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Automated Scheduling of Airside Wildlife Inspections for Wildlife Hazard Prevention Using a Greedy Algorithm at Milan Bergamo Air- port

TESI DI LAUREA MAGISTRALE IN
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Abstract

Wildlife within airport manoeuvring areas poses significant safety risks to both animals and flight operations, with strikes ranging from negligible to catastrophic events. International and national regulations, including ENAC, ICAO, and EASA standards, require airports to implement structured wildlife hazard management programs with regular airside inspections. At Milan Bergamo Airport (BGY), these inspections are currently scheduled manually using largely static, season-long timetables that do not reflect daily variations in traffic and wildlife activity.

This thesis develops an automated scheduling framework for airside wildlife inspections at BGY that integrates flight movements, wildlife activity, and regulatory constraints. It uses data collected by inspectors via a GPS-based monitoring app within a 13 km radius of the runway, combined with flight schedules from January 2023 to March 2026. Three inspection types are modeled—runway, ring, and perimeter—each with distinct routes and timing rules.

A greedy scheduling algorithm encodes ENAC and SACBO requirements, shift-buffer rules, traffic-driven feasibility constraints, and daily inspection limits through configurable parameters and movement masks (Appendix A). When tested on historical winter, summer, and future winter seasons under SACBO’s baseline configuration, the algorithm achieves full ENAC compliance for runway inspections in the historical winter dataset, 98% in summer, and $\geq 90\%$ in the future scenario. Compared with manual schedules, it better avoids peak traffic while maintaining inspection coverage.

The proposed framework provides SACBO S.p.A. with a practical decision-support tool that produces more adaptive, traffic-aware inspection plans. Future extensions may include real-time rescheduling and application to airports with different layouts and regulations.

Keywords: wildlife hazard managements; airport operations; inspection scheduling; greedy algorithm; ENAC regulations; airside safety; Milan Bergamo airport; wildlife strike risk

Abstract in lingua italiana

La presenza di fauna selvatica nelle aree di manovra aeroportuali rappresenta un rischio per la sicurezza di animali e voli, con impatti che possono variare da eventi trascurabili a incidenti gravi. Le normative internazionali e nazionali, tra cui quelle emanate da ENAC, ICAO ed EASA, richiedono agli aeroporti di attuare programmi strutturati di gestione del rischio da fauna selvatica, comprendenti ispezioni regolari in airside. Presso l'aeroporto di Milano Bergamo (BGY), tali ispezioni sono attualmente pianificate manualmente tramite orari stagionali statici, che non riflettono le variazioni giornaliere di traffico e fauna.

Questa tesi sviluppa un framework di pianificazione automatizzata per le ispezioni faunistiche in airside a BGY, integrando movimenti di volo, attività della fauna e vincoli normativi. Il modello utilizza i dati raccolti tramite un'app di monitoraggio GPS entro un raggio di 13 km dalla pista, combinati con i programmi di volo dal gennaio 2023 al marzo 2026. Sono considerati tre tipi di ispezione — pista, anello e perimetro — ciascuno con percorsi e regole temporali specifiche.

Un algoritmo di pianificazione greedy codifica i requisiti ENAC e SACBO, le regole sui turni e i buffer temporali, i vincoli di fattibilità legati al traffico e i limiti giornalieri di ispezione, tramite parametri configurabili e maschere di movimento (Appendix A). Testato su stagioni invernali e estive storiche e su uno scenario invernale futuro, l'algoritmo raggiunge piena conformità ENAC per le ispezioni pista nella stagione invernale storica, il 98% in quella estiva e almeno il 90% nello scenario futuro. Rispetto alle pianificazioni manuali, genera orari più coerenti con il traffico pur mantenendo una copertura ispettiva equivalente o migliore.

Il framework fornisce a SACBO S.p.A. uno strumento decisionale pratico, capace di generare piani di ispezione più adattivi e sensibili al traffico. Sviluppi futuri includono l'integrazione con dati di volo in tempo reale e l'estensione ad altri aeroporti.

Parole chiave: gestione del rischio da fauna selvatica; operazioni aeroportuali; pianificazione delle ispezioni; algoritmo greedy; normativa ENAC; sicurezza airside; aeroporto di Milano Bergamo; rischio d'impatto con fauna.

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Introduction

This thesis arises from an internship with SACBO S.p.A (Società per l'Aeroporto Civile di Bergamo – Orio al Serio), the private company responsible for managing and administering the infrastructure and operations of Il Caravaggio International Airport, commonly known as Milan Bergamo Airport. The in-person internship took place from October 20, 2025, to December 19, 2025, within the Operations Department, specifically the Process Engineering subdivision.

SACBO expressed interest in developing an automated method to schedule airside wildlife inspections, which are currently planned manually. The scope of this thesis is to use future scheduled flight data to generate a feasible inspection schedule for wildlife hazard prevention that respects operational constraints and regulatory requirements. At Milan Bergamo Airport there are three types of airside wildlife inspections that must be carried out to comply with ENAC regulations, and these are performed by the Bird Control Unit (BCU).

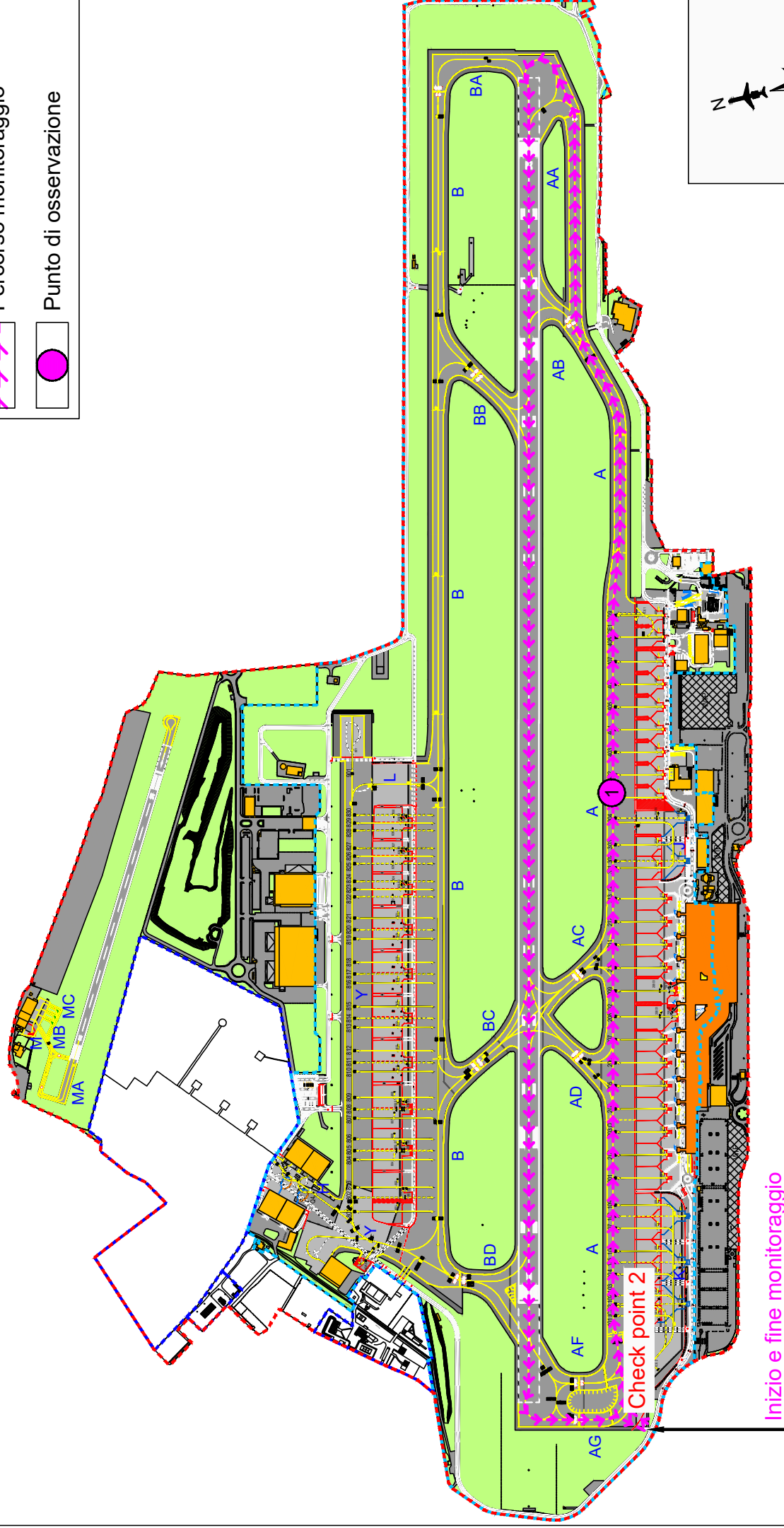
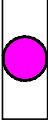
Pages 2 and 3 illustrate the runway inspection routes when runway head 28 (red) and runway head 10 (pink) are in use, respectively, and page 4 illustrates both the ring (light blue) and perimeter (dark blue) inspection routes as defined in SACBO's wildlife hazard procedure P0-17 [17]. "Inizio e fine monitoraggio" indicates the prescribed start and end point of each inspection, while observation points are represented by circles filled with the corresponding inspection-route color, marking locations where wildlife presence and habitat conditions must be checked in detail by leaving the vehicle and using binoculars to analyze areas near the runway. These prescribed paths and observation points define the spatial extent and minimum coverage of inspections, and therefore act as fixed operational constraints for the scheduling algorithm developed in this thesis.

Revisione	Aggiornamento	Issue date	Effective date
1	5	03/10/2025	08/10/2025

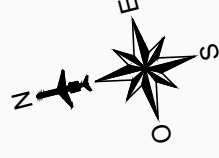
**Percorso di monitoraggio pista con
pista 10 in uso**

Percorso monitoraggio

☒ Punto di osservazione



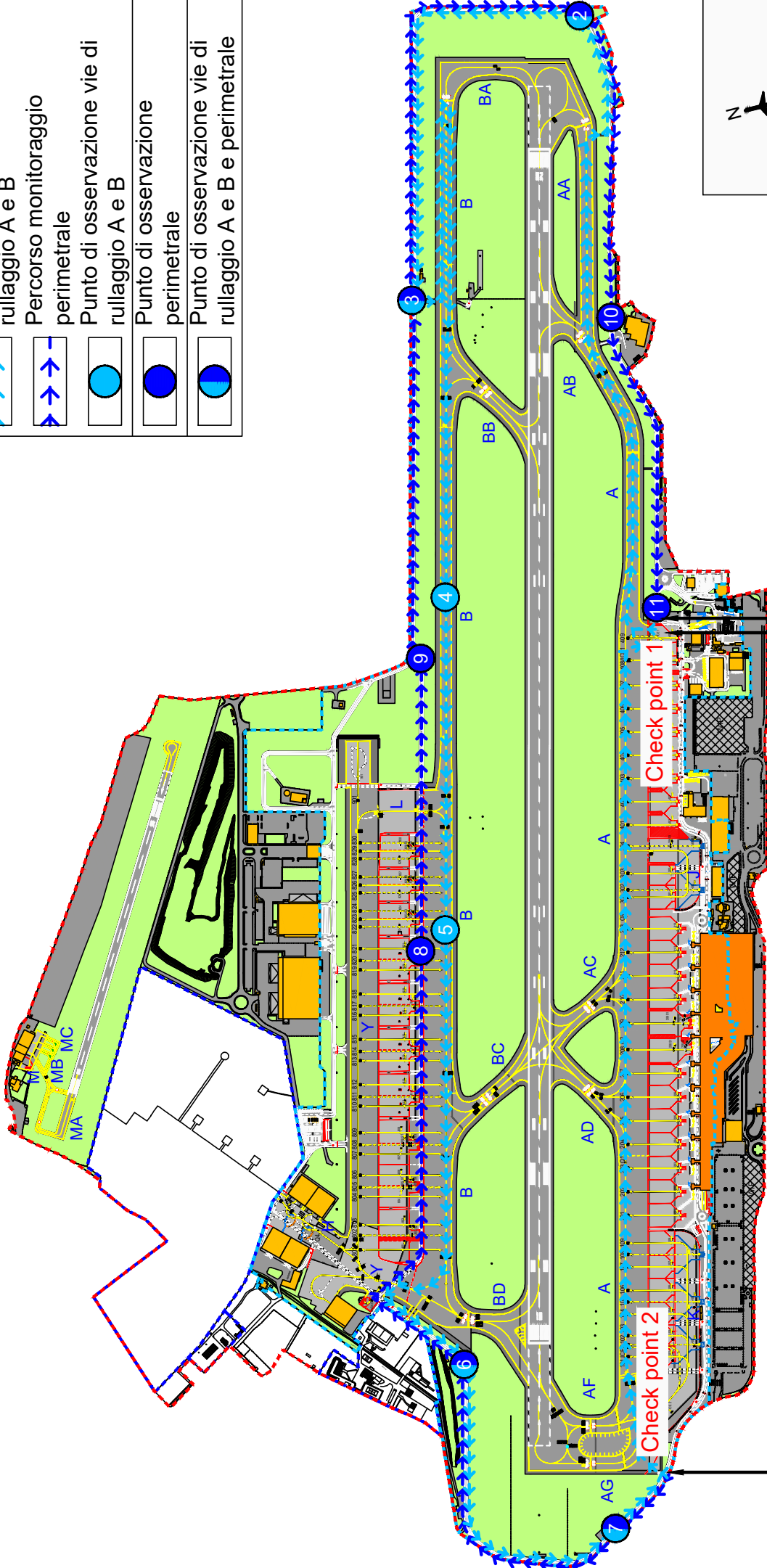
Inizio e fine monitoraggio



Revisione	Aggiornamento	Issue date	Effective date	Redatto	Modello
1	3	03/10/2025	08/10/2025	IFV	

Percorso di monitoraggio perimetrale e vie di rullaggio A e B

	Percorso monitoraggio vie di rullaggio A e B
	Percorso monitoraggio perimetrale
	Punto di osservazione vie di rullaggio A e B
	Punto di osservazione perimetrale
	Punto di osservazione vie di rullaggio A e B e perimetrale



Perimetrale: inizio monitoraggio

Rullaggio A e B: inizio e fine monitoraggio

Perimetrale: fine monitoraggio

Airside inspections for wildlife hazard prevention are essential for all airports, not only Milan Bergamo, because wildlife presence in the manoeuvring area represents a potential hazard for aircraft operations. With high traffic volumes, any inspection schedule must place safety as the top priority while remaining operationally realistic. Inspections are mandatory to prevent wildlife-related hazards, but not all animals present on or around the airfield are hazardous. Inspectors must therefore be properly trained both in the prescribed inspection routes and in recognizing when the presence, location, or behavior of wildlife constitutes an actual risk to flight operations.

