space to be adapted according to operational demand, so that the common area is expanded when there are no simultaneous international flights.

Boarding Processes

The airport does not have jet bridges at any boarding gate. Consequently, boarding processes are carried out by:

- Walking access from the terminal when the aircraft is parked in nearby positions.
- Bus transfers when the aircraft is positioned at remote stands.

Vertical access within the terminal is provided by stairs and elevators that connect to the apron.

Turnaround Operations and Operational Constraints

Turnaround operations are conditioned by the limited availability of gates during peak hours, the proximity between gates and aircraft on the apron, the absence of jet bridges (which increases passenger movement time), and the need to separate Schengen and non-Schengen flows.

These factors directly influence gate assignment planning and the need to minimize passenger walking distances.

5.2.2 Exploratory Visualization of Passenger Walking Routes

The following figure conceptually represents the distribution of passenger routes inside the terminal to each of the boarding gates, using an exploded view of the terminal to facilitate visualization. The illustration distinguishes between the two terminal floors and shows the location of the non-Schengen gates (1–7, in pink) and the Schengen gates (8–15, in green). The pink route corresponds to the path followed by passengers requiring passport control, the green route represents passengers who do not require it, and the orange route indicates the common path taken by all departing passengers from check-in to the point where the two routes diverge. The objective is to illustrate the functional separation of the space and the influence of gate location on walking distances.

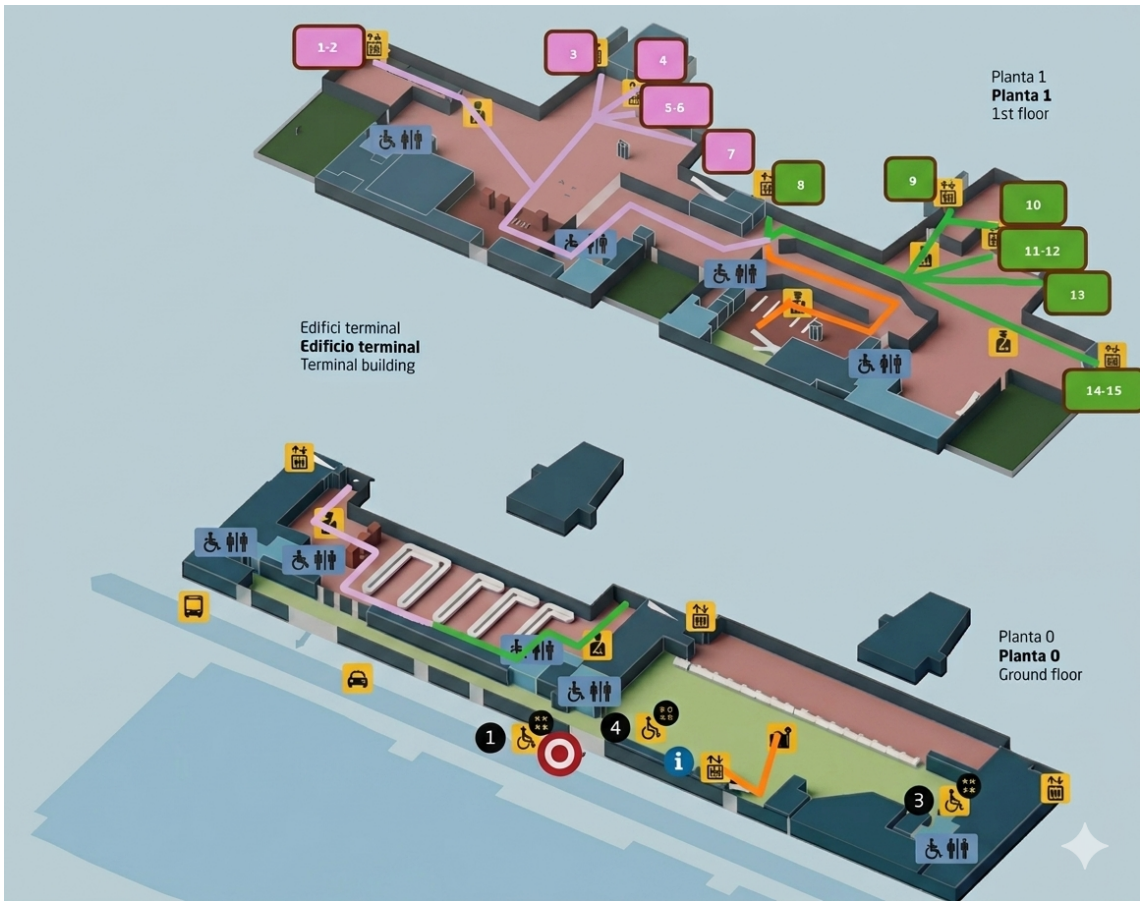

Figure 7: Conceptual representation of passenger routes inside the terminal.

This representation justifies the importance of considering walking distance as a key variable in the gate assignment model, since it directly influences passenger travel time and the overall operational efficiency of the airport.

5.3 Flight Operations and Airline Characteristics

This section describes the operational structure of the flights used in the model, considering aspects related to the airlines operating at Girona-Costa Brava Airport, the aircraft models used by each, and the routes they operate.

At the time of writing this report, eight airlines operate at Girona Airport. It should be noted that the information presented comes from the current airline schedules and may be subject to modifications beyond AENA's control.