Beyond safety, wildlife inspections interact tightly with airport capacity and efficiency, since entering the manoeuvring area requires coordination with Air Traffic Control and can temporarily limit runway and taxiway availability. This creates a scheduling problem in which regulatory requirements, wildlife activity patterns, and flight movements must be balanced to ensure that inspections occur when they are most effective, without unduly constraining airport operations.

In this context, the thesis develops a data-driven scheduling algorithm that uses historical and future flight data, discretized into 5-minute time slots, to propose inspection start times that satisfy ENAC requirements and SACBO's internal constraints while accounting for typical traffic patterns and peak wildlife activity periods. The algorithm is designed to be configurable by the user, so that different levels of conservatism and operational flexibility can be tested without changing the underlying structure.

In terms of methodology, the work formalizes operational and regulatory constraints into a configurable set of parameters and develops a greedy scheduling logic that avoids assigning runway inspections to time slots with high total movements and ring inspections to time slots with high numbers of departures, thereby reducing the likelihood of ATC-driven interruptions and canceled inspections. On the practical side, the algorithm tested on past and future Milan Bergamo data, producing feasible schedules for different days of winter and summer seasons and laying the ground work for a future version connected to real-time flight information, capable of updating inspection plans during the day based on delays and displaying the current schedule both within the BCU wildlife monitoring application and at the control tower.

Conducting this thesis in collaboration with SACBO has the explicit aim of delivering a tool that is practically useful for the company and that can be further developed into a fully integrated operational system. The work also aims to provide a methodological framework that can be adapted by other airports facing similar challenges in wildlife hazard management and inspection scheduling.

1 | Background and Related Work

The optimization of inspection schedules for wildlife hazard prevention at airports represents a relatively unexplored area in academic literature. While wildlife hazard management protocols and risk assessment methodologies are well-documented in regulations (Appendix A, Table A.1) from agencies such as the FAA [9], ICAO [22], EASA [8], and ENAC [7], the algorithmic scheduling of airside inspections to balance safety requirements with operational efficiency has received limited scholarly attention. Existing wildlife management literature focuses primarily on hazard assessment protocols [14], monitoring technologies [1], and dispersal techniques, but does not address the scheduling optimization problem fundamental to this thesis. This chapter reviews related research in airport operations scheduling and algorithmic approaches that inform the methodological framework developed in this work, and identifies the research gap this thesis addresses.

1.1. Airport Operations Scheduling and Vehicle Routing Problems

Airport scheduling problems share many structural characteristics with inspection scheduling, including discrete time representation, resource constraints, coordination with air traffic control, and the need to minimize disruption to flight operations. These characteristics also play a role in the algorithm for scheduling airside inspections for wildlife hazard prevention. In this context, Kuhn and Loth analyze the scheduling of support resources on the airside as an optimization problem in its own right, focusing on ground service vehicles rather than inspections. Kuhn and Loth investigated airport service vehicle scheduling at Hamburg and Dallas-Fort Worth airports, developing algorithms for dispatching luggage trailers and passenger buses while minimizing both service provider fuel costs and aircraft delay. Their work formulated the problem as a mixed integer linear program and compared three solution approaches: a passive dispatching strategy representing current operations, a greedy heuristic approach, and a genetic algorithm embedded within a moving time window framework [11].

The greedy approach developed by Kuhn and Loth assigns service tasks by selecting the geographically nearest idle vehicle when an aircraft requests service, prioritizing immediate distance minimization over future scheduling considerations. This strategy improved upon baseline operations by reducing mean travel distances by approximately 10% and aircraft delay by 10% at Hamburg Airport. However, the authors noted that greedy algorithms can produce suboptimal results when all idle vehicles are far from an aircraft requiring service but a nearby vehicle will become idle shortly. To address these limitations, they introduced a plan-based approach using a 60-minute plan with schedule updates every 10 minutes, combined with a genetic algorithm heuristic for solving static scheduling subproblems. This proactive method achieved travel distance reductions of 20% and delay reductions of 60% compared to current operations, though at significantly higher computational cost [11].

Recent work on airport security checkpoint scheduling by Chen et al. employed simulated integer programming techniques to optimize staff allocation and minimize passenger waiting times [3]. While addressing a different operational domain, this research demonstrates the applicability of optimization methods to time-critical airport scheduling problems with hard capacity constraints. Similarly, optimization approaches using evolutionary algorithms have been applied to airport slot scheduling to manage passenger flows and operational phases [20].

Greedy Heuristics for Scheduling Problems

Greedy algorithms construct solutions iteratively by making locally optimal choices at each decision point without reconsidering previous decisions. In vehicle routing and scheduling contexts, greedy insertion heuristics order tasks by priority criteria—such as earliest service time or geographical proximity—and assign tasks to resources in a single pass through the candidate set. Kuhn and Loth’s greedy approach to service vehicle scheduling exemplifies this methodology, achieving computational efficiency at the cost of solution quality compared to more sophisticated methods [11]. The primary advantage of greedy algorithms lies in their simplicity and speed: solution time scales linearly with problem size, making them suitable for real-time or near-real-time applications where computational resources are limited or rapid re-scheduling is required.

However, greedy methods are inherently myopic and do not guarantee optimal solutions. They perform poorly when immediate local optima conflict with better global solutions, particularly in problems with tight temporal constraints and interdependent tasks. Despite these limitations, greedy heuristics remain widely used in practice due to their transparency, ease of implementation, and ability to produce reasonable solutions quickly

without requiring specialized optimization software or mathematical programming expertise.

Research Gap and Thesis Contribution

The inspection scheduling problem developed in this thesis shares key characteristics with airport service vehicle routing: both involve discrete time representation, coordination with ATC to minimize operational disruption, and the need to respect hard constraints on resource availability and task timing. However, inspection scheduling differs in many ways that existing literature does not address.

First, inspection types have different priority levels reflecting varying safety criticality, rather than uniform service requirements. Second, mandatory inspections must be placed at specific high-risk periods (pre-night, post-night, dusk), introducing forced assignments not present in standard vehicle routing. Third, movement-based feasibility constraints link inspection timing directly to real-time flight schedules, creating dynamic dependencies between inspection opportunities and traffic patterns. The greedy approach accommodates the specific constraint structure of this problem. Unlike service vehicle routing, where all tasks have roughly equal priority and the objective is purely cost minimization, inspection scheduling must enforce strict priority ordering (runway > ring > perimeter) while satisfying minimum cardinality requirements for each type. The greedy algorithm naturally handles this through its priority-based candidate selection, ensuring runway inspections are scheduled first whenever feasible, without requiring complex multi-objective optimization formulations.

Despite extensive literature on wildlife hazard assessment protocols, real-time wildlife tracking technologies, and general airport scheduling optimization, no existing research addresses the specific problem of automated inspection schedule generation that integrates flight movement data, regulatory compliance requirements, and operational feasibility constraints for wildlife hazard prevention. The literature has the following gaps:

- no algorithm seems to exist publicly for scheduling wildlife inspections at airports that account for both regulatory requirements and operational constraints
- Previous research does not use real historical and future flight schedule data with inspection timing optimization
- Existing airport scheduling literature focuses on passenger processing, slot scheduling, and ground vehicle routing, but does not address wildlife hazard prevention airside inspection scheduling

- Wildlife hazard management literature emphasizes hazard assessment and dispersal techniques, but does not have an approach to either hand made or automatically generated inspection schedules

This thesis addresses these gaps by developing a constraint-satisfaction approach with greedy priority-based selection, tailored to the unique requirements of airside wildlife inspections at airports operating under FAA, ICAO, EASA, and ENAC regulatory frameworks. The algorithm integrates flight movement data with inspection type priorities, mandatory assignment time windows, and operational feasibility constraints to generate daily automated inspection schedules that replace currently manual planning processes. The specific algorithmic design used in this thesis is detailed in Chapter 6.

2 | Milan Bergamo Airport

2.1. Airport History and Development

Il Caravaggio International Airport (IATA: BGY, ICAO: LIME), also referred to as Milan Bergamo Airport or Orio al Serio International Airport, is managed and operated by SACBO S.p.A. It ranks as the third busiest international airport in Italy, having handled over 17 million passengers in 2024, with an average of 243 aircraft movements per day [15]. The airport is situated in Orio al Serio, approximately 4 km southeast of Bergamo and 45 km northeast of Milan. It accommodates both civil and general aviation operations, supporting international, and domestic traffic. The facility comprises a single passenger terminal and two airport runway heads designated 10 and 28 [21].

Construction of the airfield began in 1939 on the Orio al Serio site for military purposes. Initially serving as an Italian Air Force base, the site was later adapted for civil aviation. On 16 July 1971, the civil aviation authority authorized scheduled flights to various national destinations, including Rome, Cagliari, Alghero, and Catania. SACBO was established a year earlier, on 16 July 1970, and the first scheduled commercial service departed on 20 March 1972. Today, the airport offers more than 100 direct destinations across 38 countries [21].

2.2. Infrastructure and Operations

2.2.1. Runways and Apron Configuration

The figure illustrated on page 13 presents the layout of Milan Bergamo Airport. The main runway, 10/28, is oriented approximately east–west and measures 2,937 m in length. Its declared operational capacity is 26 total movements per hour between 06:00 and 22:59 local time, and 15 movements per hour between 23:00 and 05:59. Within this capacity, up to 18 departures and 16 arrivals per hour are permitted, with a maximum of three simultaneous departures between 05:30 and 06:59 and up to four simultaneous departures during all other times. The other runway designated 12/30 is mainly used by the Bergamo

Aero Club and measures 778 m in length.

The airfield includes parking stands compliant with ICAO Code B, C, D, and E aircraft categories, each defined according to aircraft wingspan and length, as stated in the Procedure for Stand Management [16]. According to three years of operational data, approximately 97% of all arrivals and departures at BGY involved aircraft within the dimensional limits of Code C stands. The airport provides a total of 48 Code C stands, distributed across five areas: Sectors 100, 200, 300, 400, and the North Area (Sector 800). Several stands offer flexible configurations, allowing the same area to accommodate multiple smaller aircraft or fewer larger aircraft as needed. This adaptability supports efficient apron utilization and dynamic stand assignment under changing traffic conditions. Of these, 40 stands are allocated for overnight parking. Stand location and configurations are shown in the illustration on page 13.

2.2.2. Passenger and Aircraft Traffic

Beyond aircraft parking infrastructure, the terminal facilities themselves impose capacity constraints on passenger processing. The airport's terminal infrastructure is designed to accommodate a balanced flow of both arriving and departing passengers across Schengen and extra-Schengen operations. The maximum passenger handling capacity is divided according to destination type and terminal processing areas.

For arriving passengers, the facility can process up to 1,250 passengers per hour from extra-Schengen (non-Schengen) destinations and 2,500 passengers per hour from national and Schengen destinations combined. Similarly, for departures, the terminal supports a bandwidth of 1,250 passengers per hour for flights bound for extra-Schengen destinations and 2,500 passengers per hour for national and Schengen services.