Historically, this airport has served as a strategic base for low-cost carriers. The main operators are detailed below.

5.3.1 Airlines Operating at Girona–Costa Brava Airport

Enter Air

Enter Air [18] is one of the largest charter airlines in Europe and a leader in the Polish market. Its business model focuses on seasonal flights for major tour operators, connecting leisure destinations in the Mediterranean, Africa, and the Middle East. The airline holds a high level of safety certification, including IATA membership and the IOSA certification, as well as operating special humanitarian aid flights worldwide.

Fleet [19]:

- Boeing 737-800: 189 seats
- Boeing 737-MAX 8: 189 seats

Routes [20]:

- Katowice / Pyrzowice (KTW)
- Poznań / Ławica (POZ)
- Warsaw (WAW)

Jet2.com

Jet2.com [21] is the third-largest airline in the United Kingdom by passenger numbers and has been named "Best Airline" for three consecutive years at the prestigious Routes Europe awards. It is recognized for offering high-quality service at an affordable price, acting as a "consumer champion." It was the first British airline to eliminate the fuel surcharge for its customers, guaranteeing that the booking price is the final price paid by the passenger.

Fleet [22]:

- Airbus A321neo: 232 seats
- Airbus A321-200: 218 seats
- Airbus A330-200: 327 seats

- Boeing 737-300: 148 seats
- Boeing 737-800: 189 seats

Routes [20]:

- Birmingham / International (BHX)
- Bristol (BRS)
- East Midlands (EMA)
- Edinburgh (EDI)
- Glasgow (GLA)
- Leeds/Bradford (LBA)
- London / Gatwick (LGW)
- London / Luton (LTN)
- London / Stansted (STN)
- Manchester (MAN)
- Newcastle (NCL)

Ryanair (RYR)

Ryanair [23] is the largest airline in Europe, recognized for its leadership in efficiency and punctuality. It was also the first airline to begin operating at Girona Airport. Currently, Ryanair remains the predominant airline at Girona–Costa Brava Airport, carrying 90% of passengers in the low season and 75% in the high season [24]. Its ultra-low-cost business model allows it to offer the lowest fares on the market. Despite industry challenges, such as fuel price volatility, Ryanair has demonstrated considerable financial strength owing to its scale and proactive fuel hedging strategy, achieving record profits.

Fleet [25]:

- Boeing 737-800: 189 seats
- Boeing 737-MAX 8: 197 seats

Routes [20]:

- Baden Baden-Karlsruhe (FKB)
- Beni Mellal (BEM)
- Birmingham / International (BHX)
- Bournemouth (BOH)
- Bristol (BRS)
- Brussels (BRU)
- Brussels / Charleroi (CRL)
- Bucharest / Baneasa (BBU)
- Cork (ORK)
- Cracow (KRK)
- Dublin (DUB)
- Düsseldorf / Weeze (NRN)
- East Midlands (EMA)
- Eindhoven (EIN)
- Frankfurt / Hahn (HHN)
- Knock – Ireland West (NOC)
- Leeds/Bradford (LBA)
- London / Stansted (STN)
- Manchester (MAN)
- Memmingen (FMM)

- Nuremberg (NUE)
- Ostrava / Mosnov (OSR)
- Paris / Beauvais-Tillé (BVA)
- Pisa / Galileo Galilei (PSA)
- Poznań / Ławica (POZ)
- Sarajevo (SJJ)
- Shannon (SNN)
- Wrocław (WRO)

Ryanair UK (RUK)

Ryanair UK [26] is a subsidiary of the Ryanair Holdings group, created specifically to maintain operations in the British market after Brexit. Although it operates under the same brand and low-cost model, it holds a UK Air Operator's Certificate (AOC), which allows it to fly both domestic routes within the United Kingdom and international routes to the EU without interruption.

Fleet [27]:

- Boeing 737-800: 189 seats
- Boeing 737-MAX 8: 197 seats

Routes [20]:

- Belfast (BFS)
- Manchester (MAN)

Transavia (TRA)

Transavia [28] is the leading low-cost airline in the Netherlands and the second largest carrier in the country, and belongs to the Air France KLM group. It is characterized by offering affordable fares without sacrificing comfort, and is a leader in hospitality, service, and digitalization. With over 50 years of history, it connects the Netherlands to more than 100 destinations across Europe and the Mediterranean.

It offers both business and leisure travelers competitive base fares with optional additional services. Each year, it transports around 9 million passengers with a modern fleet.

Fleet [29]:

- Airbus A320-200: 180 seats
- Airbus A321neo: 232 seats
- Boeing 737-800: 189 seats

Routes [20]:

- Amsterdam / Schiphol (AMS)
- Rotterdam (RTM)

Travel Service Polska (Smartwings)

Travel Service Polska [30] operates under the Smartwings Group brand, the largest aviation group in the Czech Republic. The company specializes in charter and scheduled flights for major travel agencies. A distinguishing feature is its high standard of safety and operational quality, having successfully completed the IATA IOSA audit on multiple occasions and meeting the stringent requirements of the US Federal Aviation Administration (FAA) to operate commercial flights to the United States.