These nominal capacities reflect the airport's design limits based on terminal size, security screening areas, baggage handling systems, border control facilities, and overall safety. Passenger capacity planning ensures that peak-hour volumes—particularly during seasonal high-demand periods—can be effectively managed without compromising safety, efficiency, or passenger comfort levels.

2.2.3. Operational Capacity and Traffic Patterns

These passenger and aircraft capacity limits interact with temporal traffic patterns that vary seasonally throughout the year. The aviation industry at Milan Bergamo Airport operates on two distinct seasonal schedules that align with daylight saving time changes. The winter season runs from the end of daylight saving time to when it starts again the following year, while the summer season spans from when daylight saving time begins until it ends. The historical dataset analyzed covers one complete winter season (October 27, 2024 to March 29, 2025) and one complete summer season (March 30, 2025 to October 25, 2025), providing comprehensive movement data organized into 5-minute time slots.

Traffic patterns in the winter season show distinct characteristics. As shown in figure 2.2, movement activity stays minimal during the overnight period between approximately 01:30 and 05:30, when the airport has almost no operational activity. The day's traffic picks up around 05:30, reaching the main morning peak near 07:00 with a maximum observed intensity of 441 movements per 5-minute interval. Throughout the operational day, the airport maintains steady moderate activity levels, with a secondary evening peak appearing around 20:45. Winter baseline activity typically ranges between 100-250 movements per interval, with these peak periods standing out above this range.

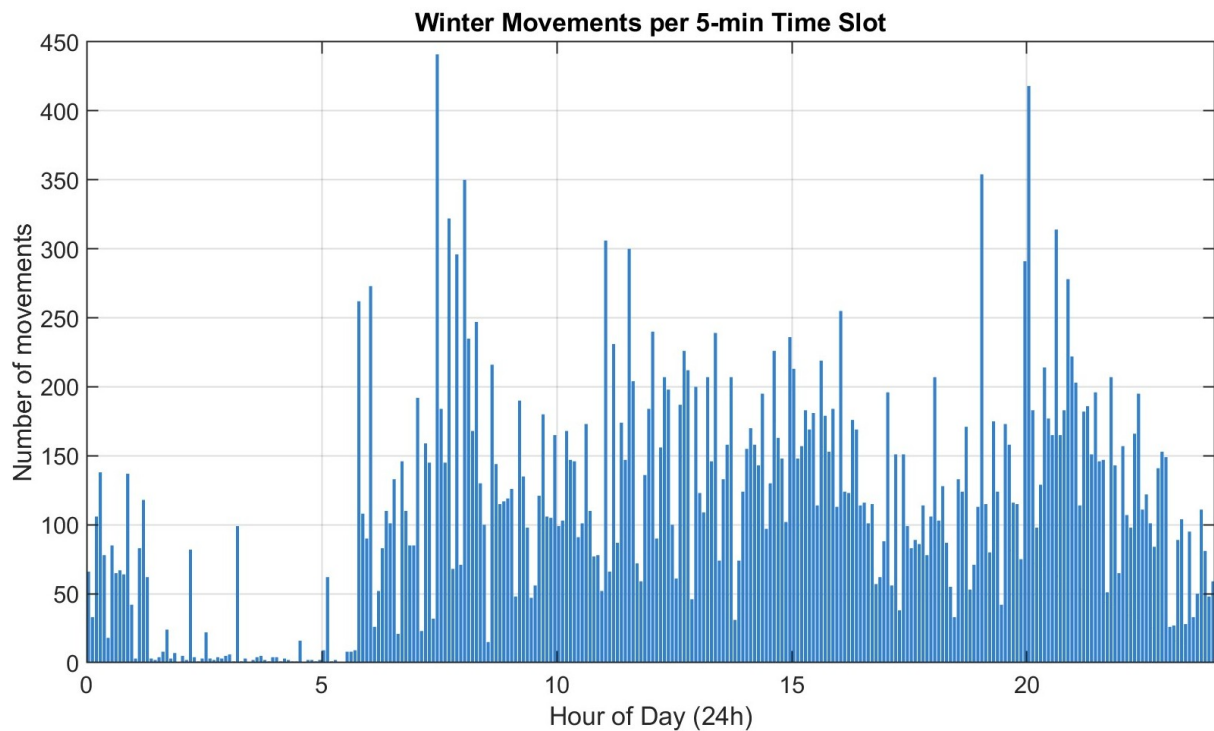


Figure 2.2: Number of total movements per 5-minute time slot occurring throughout the entire winter season.

Traffic patterns in the summer season show much higher intensity while keeping a similar time structure. Figure 2.3 shows that the overnight quiet period stays in the same 01:30-05:30 window, as shown in the winter, mainly due to noise restrictions as the airport is in close proximity to the town of Orio al Serio, but operational activity during the day reaches much higher levels. Summer traffic has three clear peak windows: a morning peak around 07:15, an evening peak near 19:30, and a later evening peak around 22:00, with the maximum observed intensity reaching 682 movements per 5-minute interval. Summer baseline activity typically ranges between 200-400 movements per interval - roughly double the winter levels - reflecting increased seasonal demand for leisure and holiday travel.

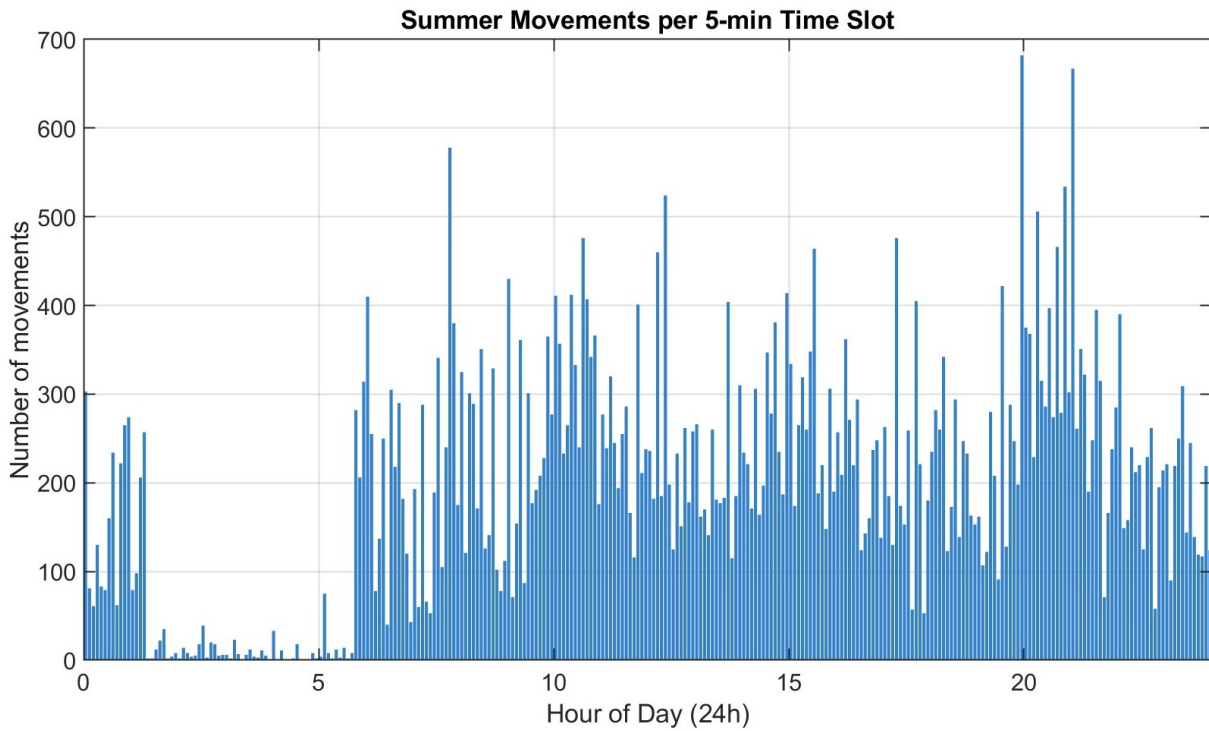


Figure 2.3: Number of total movements per 5-minute time slot occurring throughout the entire summer season.

While the exact sequence of flights changes daily due to flight frequency variations and schedule adjustments, analysis revealed consistent weekly patterns within each season (see Figure 2.4 for winter and Figure 2.5 for summer). In these heatmaps, rows correspond to weeks of the year, columns to days of the week, and the color scale indicates the total number of movements per week-day cell, with warmer colors representing higher traffic levels. Each day of the week (Sunday, Monday, etc.) shows a very similar traffic profile throughout the season, with peak timing and relative intensity staying stable week to week. This regularity allows for the possibility of further developing an algorithm for weekly inspection schedules that can be applied consistently across each seasonal period.

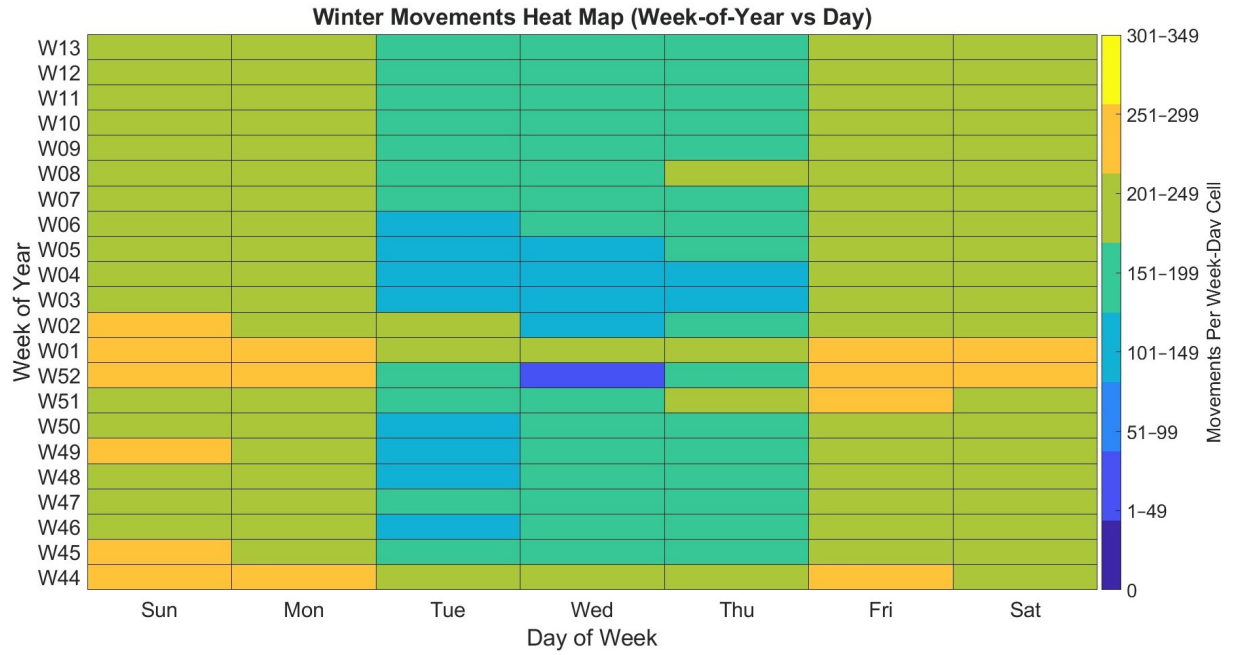


Figure 2.4: Total winter aircraft movements by week and weekday (heatmap).

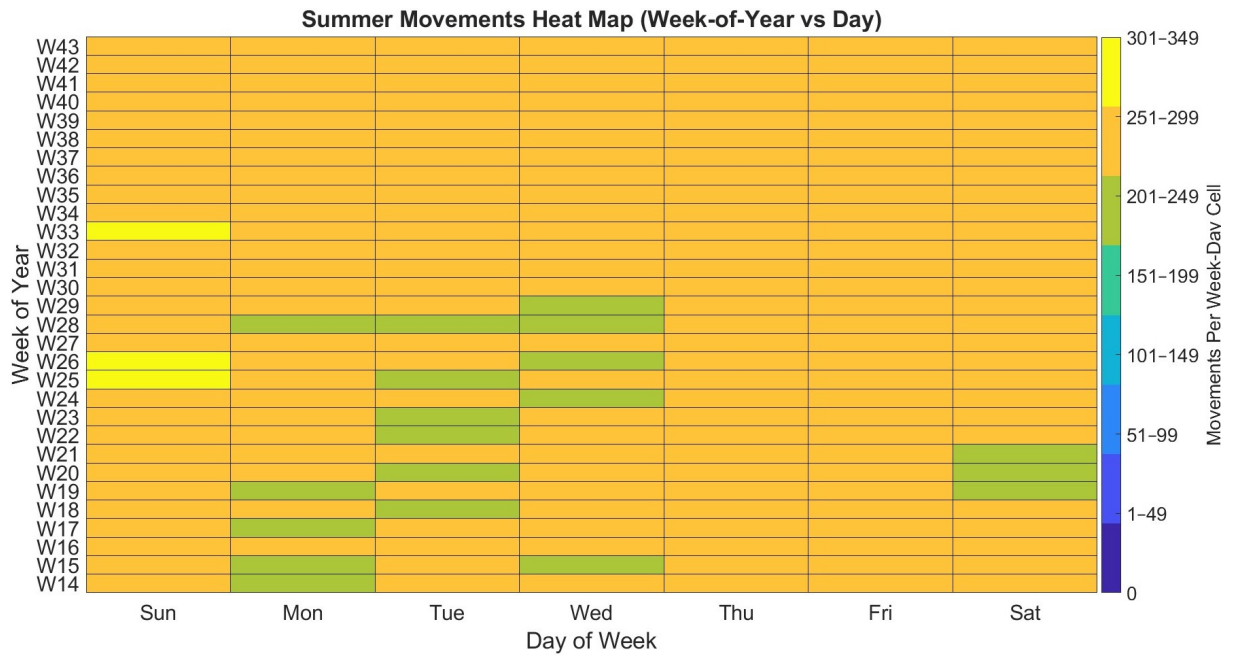


Figure 2.5: Total summer aircraft movements by week and weekday (heatmap).

The winter and summer heatmaps show similar numbers of movements across each day of the week, for each season, with slightly higher intensities surrounding weekends. It is highly noticeable that there is more travel activity during the summer season.

These seasonal traffic characteristics directly inform the constraint formulation developed

in Chapter 6. The identified peak movement windows establish critical avoidance periods for runway inspections, while high departure concentration periods define constraints for ring inspection scheduling. The overnight quiet periods provide natural opportunities for no inspection activities. By characterizing these patterns with numbers, the optimization algorithm can balance operational safety requirements with minimal disruption to flight operations across both seasonal contexts.

2.2.4. Wildlife Hazard Management Context at BGY

Like many airports, Milan Bergamo faces notable wildlife hazard risks that require systematic management. The airport's location and surrounding environment attract various animals, necessitating regular airside inspections to identify and mitigate potential strike hazards. These inspection requirements must be balanced against the operational traffic patterns described above, forming the foundation for the optimization approach developed in subsequent chapters.

3 | Wildlife Hazard Management at Airports

3.1. Global Context and Aviation Safety

3.1.1. Wildlife Strike History and Impact on Aviation

The first recorded powered flight took place on December 17, 1903, at Kitty Hawk, North Carolina, piloted by Orville Wright. Only two years later, in 1905, the Wright brothers experienced the first documented non-fatal bird strike when a bird collided with Orville Wright's aircraft, causing minor damage. The first fatal bird strike occurred in 1912, when aviation pioneer Calbraith Rodgers' aircraft struck a gull while flying along the coast of California. The collision led to a loss of control and a subsequent crash that resulted in his death [6].

3.1.2. Italian Regulatory Framework and the Bird Strike Committee

In Italy, awareness of bird strikes and their potential impact on aviation safety increased following regulatory reforms in the early 1990s. The Bird Strike Committee Italy (BSCI) was established in 1993 by the Ministry of Transport, following a 1992 law mandating the systematic monitoring of bird populations at airports. The committee functions as a government-led body tasked with enforcing and promoting national standards for bird strike prevention [7]. It operates under the authority of the Ente Nazionale per l'Aviazione Civile (ENAC), the Italian Civil Aviation Authority. ENAC regulations require airports across Italy to maintain a permanent service for the control, monitoring, and removal of birds and other fauna from airport premises [7].

3.2. Wildlife Hazard Management at Milan Bergamo Airport

Building on the infrastructure and operational profile described in Chapter 2, this section examines the wildlife hazard management system implemented at Milan Bergamo Airport. As noted in Section 1.2.4, the airport's environmental setting necessitates comprehensive wildlife control measures aligned with Italian and European regulatory standards.

3.2.1. Ecological Context and Wildlife Attractants

The airport environment comprises both natural features and man-made habitats that can significantly increase its attractiveness to wildlife. Natural elements such as the Serio River (located on the east side of runway head 28), along with surrounding patches of trees and grassland, provide water, cover, and abundant foraging opportunities, allowing birds like pigeons, mammals such as hares, and other species to use these areas as feeding and resting grounds. Preserved or poorly managed vegetated areas in close proximity to the airfield further enhance habitat quality and consequently draw unwanted wildlife towards the operational area. Page 13 clearly illustrates the Milan Bergamo Airport airside and its surrounding environment.

In parallel, man-made components of the airport create artificial habitats that animals may interpret as safe, open spaces. The extensive, unobstructed surfaces of the airside – including runways, taxiways, and infield grassed areas – can resemble open fields to birds and small mammals, encouraging them to land, forage, or move across these zones. Moreover, human activity around terminal buildings, particularly inadequate management of food waste and litter, generates additional food resources that attract opportunistic and non-domesticated species that are habituated to coexisting with humans, such as pigeons, and gulls. These combined natural and anthropogenic attractants underscore the need for systematic, optimized airside inspection schedules aimed at early detection and timely mitigation of wildlife presence as a core component of the airport's wildlife hazard prevention strategy.

3.2.2. Primary Wildlife Species of Concern

Like many European airports, Milan Bergamo encounters a range of wildlife species that pose varying levels of hazard to aircraft operations. The most frequently observed species include European hares (*Lepus europaeus*), which are commonly found on airside grass areas and require active trapping and removal. Avian species of concern include rock pigeons

(*Columba livia*), common wood-pigeons (*Columba palumbus*), and various gull species, all of which are attracted to open airfield surfaces and can form flocks near active runways. Additionally, raptors such as common kestrels (*Falco tinnunculus*) are periodically observed, though their solitary hunting behavior typically results in less frequent strike incidents compared to flocking species. The diversity and abundance of these species vary seasonally and are influenced by weather conditions, migratory patterns, and availability of food sources both on and around the airport. A full list of species that have been spotted in the area can be found in Appendix B, Table B.1.

3.2.3. Wildlife Hazard Management Plan and Environmental Policy

The BCU operates in accordance with the airport's Environmental Policy, which is outlined in the Wildlife Hazard Management Plan (WHMP) approved by ENAC. The WHMP, developed by the Movement Area Post Holder, specifies preventive and corrective actions designed to minimize wildlife attractants both inside and around the airport perimeter. These measures include prohibiting fertilization, cultivation, or breeding activities within airport boundaries; regulating waste accumulation and storage areas to prevent feeding or nesting sites; and managing spontaneous vegetation through pruning and felling.

Within the movement area, a short grass policy is applied in runway strips, taxiway strips, RESA, aprons, and lateral areas close to the runway to reduce wildlife hazards and maintain clear visibility of airfield markings, in line with ICAO Annex 14 and ENAC guidance. Grass height is maintained at approximately 10–13 cm in these critical areas, as values >15–20 cm encourage bird nesting and rodents, increasing bird strike risk, while grass <5 cm favors some granivorous species and insect proliferation. Perimeter grassland outside these safety strips is managed through controlled periodic maintenance, allowing grass to grow up to 90 cm before mowing, baling, and prompt removal to prevent foreign object debris (FOD) [17]. Mowing operations are primarily scheduled at night or coordinated with runway closures under NOTAM procedures to minimize interference with flight operations.

In addition, routine structural inspections of perimeter fences and gates are conducted to prevent terrestrial fauna access to the movement area. Environmental monitoring is extended beyond the airport boundary, up to a radius defined in the WHMP (typically on the order of several kilometers), to identify natural or anthropogenic wildlife attractants such as rivers, agricultural areas, and waste disposal facilities that may influence bird presence and movement patterns around the aerodrome.

3.2.4. Bird Control Unit: Organization and Operations

Milan Bergamo Airport fulfills the legal and operational requirements of Ente Nazionale per l'Aviazione Civile (ENAC), European Union Aviation Safety Agency (EASA), and International Civil Aviation Organization (ICAO) through the establishment of its Bird Control Unit (BCU). The BCU is a dedicated operational department responsible for monitoring, managing, and dispersing wildlife within and around the airfield to ensure safe flight operations. The unit operates on a continuous 24-hour basis, divided into three eight-hour shifts to provide uninterrupted coverage of all airside areas, including during night hours and reduced traffic periods.

Each BCU member holds an ADC-R driver's license, required for operating vehicles on airside service roads, and receives formal training in wildlife management through the Bird Control Italy Unit. The training program integrates both theoretical instruction and field exercises, focusing on species identification, ecological behavior, safe dispersal techniques, and accurate data logging. Recurrent training is conducted annually to maintain professional standards and ensure compliance with ENAC requirements [17].

Within the organizational hierarchy, three core roles structure the BCU's operations:

BCU Coordinator oversees daily field operations, defines inspection schedules, and manages operational priorities.

BCU Contact serves as liaison between SACBO management and the BCU team, ensuring efficient resource allocation, data reporting, and equipment readiness.

BCU Officer performs field inspections, records wildlife observations, and implements dispersal actions based on situational risk assessments.

3.3. Airside Inspection Operations

3.3.1. Inspection Requirements and Scheduling Principles

Preventive monitoring at Milan Bergamo Airport requires a minimum of fourteen inspections per day, scheduled based on both operational demand and ecological risk factors. The timing and frequency of these inspections are influenced by variables such as peak traffic periods, daylight availability, activity patterns of bird species, missed inspections, recent wildlife strike incidents, and the airport's wildlife risk index.

3.3.2. Inspection Types and Routes

Pages 2 and 3 illustrate the runway inspection routes when runway head 28 (red) and runway head 10 (pink) are in use, respectively, and page 4

Milan Bergamo Airport implements three main types of inspections, each following predefined routes with designated observation checkpoints:

Runway inspections focus on detecting wildlife presence or carcasses within runway strips and adjacent areas, typically requiring approximately ten minutes to complete. The inspection route varies depending on which runway head is actively in use, with separate predefined paths for operations on runway head 28 (inspection route found on page 2 and runway head 10 (inspection route found on page 3) to ensure comprehensive coverage while minimizing interference with aircraft movements.

Ring inspections cover intermediate zones between the airside and perimeter areas, with a duration of about twenty-five minutes. This inspection type monitors transition zones where wildlife may move between outer areas and the operational surfaces. Page 4 illustrates the ring inspection route.

Perimeter inspections monitor the external boundaries and surrounding fields, generally taking around twenty-three minutes to complete. Given that this inspection occurs outside the movement area, inspectors halt at designated checkpoints, exit the vehicle, and use visual observation tools including binoculars to identify hazardous wildlife without entering the manoeuvring areas. Page 4 illustrates the perimeter inspection route.

3.3.3. Communication and Coordination Protocols

Safe execution of airside inspections requires strict adherence to air traffic control (ATC) communication procedures. Inspectors must request and receive explicit permission from the control tower before entering taxiways and runways. ATC may authorize partial entry, requiring the inspector to hold position for passing aircraft, which always maintain right-of-way, before proceeding at safe separation distances. Safety protocols mandate minimum separation of one aircraft length when engines are at idle power, and two aircraft lengths when engines are operating at medium thrust.

When hazardous wildlife is observed near the path of inbound or outbound aircraft, inspectors immediately communicate the threat to ATC, enabling controllers to delay aircraft movements until the hazard is cleared. This real-time coordination between BCU officers and air traffic control forms a critical safety layer in the airport's wildlife management

system.

3.3.4. Wildlife Management Actions and Documentation

BCU officers are trained in multiple wildlife management techniques deployed during inspections. Inspectors monitor and service wildlife traps placed at strategic airside locations for capturing hares and other small mammals. When animal carcasses are discovered, officers use specialized tools including nets and brooms with dustpans to remove them promptly, as deceased animals can attract scavenger species and compound wildlife hazards. Removed carcasses are stored in dedicated freezers until a contracted third-party disposal service collects and properly disposes of them.

At the start of each shift, inspectors activate a wildlife monitoring application on their authorized mobile devices. The application automatically logs the time and uses GPS tracking throughout the inspection. Inspectors manually input environmental conditions including temperature and weather observations (cloud cover, precipitation, etc.). When hazardous or potentially hazardous wildlife is detected, the inspector marks the precise location on the application's airport grid map. This data feeds into a centralized database, supporting long-term analysis of wildlife distribution patterns and high-risk zones.

Before concluding a shift, the outgoing BCU officer documents inspection outcomes in a digital notes system, recording wildlife encounters, hazard levels, and general conditions. During shift handover, this information is communicated both verbally and through the shared notes application, ensuring continuity of situational awareness across the 24-hour operational cycle.

3.3.5. Operational Constraints and Field Observations

Direct observation of BCU operations revealed important practical constraints for inspection scheduling. Shift change times must be respected, and inspection schedules should avoid assigning inspections that could extend across shift boundaries, as this creates handover complications and potential safety gaps. Additionally, while consecutive inspections of the same type may be operationally necessary during high-movement periods, BCU officers indicated that scheduling more than two identical consecutive inspections can become redundant and yield diminishing returns in terms of wildlife detection, except during peak traffic windows when heightened vigilance is called for.