Fleet [31]:

- Airbus A320-200: 180 seats
- Airbus A220-300: 149 seats
- Boeing 737-800: 189 seats
- Boeing 737-900: 212 seats
- Boeing 737-MAX 8: 189 seats

Routes [20]:

- Warsaw (WAW)

TUI Airways

TUI Airways [32] is the fourth-largest airline in the United Kingdom by passenger volume and the British arm of the global tourism group TUI. It operates scheduled and charter flights from 19 base airports in the United Kingdom to holiday destinations in the Mediterranean, the Caribbean, and the Indian Ocean. It is one of the largest operators of long-haul flights to North America and the Caribbean from the United Kingdom.

Fleet [33]:

- Boeing 737-800: 189 seats
- Boeing 737-MAX 8: 189 seats
- Boeing 787-8: 300 seats
- Boeing 787-9: 345 seats

Routes [20]:

- Birmingham / International (BHX)
- London / Gatwick (LGW)
- Manchester (MAN)

TUI fly Belgium

TUI fly Belgium [34] is the Belgian airline of the TUI group, formerly known as Jetairfly. Its operations are fully integrated into the group's tour operator model, offering flights to an extensive network of more than 105 destinations. The airline is known for offering a differentiated in-flight experience across various service classes to suit both leisure and business travelers.

Fleet [35]:

- Boeing 737-800: 189 seats
- Boeing 737-MAX 8: 189 seats
- Embraer 195: 136 seats

Routes [20]:

- Brussels (BRU)

5.4 Input Excel File Structure

The following section describes the different worksheets of the Excel file used as input for the model, as well as the methodological considerations adopted for the definition of each worksheet.

5.4.1 Distances

To measure passenger walking distances inside the terminal of Girona-Costa Brava Airport, the Google Earth tool was used. This tool allows measurements to be taken from satellite images that, although approximate, are sufficiently representative for the purposes of this study, in both 2D and 3D. The colour-coded routes used for this purpose are described in detail in Section 5.2.2. Figures 8 and 9 show the routes measured for departing and arriving passengers respectively.

It should be noted that all distances are approximate values rounded to the nearest integer, obtained by overlaying reference points on the exploded view of the airport map.



Figure 8: Routes to different gates (departures).



Figure 9: Routes to baggage claim area (arrivals).

5.4.2 Flights

Twenty flights have been selected as a representative sample for analysis, as shown in Figure 10. The flight time slots range from approximately 8:00 to 12:30, covering a period of moderate demand that allows the behaviour of the model to be observed without the additional complexity of peak occupancy scenarios. The schedules were entered in unsorted order in the Excel file, since the program handles chronological sorting using the `sort_values()` function. The flights have been scheduled so that their distribution among airlines is broadly proportional to each carrier's share of operations at the airport. Consequently, Ryanair accounts for the largest proportion of flights in the sample, consistent with its position as the airport's main base carrier, followed by Jet2.com as the second most significant operator. The remaining airlines are represented in smaller proportions, reflecting their comparatively limited presence in the airport's route network. The flights are distributed among different airlines and routes, as detailed in the `Destinations` worksheet.

5.4.3 Turnaround

Wide-body aircraft (such as the A330 or B787) have not been considered in this study, since the runway length of Girona-Costa Brava Airport (2.400 meters) is insufficient for their operational requirements. Therefore, turnaround times have been defined exclusively for narrow-body aircraft.

Ultra-low-cost carriers, such as Ryanair, operate with the shortest turnaround times to maximize efficiency. Standard low-cost airlines require slightly longer intervals. Tour operators, which typically handle greater luggage volumes and charter operations, require more extensive turnaround times.

5.4.4 Destinations

A compatibility matrix between airlines and airports has been defined. This matrix includes the set of airports with which each airline operates at Girona-Costa Brava Airport [20], and is used by the system to validate that the routes entered in the FLIGHTS worksheet are consistent with the actual route network described in Section 5.3.

5.5 Results

Once the optimization model was executed with the input data described above, the results presented below were obtained. The algorithm assigned each flight to the available gate that minimized the passenger-weighted walking distance, in all cases respecting the temporal, physical, and regulatory constraints. In one instance, a Schengen flight required rescheduling due to the unavailability of compatible gates at the time of assignment. The analysis focuses on three fundamental aspects: the chronology of operations, the walking distance distribution per gate, and the detection of potential scheduling conflicts.

5.5.1 Flight Timeline Analysis

Figure 10 presents the temporal distribution of gate occupancy throughout the morning session. Each horizontal bar represents a flight, spanning from its arrival time to its estimated departure time, the latter being calculated by adding the corresponding turnaround time to the arrival. The timeline covers the period from approximately 08:26, when the first flight arrives, to 12:16, when the last flight departs.

Most flights are concentrated in the interval between 09:30 and 10:30, generating a notably high operational density during this period. This concentration is intentional, as the scenario was designed to test the full range of functionalities and capabilities of the model, including its ability to manage simultaneous gate demand. It should be noted that, under normal operating conditions, Girona-Costa Brava Airport typically experiences a more evenly distributed traffic pattern throughout the day, although demand peaks can occur as a result of operational factors.