3.4. Wildlife Control Methods and Tools

The Bird Control Unit (BCU) utilizes a 4x4 pickup vehicle equipped with airfield-compliant lighting, radio transceivers, and specialized wildlife deterrent tools to support its activities. Dispersal methods are divided into two main categories. Active control methods employ movement or noise to scare animals away, using tools such as distress call devices, gas cannons, pyrotechnic devices, and blank-firing pistols. Static control methods rely on physical or visual deterrents, including barriers and reflective materials, to discourage wildlife habitation. Active control techniques are generally more effective as they maintain unpredictability and prevent habituation; however, their use is moderated to ensure long-term effectiveness [7].

3.5. Data Collection, Reporting, and Risk Assessment

3.5.1. Wildlife Monitoring and Data Collection Protocols

After each inspection, the BCU completes a standardized Bird Strike Report Form (BSRF) documenting wildlife observations, removals, impact events, and carcass recoveries (within 60 meters of the runway centerline). Additional information—such as control actions performed, monitored attractants, and inspection results—is recorded through authorized mobile devices. These data are uploaded to a centralized digital platform accessible to the airport operator and relevant authorities for analysis and reporting purposes.

The log includes data points on route coverage, species composition, abundance levels, temporal distribution, and response measures. Consistent data collection supports long-term trend analysis, identification of high-risk zones, and evaluation of the effectiveness of implemented mitigation strategies.

3.5.2. Bird Strike Risk Index (BRI_2)

The Bird Strike Risk Index BRI_2 is a standardized algorithmic indicator, adopted by ENAC as the national reference tool for wildlife strike risk assessment [7]. It provides a site-specific, yet nationally comparable, monthly risk score by integrating historical strike data, routine wildlife observations, and airport traffic patterns. Beyond simple event counts, BRI_2 explicitly accounts for local ecological conditions and species distribution, species ecology (for example flocking behavior and typical flight altitude), aircraft

movements, and species composition grouped into 17 functional categories, as well as the abundance and persistence of fauna near the airfield [20]. When the BRI_2 value exceeds a threshold of 0.5, predefined corrective actions are mandated at the airport level. In this way, the index supports proactive wildlife control by allowing SACBO to monitor changes in wildlife pressure over time, evaluate the effectiveness of mitigation measures, identify peak-risk periods, and prioritize operational adjustments within inspection schedules.

3.5.3. Integration with Inspection Optimization

Despite these comprehensive monitoring procedures and established protocols, the manual scheduling of inspections faces inherent challenges in balancing operational constraints with ecological risk factors across varying traffic patterns. The optimization approach developed in subsequent chapters addresses these scheduling complexities by systematically incorporating the traffic patterns, inspection requirements, and operational constraints described in chapters 2 and 3.

4 | Species Distribution and Strike Risk at Milan Bergamo Airport

4.1. Data Collection and Analysis Framework

4.1.1. Wildlife Monitoring Database and Methods

Wildlife observations are recorded in the national database accessible through birdsafety.it. Each sighting is logged through a mobile device used by wildlife inspectors during their routine airside inspections. The device integrates GPS coordinates and time-stamped inputs to geolocate each detected animal, allowing sightings to be visualized on spatial heatmaps of the airport environment.

Milan Bergamo operates under a two-season schedule aligned with daylight saving time transitions. The winter season extends from October 27, 2024, through March 29, 2025, while the summer season covers March 30 through October 25, 2025. For the purposes of this analysis, the dataset was divided accordingly to investigate potential seasonal patterns in wildlife presence and strike activity.

4.1.2. Overall Wildlife Observations and Strike Statistics

Between October 27, 2024, and October 25, 2025, a total of 10,213 individual animals were recorded within a 13 km radius of Milan–Bergamo Airport, representing 43 distinct species. Of these, 28 species have been involved in at least one reported wildlife strike with an aircraft during the same period. In total, 318 strike events were documented, with the involved species successfully identified in 153 cases.

Figure 4.1 presents the seasonal distribution of wildlife observations for the twelve most frequently recorded species, combining winter and summer sightings into a single visualization. The stacked bars illustrate how total abundance varies by species while also highlighting the relative contribution of winter and summer detections for each taxon. During the winter period, 6,542 animals were detected, with particularly high counts for

Pigeon (2,240), Common Starling (1,933), Cattle Egret (540), Spotless Starling (500), and Italian Sparrow (430). In the summer season, 3,671 animals were detected, with the most frequent species being Carrion Crow (972), Pigeon (673), Barn Swallow (568), Eurasian Magpie (338), and Cattle Egret (288).

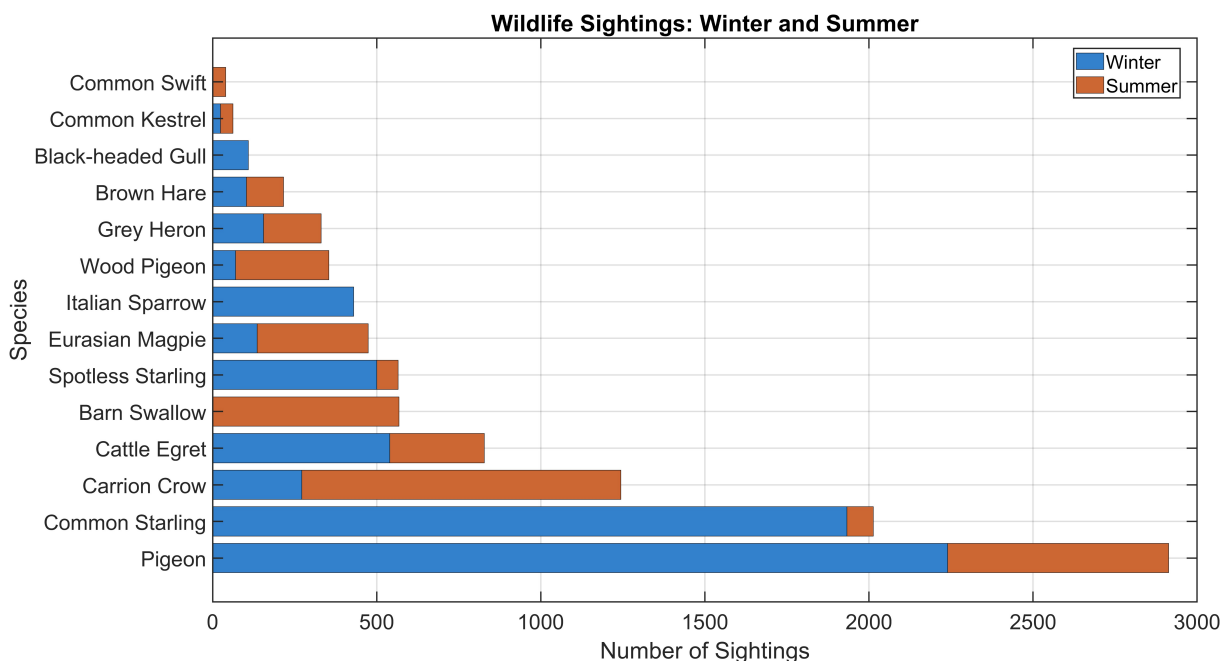


Figure 4.1: Top 14 wildlife sightings in 2024–2025, stacked winter and summer counts within 13 km of BGY.

Figure 4.2 presents the total number of wildlife strikes for the twelve species most frequently involved during the 2024–2025 operational year, combining winter and summer strike occurrences in a single stacked representation. During the winter months, 15 wildlife strikes were reported. The most affected species included the European Hare (8), Pigeon (2), Grey Heron (1), Cattle Egret (1), and Common Kestrel (1). In contrast, the summer season experienced 48 strikes, most commonly involving the Common Kestrel (9), European Hare (8), Pigeon (7), Cattle Egret (3), and Black-headed Gull (3), with eight additional events attributed to unidentified species because remains were not recoverable or provided no biological trace for identification. Notably, several of these species (e.g. Pigeon, Cattle Egret, Barn Swallow) also rank among the most frequently observed in the sighting data, suggesting that species abundance around the aerodrome may play an important role in determining strike risk.

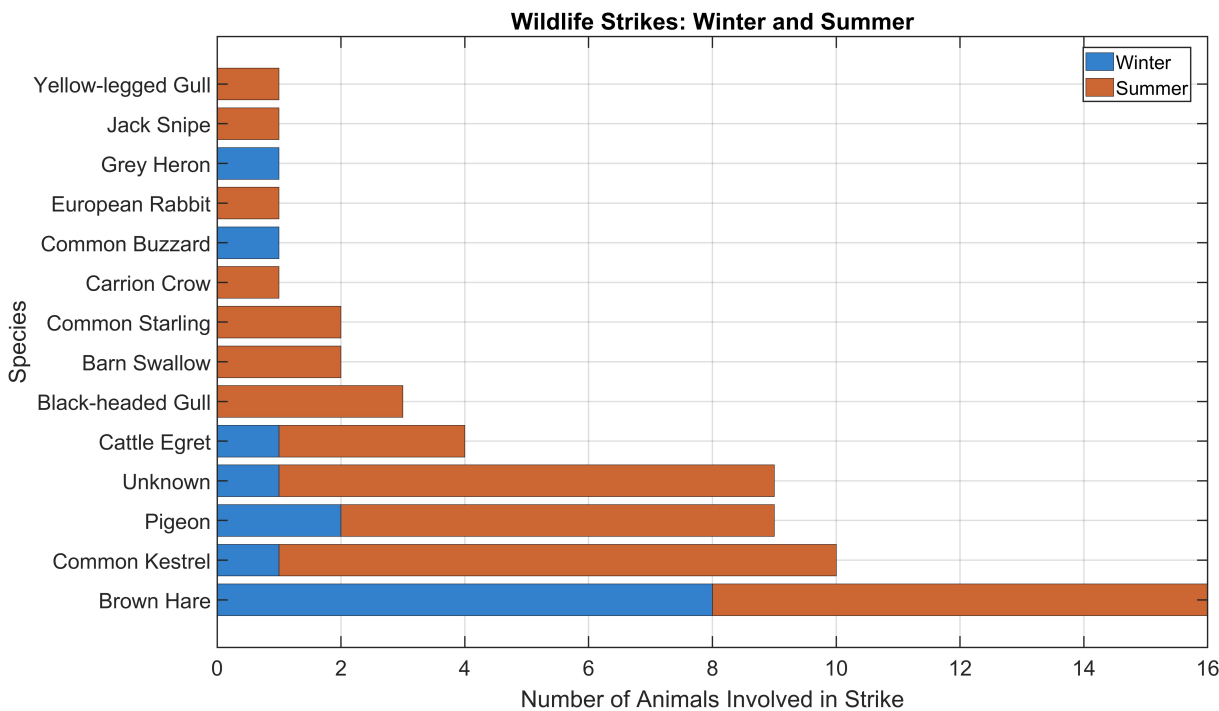


Figure 4.2: Wildlife strike counts for the 14 most frequently involved species, winter and summer stacked, within 13 km of BGY (2024–2025).

Based on these findings, the overall probability of a wildlife strike within the analyzed time frame is estimated at 0.52% (318 strikes across approximately 60,000 total movements).

Strike severity is strongly influenced by wildlife body size and mass. Research indicates that larger-bodied species, despite representing a smaller proportion of total strike events, consistently produce a higher percentage of damaging strikes compared to smaller species. Analysis of engine strike data from 2009-2023 showed that while small-bodied species accounted for 64% of engine strikes, large-bodied species—representing only 7% of strike events—were responsible for 62% of damaging engine strikes. This size-damage relationship emphasizes the importance of prioritizing detection and dispersal efforts for larger species within inspection scheduling protocols [13].

4.2. Species Profiles: Year-Round Strike Risk Species

To support risk-informed inspection scheduling, this section provides detailed behavioral and temporal profiles for species that demonstrate consistent strike involvement across both seasonal periods. Species were selected for detailed profiling if they appeared among the top five strike-involved species in both winter and summer seasons.

As introduced in Chapter 2, several species at Milan Bergamo Airport present recurring

hazards due to their abundance, behavior, and strike involvement. The following sections provide detailed ecological and behavioral profiles of the most significant species identified through the sighting and strike data. Among the many species observed at BGY, several show recurring significances both in sightings and in strike data. The Pigeon and Cattle Egret appear in the top five most frequently sighted and struck species during both winter and summer, indicating a consistent year-round presence near operational areas. The European Hare and Common Kestrel also appear repeatedly among the top five strike-involved species across both seasons, suggesting high exposure or vulnerability due to behavioral patterns and activity periods.

In contrast, the Grey Heron is predominantly involved in strikes during the winter season, while the Black-headed Gull is more relevant in the summer season. Species such as Starlings and Sparrows tend to be more abundant during winter, whereas Crows, Swallows, and Magpies are more prevalent in the summer. Despite their high seasonal presence, these latter species were not reported in any strike events during the analyzed period.