Flights shown in orange indicate temporal overlaps, meaning that two or more flights are simultaneously occupying gates within the same time window. Multiple overlaps are observed, particularly between 09:30 and 10:45, where the concentration of flights generates peak demand that the algorithm must manage. It is important to note that these overlaps do not represent assignment conflicts, as each flight has been assigned to a different gate, they reflect situations in which several aircraft are on the ground at the same time.

As shown in the figure, one Schengen flight (FKB $\rightarrow$ CRL) required rescheduling and is therefore shown in red. This occurred because all compatible Schengen gates were occupied at the time of the flight's originally scheduled arrival. The algorithm detected the inaccessibility of the gates and prompted the user to delay the flight until a gate was free. Upon acceptance, the flight was automatically reassigned to the earliest available slot. Had the user rejected the rescheduling proposal, the flight would have been canceled and would not appear on the timeline.

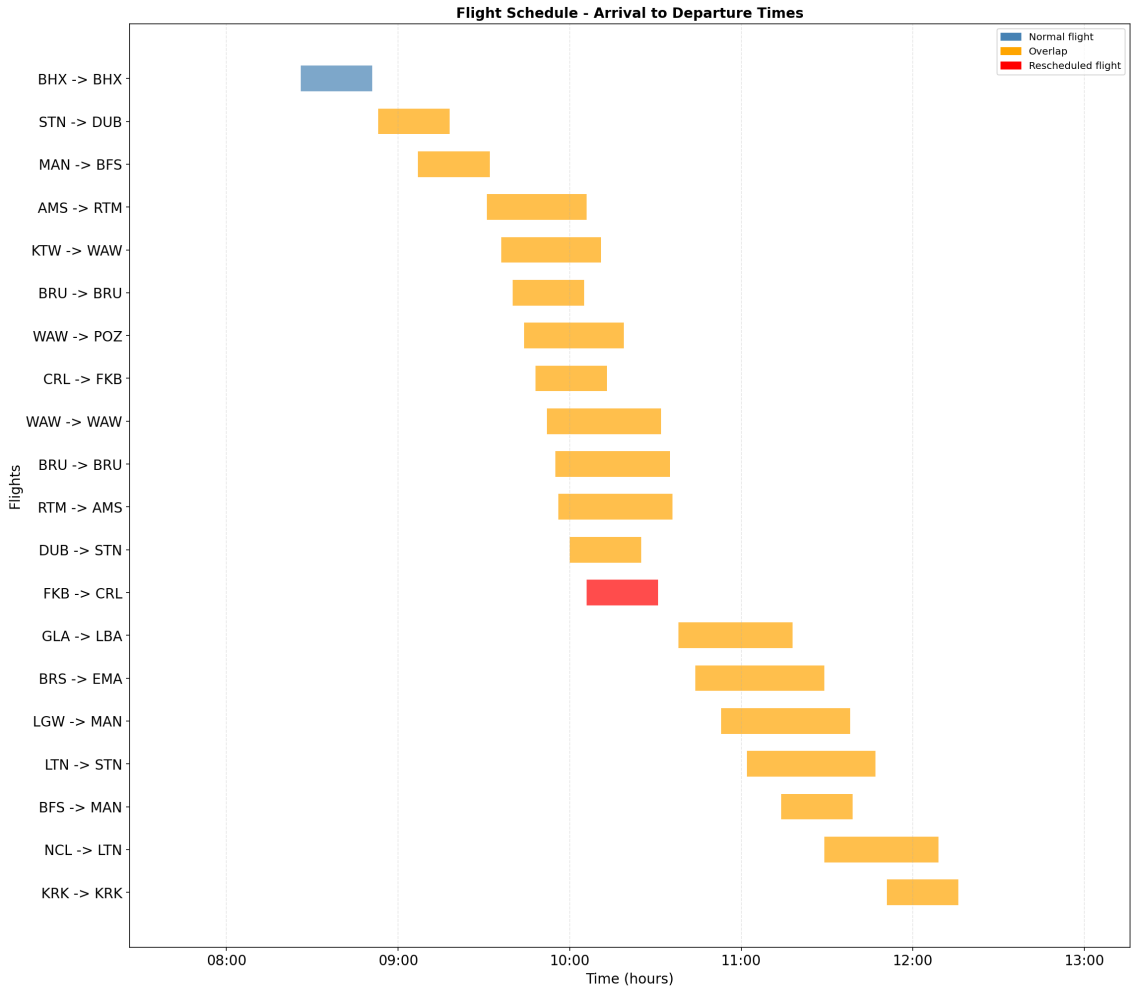

Figure 10: Flight Schedule – Arrival to Departure Times.

5.5.2 Walking Distance Analysis

Figures 11, 12 and 13 present the total weighted passenger accumulated walking distance per boarding gate, both individually by gate type and combined into a single global representation. The results reveal a notable uneven distribution of operational load across gates.

Regarding non-Schengen gates, shown in Figure 12, Gate 5 concentrates the highest accumulated distance by a considerable margin, reaching 308.850 meters, equivalent to 50,6% of the total non-Schengen walking distance. This is a direct consequence of its physical location within the terminal: at only 318 meters from the check-in area, it represents the shortest walking distance among all non-Schengen gates and is therefore systematically prioritized by the greedy algorithm whenever it is available. Gate 6, which shares the same physical space as Gate 5 but boards passengers from the other side, also registers a significant load of 123.244 meters. In contrast, Gates 1 and 2 record zero assignments, indicating that the algorithm consistently avoided them due to their greater distance from the passenger control points, approximately 347 meters. The remaining non-Schengen gates (3, 4, and 7) present moderate and relatively similar values, ranging between 46.700 and 68.600 meters. The total accumulated distance for non-Schengen gates amounts to

611.134 meters, with only 5 of the 7 available gates receiving assignments.

Regarding the Schengen gates, shown in Figure 13, the distribution is considerably more balanced, with values ranging from 33.420 meters at the Gate 15 to 90.943 meters at the Gate 11. This more uniform distribution is attributable to the high concentration of Schengen flights during the 09:30–10:30 interval, which forced the algorithm to make use of all eight available gates simultaneously. As a result, 100% of Schengen gates were used, with an average load of 51.408 meters per gate, significantly lower than the non-Schengen average of 87.305 meters per gate.

The global comparison, presented in Figure 11, highlights the asymmetry between the two operational areas. Non-Schengen gates bear a total accumulated distance of 611.134 meters against 411.265 meters for Schengen gates, despite having fewer gates available. This imbalance, combined with the concentration of load at Gate 5, suggests that while the greedy heuristic is effective at minimizing total walking distance, it tends to overload the gates clos est to passenger control points. A multi-objective approach that also considers load balancing across gates could mitigate this effect without significantly compromising the overall distance minimization objective.

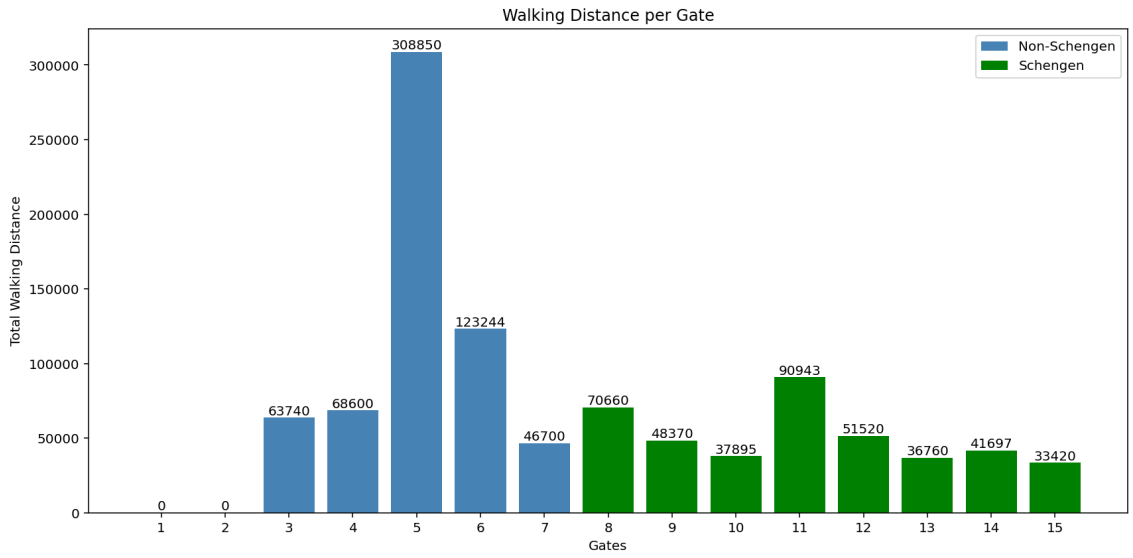

Figure 11: Walking Distances per Gate.

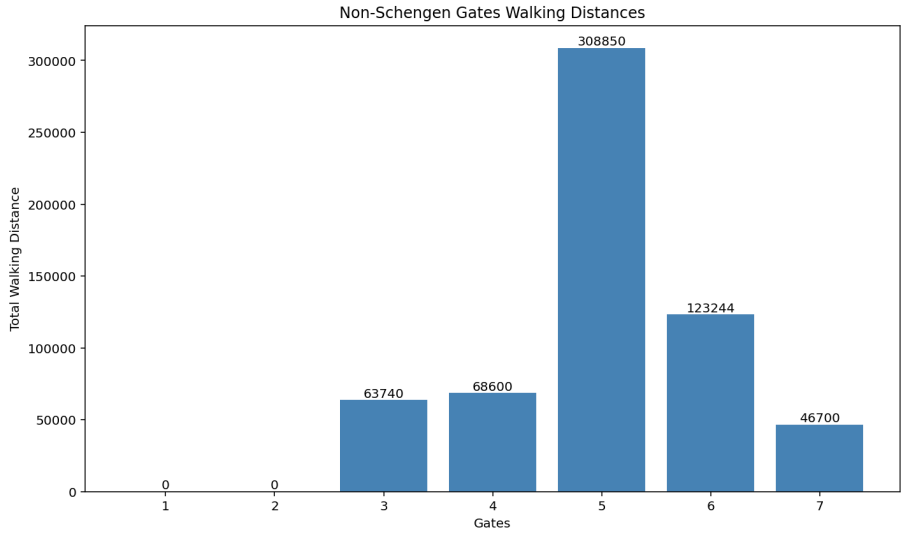

Figure 12: Non-Schengen Gates Walking Distances.