Understanding these species-specific and seasonal trends is critical for optimizing airside inspection schedules. The following subsections provide detailed profiles of the four species that appear in the top five strike-involved species in both winter and summer seasons: European Hare, Pigeon, Cattle Egret, and Common Kestrel. These species demonstrate consistent year-round strike risk, making their behavioral patterns and temporal activity particularly relevant for inspection scheduling across both seasonal periods developed in Chapter 7.

Photographic identification references for the top 8 species observed at Milan Bergamo Airport, together with Table B.1 reporting, for all 43 species, the total number of sightings and the number of animals involved in strikes, are provided in Appendix B.

4.2.1. Rock and Wood Pigeons

There are two types of pigeons commonly observed at BGY: the rock pigeon (*Columba livia*) and the wood pigeon (*Columba palumbus*). The rock pigeon is characterized by its bluish-grey head, neck, and chest, with yellow, green, and red hues on the neck and wings, a white lower back, and a black tail band. Its wings are broad and pointed, and they are held in a V-shape during gliding flight. The wood pigeon is larger than the rock pigeon, with a predominantly grey plumage, pinkish breast, a large white patch on the neck, a red bill with a yellow tip, and red legs and feet [4]. Refer to Appendix B for images.

The rock pigeon is present year-round at BGY, while the wood pigeon is migratory, with its peak presence occurring from October to November [4]. This seasonal influx results in

a higher total number of pigeons observed during this period. Rock pigeons are typically found in fast-moving, clustered colonies, which may restrict their freedom of movement and ability to avoid oncoming aircraft. In contrast, wood pigeons are commonly observed in flocks or loose groups at airports, flying at low altitudes while foraging in the airside area [19][18].

Both rock and wood pigeons are primarily sighted during daylight hours, from dawn to dusk during both the winter and summer season as shown in figures 4.3 and 4.4. There are roughly four times as many pigeons during the winter season compared to the summer season.

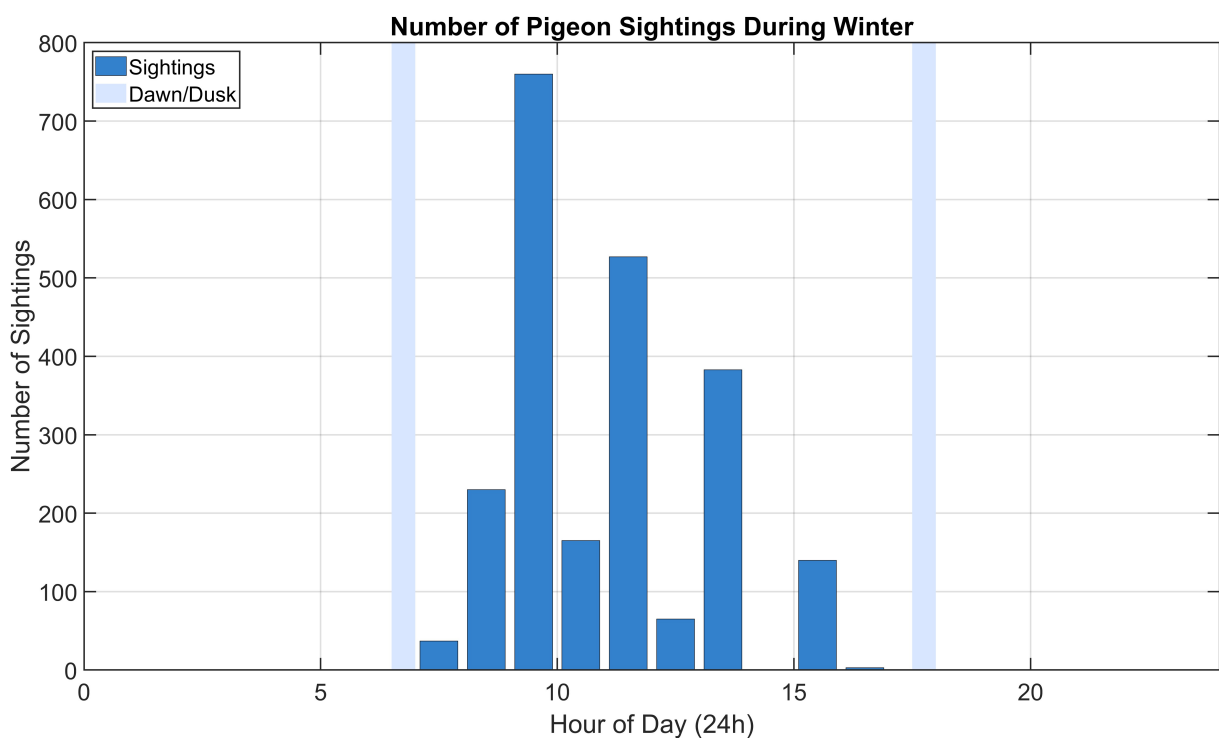


Figure 4.3: Rock and wood pigeon sightings at BGY in winter, aggregated in 5-minute intervals; shaded bands mark average winter nautical dawn and dusk.

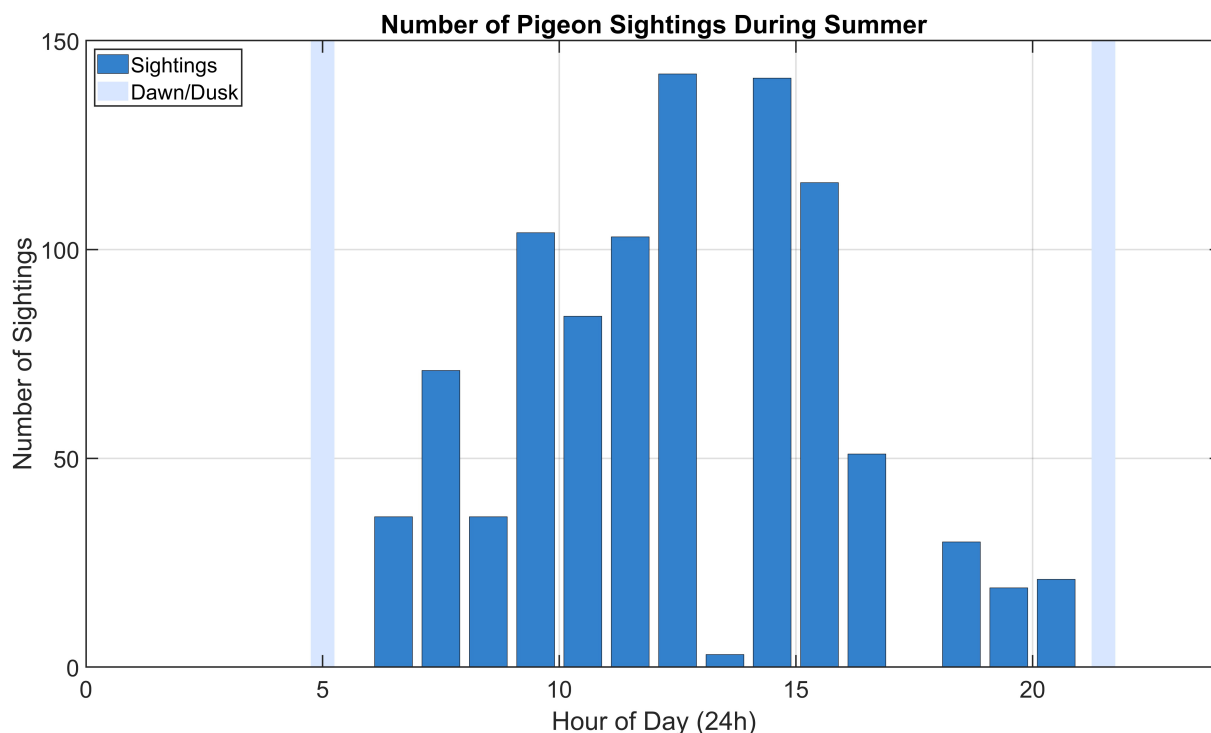


Figure 4.4: Rock and wood pigeon sightings at BGY in summer, aggregated in 5-minute intervals; shaded bands mark average summer nautical dawn and dusk.

4.2.2. Cattle Egret

The Cattle Egret (*Bubulcus ibis*) is a medium-sized heron that is present year-round at BGY. It has a compact, stocky body and a characteristic hunched posture. Outside of the breeding season, adults display mostly white plumage, while during breeding, they develop bright orange-yellow or buff feathers on their crown, lower back, and chest. Their legs are grayish-yellow in color [10]. Refer to Appendix B for images.

Cattle Egrets tend to migrate towards warmer coastal areas during the winter months, which results in a noticeable reduction in their numbers at BGY during this period. Figures 4.5 and 4.6 illustrate that the population of Cattle Egrets at BGY during winter is approximately half of what is observed in the summer. They are primarily sighted during daylight hours, from dawn to dusk.

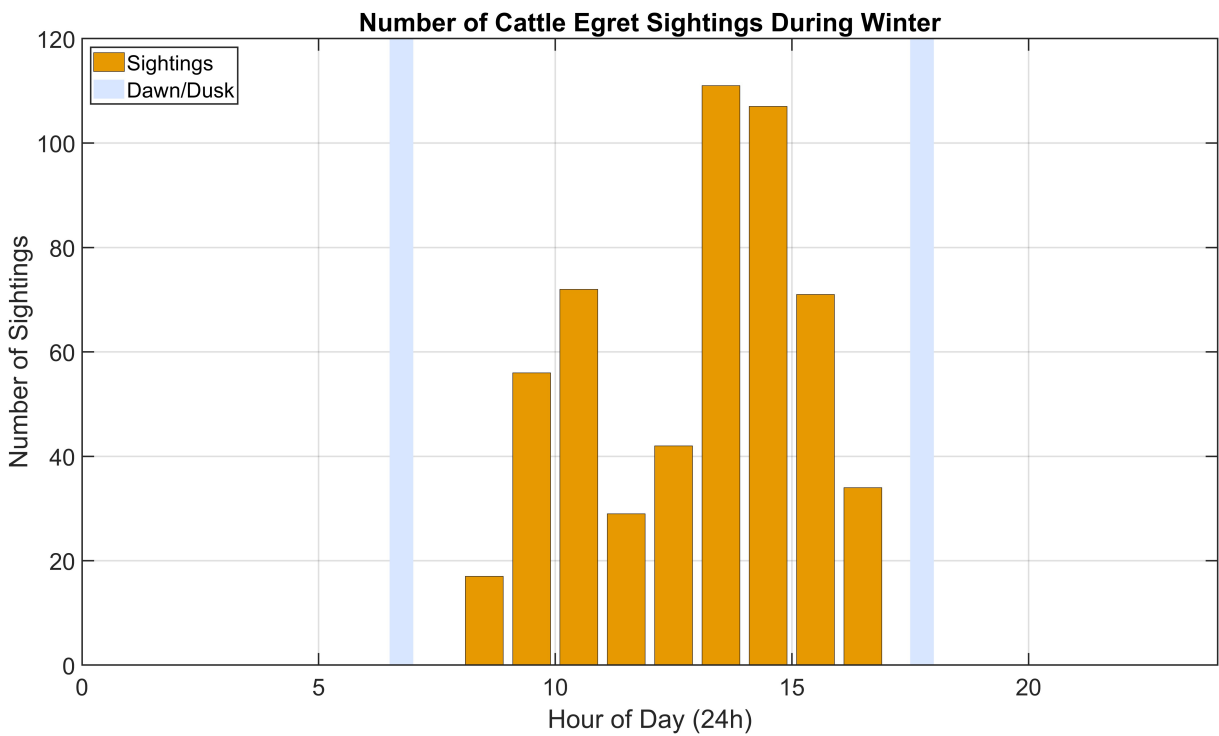


Figure 4.5: Cattle Egret sightings at BGY in winter, aggregated in 5-minute intervals; shaded bands mark average winter nautical dawn and dusk.