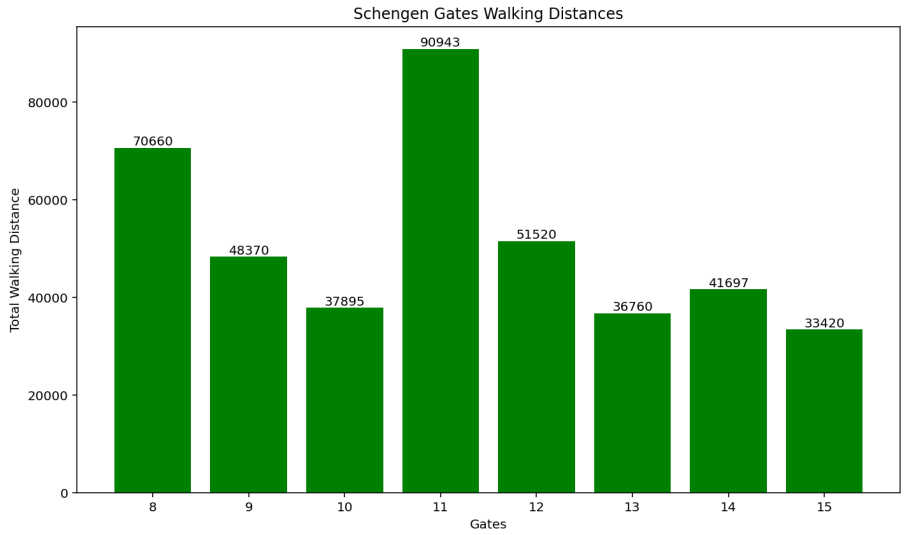

Figure 13: Schengen Gates Walking Distances.

5.5.3 Rescheduling and Conflicts

As described in Section 3.4, the model incorporates a rescheduling mechanism that is activated when all compatible gates for a given flight are occupied at the time of its scheduled arrival. In the execution carried out, this situation occurred once, affecting the Schengen flight operating the FKB → CRL rotation, as shown in red in Figure 10.

At the time of the originally scheduled arrival of this flight, all available Schengen gates were simultaneously occupied due to the high concentration of flights in the 09:30–10:30 interval. The algorithm detected the inaccessibility of compatible gates and prompted the user to delay the flight until the first Schengen gate was free. This was Gate 11, which was released at 10:05 upon departure of the BRU → BRU rotation, and to which the FKB → CRL flight was subsequently reassigned. Upon acceptance of the

rescheduling proposal, the flight was automatically reassigned to the earliest available slot, and its updated time interval is reflected in the flight timeline. Had the user rejected the proposal, the flight would have been canceled and would not appear in any of the output visualizations.

It is worth noting that this rescheduling event is a direct consequence of the deliberately high operational density of the scenario, which was designed to stress-test the full range of functionalities of the model. Under normal operating conditions at Girona-Costa Brava Airport, where traffic is more evenly distributed throughout the day, such situations would be less frequent. Nevertheless, their occurrence in real operations cannot be ruled out, particularly during demand peaks caused by weather disruptions, restrictions in air traffic control, or other operational factors. In such cases, the rescheduling mechanism constitutes an essential tool for maintaining operational continuity and avoiding flight cancelations.

6 | Discussion of Operational Insights

6.1 Operational Interpretation

The results obtained demonstrate that the implemented greedy heuristic can find a viable and efficient assignment for the flights considered. The algorithm prioritizes the minimization of passenger walking distance, which translates into an improvement in traveler experience without compromising operational viability. The classification of gates into Schengen and non-Schengen has proven essential for ensuring compliance with regulatory requirements. However, although the load distribution among gates is not uniform, this behavior is inherent to the greedy approach, because the algorithm assigns each flight to the best available gate at each step without considering future load balance. This leads to a concentration of flights at the gates closest to passenger control points, particularly Gate 5 for non-Schengen operations while leaving more distant gates underutilized. This aspect warrants further attention in subsequent iterations of the model, for instance by introducing a multi-objective approach that also considers load balancing across gates, which could mitigate this effect without significantly compromising the overall distance minimization objective.

6.2 Limitations of the Model

It must be acknowledged that the present approach entails some limitations. Firstly, the model does not consider operational uncertainty associated with delays, cancellations, or last-minute schedule changes. All executions are carried out with fixed time intervals due to the complexity that dynamic scheduling would entail, which would require additional development time and more sophisticated algorithmic solutions. Secondly, the greedy heuristic does not guarantee the global optimum but rather provides a locally optimal solution at each iteration. Thirdly, the model excludes transfer passengers, which may lead to an underestimation of the actual total walking distance at airports with a significant volume of connecting traffic. Finally, the model has been designed and tested for a single-terminal airport, which limits its direct applicability to larger, multi-terminal infrastructures where passenger flows and gate assignment dynamics are considerably more complex.