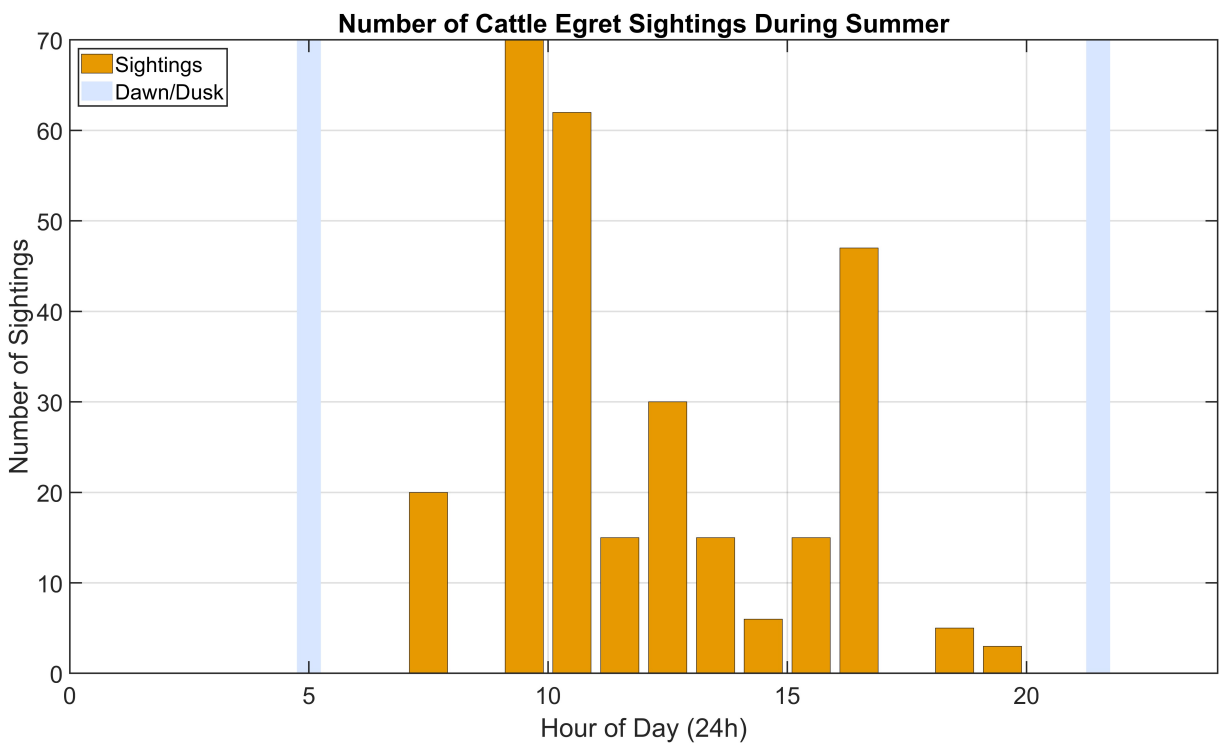


Figure 4.6: Cattle Egret sightings at BGY in summer, aggregated in 5-minute intervals; shaded bands mark average summer nautical dawn and dusk.

4.2.3. European Hare

The European Hare (*Lepus europaeus*), also known as the brown hare, is the largest hare native to Europe and can be found on and near the BGY airport grounds. It typically weighs between 3.5 and 5 kg and is characterized by long ears with black tips, brown fur with a white underside, and a tail that is black on top and white underneath. During winter, white patches begin to appear on the sides of the head and ears. Their body shape allows them to run at speeds of up to 56 kph with notable endurance [2]. Refer to Appendix B for images.

European Hares are primarily active around dawn and dusk. Although they may be sighted during the day, such occurrences are relatively infrequent. Figures 4.7 and 4.8 illustrate this activity pattern for both the winter and summer seasons, showing that hare sightings in winter are approximately half the number recorded in summer.

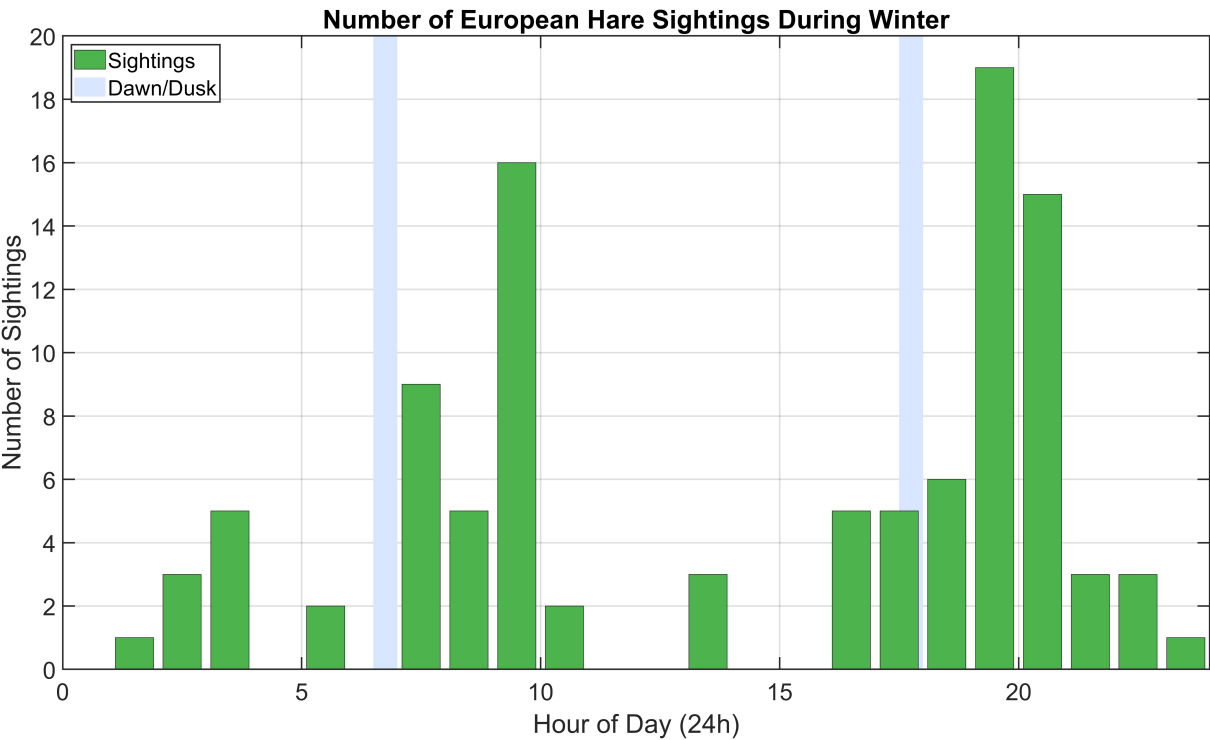


Figure 4.7: European Hare sightings at BGY in winter, aggregated in 5-minute intervals; shaded bands mark average winter nautical dawn and dusk.

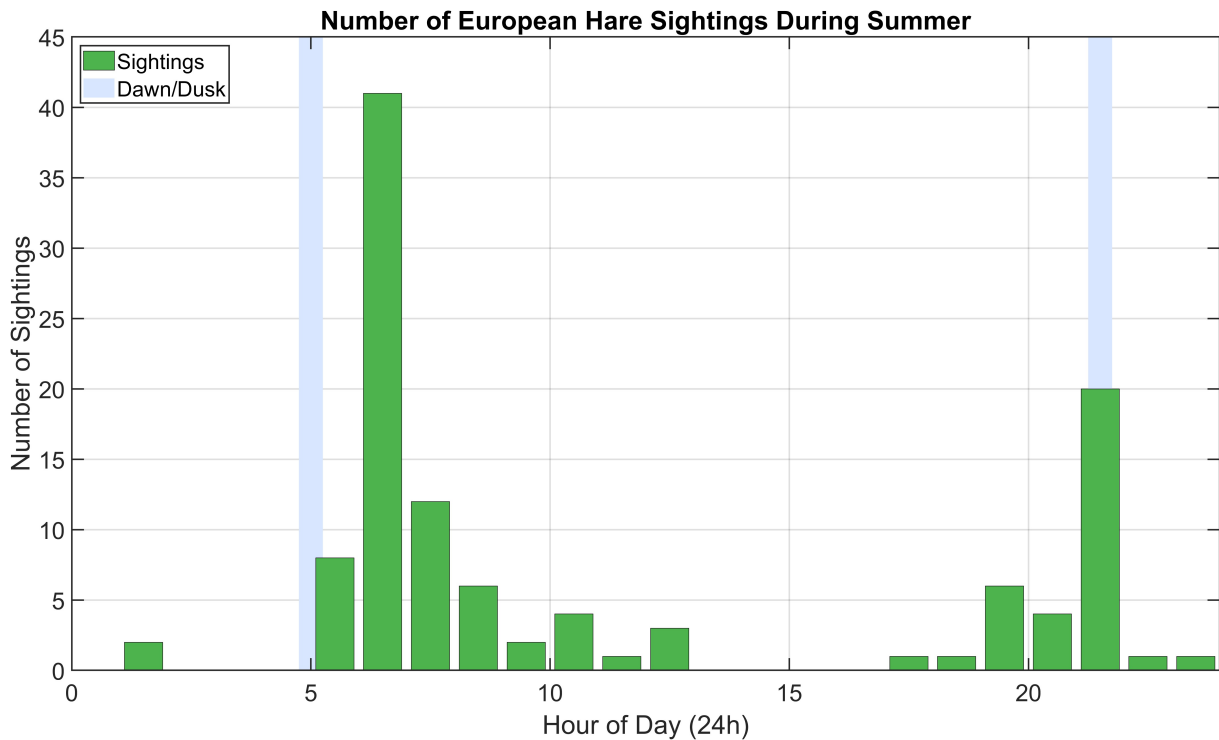


Figure 4.8: European Hare sightings at BGY in summer, aggregated in 5-minute intervals; shaded bands mark average summer nautical dawn and dusk.

4.2.4. Common Kestrel

The Common Kestrel (*Falco tinnunculus*), also known as the European kestrel, is a small to medium-sized falcon distinguished by its slim body, sharply pointed wings, and a long tail that fans out while the bird is hovering. Sexual dimorphism is apparent in this species: females and juveniles display predominantly brown plumage with barred tails and extensive spotting, whereas males are recognized by their bluish-grey head and tail—marked with a distinct black terminal band—brown back, yellow feet, and wings spotted with dark markings. Both sexes possess a noticeable malar stripe that extends from the eye downward. Refer to Appendix B for images.

The Common Kestrel is capable of remarkable flight control, allowing it to hover by flying into the wind at the same speed as the airflow. It uses its wings and tail to hold its position steadily in the air [23]. This hovering behavior is important for spotting prey from above, and the bird often hunts either by hovering or from exposed perches over open areas such as grasslands, farmland, and roadside verges

Figures 4.9 and 4.10 demonstrate that at BGY, the Common Kestrel is present throughout the year, with observed activity spanning from dusk to dawn. This continuous and

widespread activity pattern, combined with its adaptability to a range of open habitats—including modified environments like airfields—emphasizes the importance of incorporating targeted inspection and deterrence measures for kestrels within airside wildlife hazard management schedules.

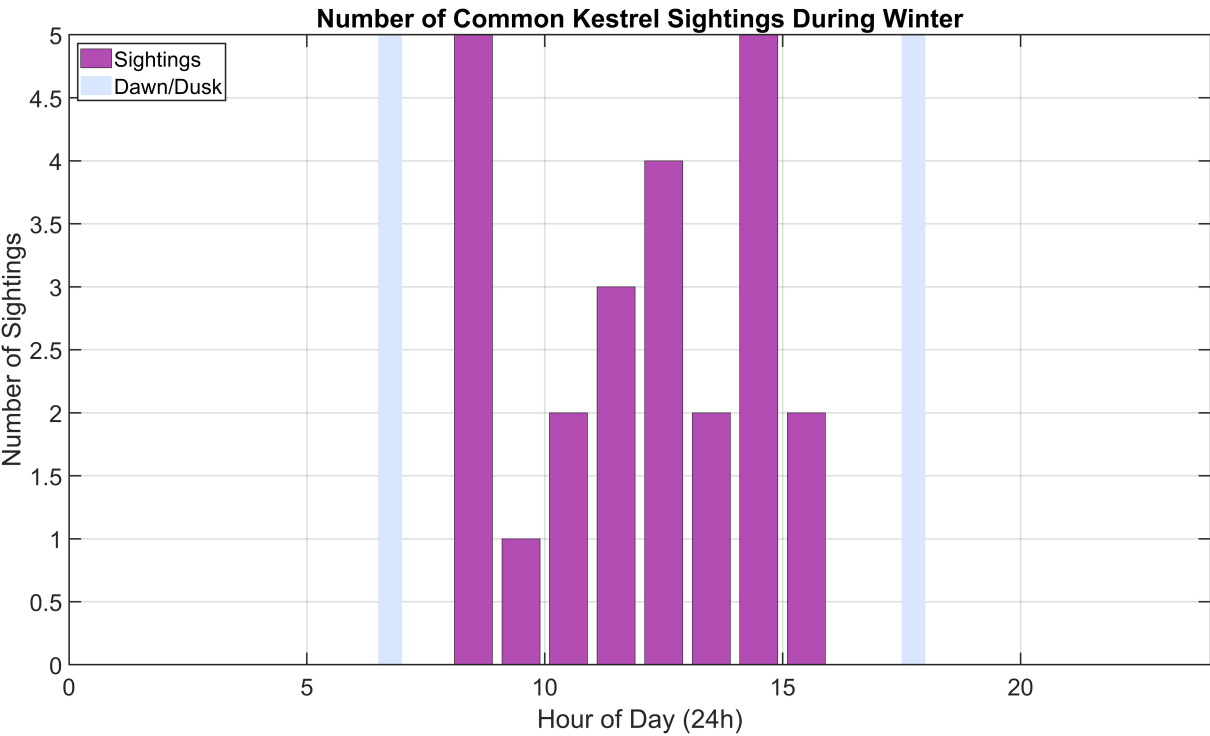


Figure 4.9: Common Kestrel sightings at BGY in winter, aggregated in 5-minute intervals; shaded bands mark average winter nautical dawn and dusk.