6.3 Possible Improvements

Several avenues for improvement could be explored in future work. The use of more advanced metaheuristic algorithms such as simulated annealing [13] or tabu search [14] could yield solutions closer to the global optimum, overcoming the locally optimal nature of the current greedy heuristic. Incorporating real-time data and uncertainty through stochastic models would increase the realism of the approach, enabling the model to respond dynamically to delays, cancellations, or other operational disruptions. The extension of the model to include transfer passengers and multi-terminal scenarios would broaden its applicability to larger and more complex airport infrastructures. In this context, the introduction of a clustering mechanism to group gates by proximity could constitute a valuable improvement. As noted in Section 5.2, airport operators tend to avoid the simultaneous use of adjacent gates when traffic volume does not justify it, assigning flights preferentially to gates that are sufficiently separated from one another. Incorporating this criterion into the model by defining a minimum separation distance between simultaneously assigned gates and only allowing adjacent gates to be used when demand is high enough to leave no alternative which would bring the assignment logic closer to real operational practice, while also reducing potential congestion at specific areas of the terminal. Finally, the application of artificial intelligence and machine learning techniques represents a particularly promising direction for further research. These approaches could be used to predict delays based on historical patterns, to learn optimal assignment strategies from past operational data, or to develop adaptive models capable of improving their performance over time as new data becomes available.

7 | Conclusions

This work has addressed the boarding gate assignment problem from a passenger-centered perspective, with the aim of minimizing the total passenger-weighted walking distance inside the terminal. To this end, a computational tool has been developed in Python that reads operational input data from a structured Excel file, applies a greedy heuristic to determine gate assignments, and generates the resulting output together with associated performance indicators in the form of visual representations.

The application of the model to a representative scenario based on Girona-Costa Brava Airport demonstrates that the proposed approach provides a feasible assignment that prioritizes the reduction of passenger walking distance while complying with all operational constraints such as temporal, physical, and regulatory. The rescheduling mechanism proved functional in handling gate saturation situations, as evidenced by the successful reassignment of one Schengen flight during the execution.

Several limitations have been identified. The model does not account for operational uncertainty such as delays or cancellations, operates under fixed time intervals, and excludes transfer passengers. Furthermore, the locally optimal nature of the greedy heuristic may lead to an uneven distribution of load across gates, as observed in the walking distance analysis, where Gate 5 concentrated a disproportionate share of non-Schengen assignments.

As future work, it is proposed to extend the model to include transfer passengers and multi-terminal configurations, to incorporate stochastic elements using historical delay data, and to validate the model against larger airports with different operational structures. The introduction of a gate clustering mechanism based on proximity criteria, as well as the use of more advanced metaheuristic algorithms or machine learning techniques, could further improve the quality and balance of the assignments. These developments would contribute to the consolidation of a more robust and comprehensive decision-support tool applicable to real operational environments.

References

[1] Y. She, Q. Zhao, R. Guo, and X. Yu, "A robust strategy to address the airport gate assignment problem considering operators' preferences," *Computers & Industrial Engineering*, vol. 168, p. 108 100, Jun. 1, 2022. Accessed: Apr. 2, 2026. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S036083522200170X.

[2] A. Lim and F. Wang, "Robust airport gate assignment," in *17th IEEE International Conference on Tools with Artificial Intelligence (ICTAI'05)*, ISSN: 2375-0197, Nov. 2005, 8 pp.–81. Accessed: Apr. 2, 2026. [Online]. Available: https://ieeexplore.ieee.org/document/1562918.

[3] Y. Shan, Y. Shao, Q. Yuan, and Y. Jiang, "Multiobjective gate assignment model considering carbon emissions," *International Journal of Environmental Research and Public Health*, vol. 20, no. 5, p. 3952, Jan. 2023. Accessed: Apr. 2, 2026. [Online]. Available: https://www.mdpi.com/1660-4601/20/5/3952.

[4] A.-F. Aeronáutica. "Blog AVSAF / AVSEC — Señalizaciones en plataforma," Avsaf. Section: Uncategorized, Accessed: Mar. 24, 2026. [Online]. Available: https://avsaf.es/post/senalizaciones-en-plataforma-de-un-aeropuerto/.

[5] "El aeropuerto pone a punto su pista de despegue tras una década de vuelos," castellonaldia.elmundo.es, Accessed: Apr. 3, 2026. [Online]. Available: https://castellonaldia.elmundo.es/economia/turismo/aeropuerto-pone-a-punto-pista-despegue-tras-una-decada-de-vuelos-EJ24967003.

[6] N. M. "Airport signs explained. "[Online]. Available: https://www.linkedin.com/posts/nadjim-m-408109158%5C_airport-signs-explained-this-diagram-shows-share-7379183814117404672-5yRc/.

[7] "AC 150/5360-13a - airport terminal planning." Last Modified: 2024-03-25T13:35:08-0400, Accessed: Mar. 25, 2026. [Online]. Available: https://www.faa.gov/documentLibrary/media/Advisory%5C_Circular/AC-150-5360-13A-Airport-Terminal-Planning.pdf.

[8] International Air Transport Association (IATA), "Airport service quality frameworks," Nov. 2022. [Online]. Available: https://www.iata.org/contentassets/d1d4d535bf1c4ba695f43e9beff8294f/airport-service-quality-frameworks.pdf.

[9] "Travel documents for EU nationals," Your Europe, Accessed: May 21, 2026. [Online]. Available: https://europa.eu/youreurope/citizens/travel/entry-exit/eu-citizen/index%5C_en.htm.

[10] O. Babić, D. Teodorović, and V. Tošić, "Aircraft stand assignment to minimize walking," *Journal of Transportation Engineering*, vol. 110, pp. 55–66, 1984.

[11] *Airports-py: A comprehensive library providing easy retrieval of airport data based on IATA, ICAO, city codes, country codes, and continents. features geographic search, distance calculation, timezone lookup, and external links integration.* Version 3.1.0. Accessed: May 18, 2026. [Online]. Available: https://airportdata.dev.

[12] *Greedy algorithm*, in *Wikipedia*, Page Version ID: 1353576456, May 11, 2026. Accessed: May 18, 2026. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Greedy%5C_algorithm%5C&oldid=1353576456.

[13] *Simulated annealing*, in *Wikipedia*, Page Version ID: 1351897656, Apr. 30, 2026. Accessed: May 18, 2026. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Simulated%5C_annealing%5C&oldid=1351897656.

[14] *Tabu search*, in *Wikipedia*, Page Version ID: 1304484154, Aug. 6, 2025. Accessed: May 18, 2026. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Tabu%5C_search%5C&oldid=1304484154.

[15] 02/07/2020. "Els primers turistes aterren a l'aeroport de girona després de l'aturada per la pandèmia," Ràdio Calella Televisió, Accessed: May 20, 2026. [Online]. Available: https://www.radiocalellatv.cat/els-primers-turistes-aterren-a-laeroport-de-girona-despres-de-laturada-per-la-pandemia/.

[16] Aena, "Provisional statistics 2025," Aena S.M.E., S.A., 2025. [Online]. Available: https://www.aena.es/sites/Satellite?blobcol=urldata%5C&blobkey=id%5C&blobtable=MungoBlobs%5C&blobwhere=1576873058155%5C&ssbinary=true.

[17] *Girona–costa brava airport*, in *Wikipedia*, Page Version ID: 1355280600, May 20, 2026. Accessed: May 21, 2026. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Girona%5C%E2%5C%80%5C%93Costa%5C_Brava%5C_Airport%5C&oldid=1355280600.

[18] "Enter air," Enter Air Fly Portal, Accessed: May 21, 2026. [Online]. Available: https://fly.enterair.pl/en/about-us/.

[19] "Enter air fleet — airfleets aviation," Accessed: May 21, 2026. [Online]. Available: https://www.airfleets.net/flottecie/Enter%5C%20Air.htm.

[20] "Aerolíneas — aeropuerto de girona-costa brava — aena," Accessed: May 21, 2026. [Online]. Available: https://www.aena.es/es/girona-costa-brava/aerolineas-y-destinos/aerolineas.html.

[21] "About us — jet2.com," Accessed: May 21, 2026. [Online]. Available: https://www.jet2.com/en/about-us.

[22] "Jet2 fleet — airfleets aviation," Accessed: May 21, 2026. [Online]. Available: https://www.airfleets.net/flottecie/Jet2.htm.

[23] Ryanair, "The people of ryanair," Ryanair, Dublin, Ireland, Oct. 2017.

[24] "El aeropuerto de Girona vuelve a superar los dos millones de pasajeros tras siete años sin lograrlo," La Vanguardia. Section: Girona, Accessed: May 19, 2026. [Online]. Available: https://www.lavanguardia.com/local/girona/20260113/11434478/aeropuerto-girona-vuelve-superar-dos-millones-pasajeros-siete-anos-lograrlo.html.

[25] "Ryanair fleet — airfleets aviation," Accessed: May 21, 2026. [Online]. Available: https://www.airfleets.net/flottecie/Ryanair.htm.

[26] *Ryanair UK*, in *Wikipedia*, Page Version ID: 1354004643, May 13, 2026. Accessed: May 21, 2026. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Ryanair%5C_UK%5C&oldid=1354004643.

[27] "Ryanair UK fleet — airfleets aviation," Accessed: May 21, 2026. [Online]. Available: https://www.airfleets.net/flottecie/Ryanair%5C%20UK.htm.

[28] "Transavia corporate — company profile," Accessed: May 21, 2026. [Online]. Available: http://www.transavia.com/.

[29] "Transavia airlines fleet — airfleets aviation," Accessed: May 21, 2026. [Online]. Available: https://www.airfleets.net/flottecie/Transavia%5C%20Airlines.htm.

[30] L. Dvorožňáková. "About smartwings group," Smartwings, a.s. Accessed: May 21, 2026. [Online]. Available: https://www.smartwings.com/en/about-smartwings.

[31] "SmartWings fleet — airfleets aviation," Accessed: May 21, 2026. [Online]. Available: https://www.airfleets.net/flottecie/SmartWings.htm.

[32] *TUI airways*, in *Wikipedia*, Page Version ID: 1353239531, May 9, 2026. Accessed: May 21, 2026. [Online]. Available: https://en.wikipedia.org/w/index.php?title=TUI%5C_Airways%5C&oldid=1353239531.

[33] "TUI airways fleet — airfleets aviation," Accessed: May 21, 2026. [Online]. Available: https://www.airfleets.net/flottecie/TUI%5C%20Airways.htm.

[34] "Company information — TUI fly," Accessed: May 21, 2026. [Online]. Available: https://www.tuifly.be/en/company-information.

[35] "TUI airlines belgium fleet — airfleets aviation," Accessed: May 21, 2026. [Online]. Available: https://www.airfleets.net/flottecie/TUI%5C%20Airlines%5C%20Belgium.htm.