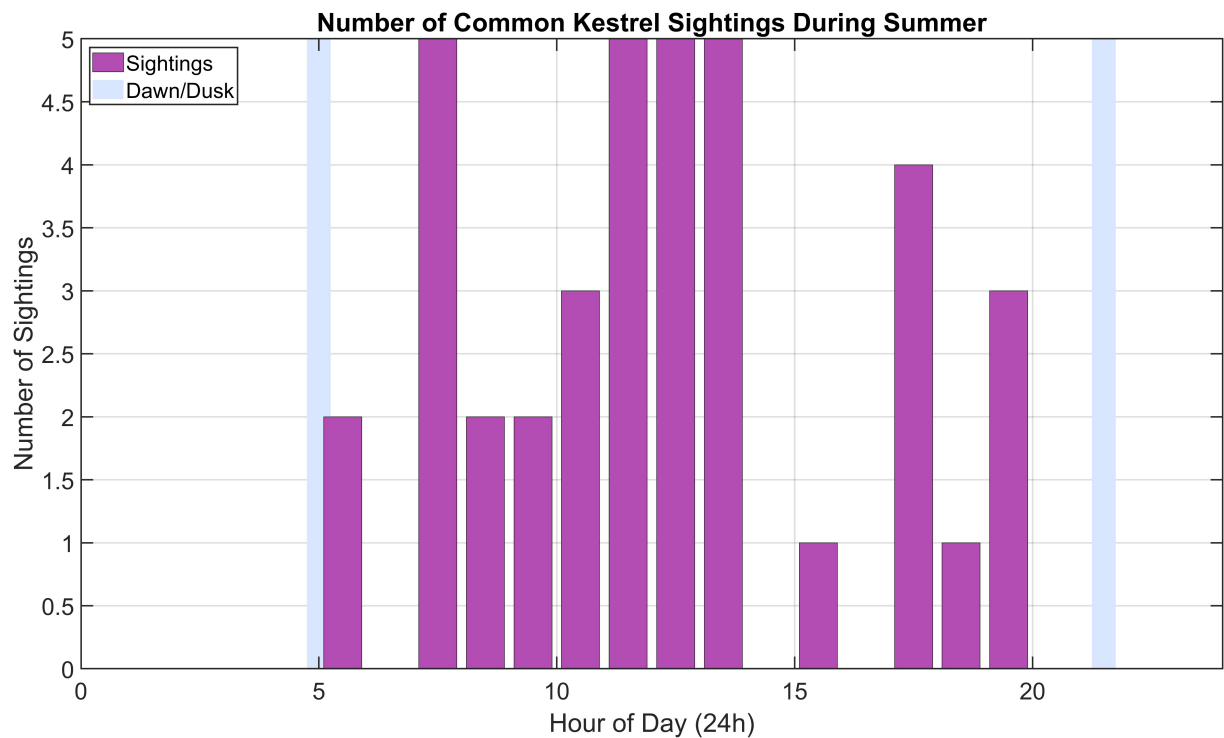


Figure 4.10: Common Kestrel sightings at BGY in summer, aggregated in 5-minute intervals; shaded bands mark average summer nautical dawn and dusk.

4.2.5. Combined Daily Activity of Key Strike Species

The four species most frequently involved in wildlife strikes at BGY—pigeons, Cattle Egret, European Hare, and Common Kestrel—show distinct but overlapping daily activity patterns. Figures 4.11 and 4.12 summarize their combined hourly distributions during the winter and summer seasons, respectively.

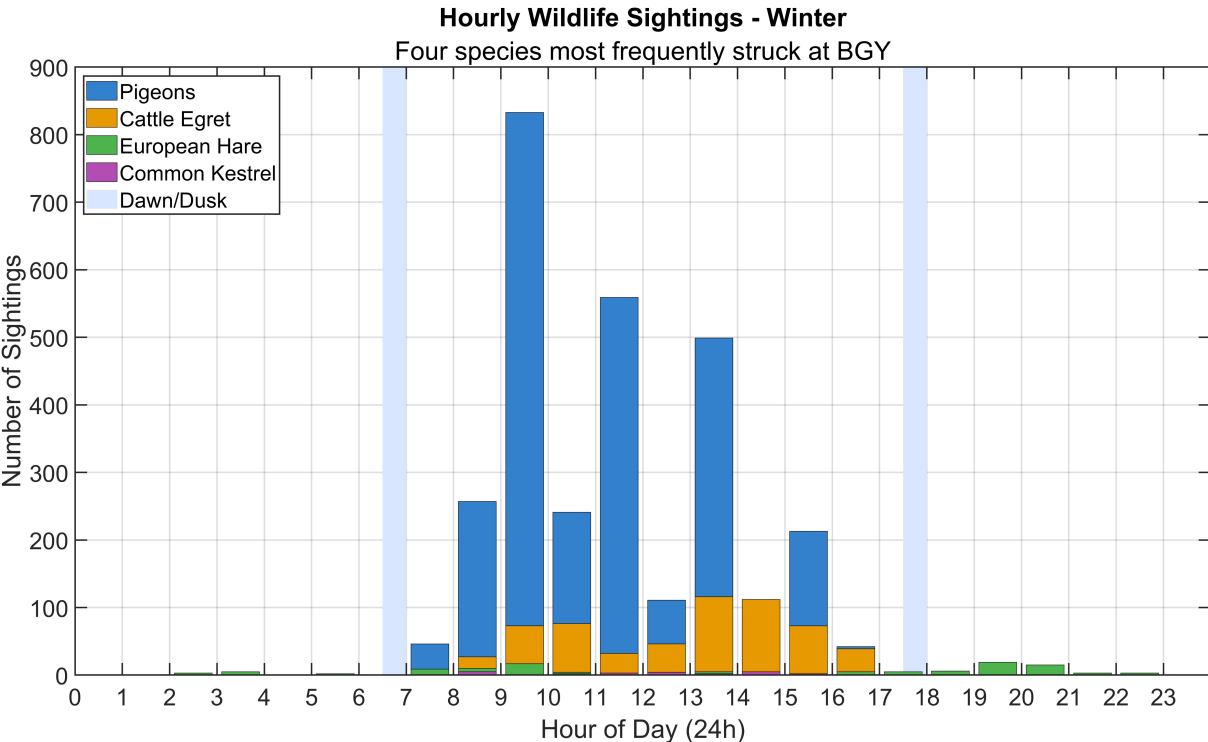


Figure 4.11: Hourly winter sightings at BGY for four key strike species; stacked bars by species, shaded bands mark average winter dawn and dusk.

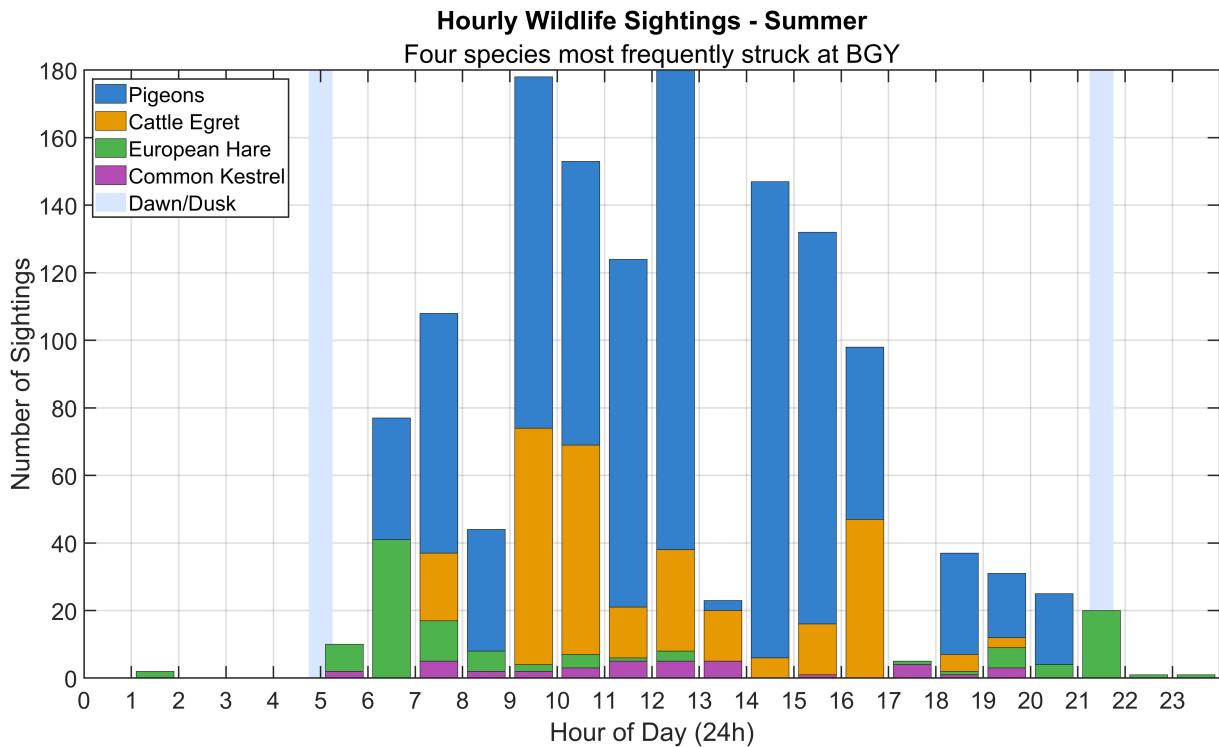


Figure 4.12: Hourly summer sightings at BGY for four key strike species; stacked bars by species, shaded bands mark average summer dawn and dusk.

The species profiled in this chapter, and their combined hourly patterns in Figures 4.11 and 4.12, exhibit distinct temporal and seasonal activity patterns that influence wildlife strike risk at different times of day and year. Diurnal species (pigeons, Cattle Egret, Common Kestrel) present higher risks during daylight operational hours, while crepuscular species (European Hare) are most active during dawn and dusk periods that coincide with peak departure and arrival waves described in Chapter 2. Summer months show greater overall wildlife diversity and strike frequency (48 strikes) compared to winter (15 strikes), though certain species such as the European Hare and Common Kestrel maintain consistent strike involvement year-round. These species-specific risk profiles, particularly the high activity during dawn and dusk periods, directly informed constraint development in Chapter 6. The optimization algorithm prioritizes runway inspection scheduling during these crepuscular windows when feasible, balancing wildlife hazard mitigation with operational traffic constraints described in Chapter 7.

5 | Flight Operations Data Analysis

5.1. Data Collection and Processing

Historical flight data from January 1, 2023 to October 25, 2025 were extracted from SACBO's internal database for analysis. The dataset included aircraft movements, taxi times, stand assignments, aircraft types, and operational timestamps. Additionally, hand-made seasonal airside inspection schedules were collected to serve as validation benchmarks for algorithm-generated schedules.

The analysis focused on taxi times as the primary filtering criterion, as these values represent the duration aircraft occupy the manoeuvring area - the critical parameter affecting inspection window availability. Movements affect inspection scheduling differently depending on the area: both departures and arrivals impact runway inspection times since both aircraft types utilize the runway, while ring inspections are primarily affected by departures as these operations involve extended taxiway usage. Analysis of the BGY dataset revealed that departing flights averaged 10-minute taxi times, while arriving flights averaged 5 minutes due to shorter taxi routes from runway to parking stand.

Data quality was ensured through outlier detection using MATLAB's `isoutlier` function, which identifies anomalous values exceeding three standard deviations from the mean [12]. This statistical filtering removed erroneous records caused by operational disruptions, system logging errors, or atypical aircraft handling procedures. Operational observations indicated that approximately 97% of aircraft at BGY are assigned by the COS (Coordinamento Operativo di Scalo - Operational Coordination Office) to Code C stands. To reflect the airport's operational reality and ensure model relevance, the dataset was filtered to include only aircraft types compatible with Code C stand classification. This subset primarily consists of narrow-body commercial aircraft including the Airbus A320 family, Boeing 737 variants, and regional jets from Embraer and Bombardier manufacturers (final filtered dataset is found in Appendix C).

5.2. Traffic Pattern Analysis

5.2.1. Temporal Distribution

Analysis includes 88,429 flights from October 27, 2024 through October 25, 2025, covering a complete winter season (Oct 27-Mar 29) and summer season (Mar 30-Oct 25) after outlier removal per Section 5.1. The busiest day of the week is Sunday across both seasons, with winter Sundays averaging 244 movements/day (n=22 days) and the least busy day being Wednesday with 158 movements/day (n=22 days), representing a 54% difference (Figure 5.1). Summer operations showed the same pattern with Sunday averaging 290 movements/day (n=30 days) and Wednesday 255 movements/day (n=30 days) (Figure 5.1). Absolute traffic increased across all weekdays from winter to summer, with Wednesday traffic alone rising 61%. These trends are shown in Figure 5.1.

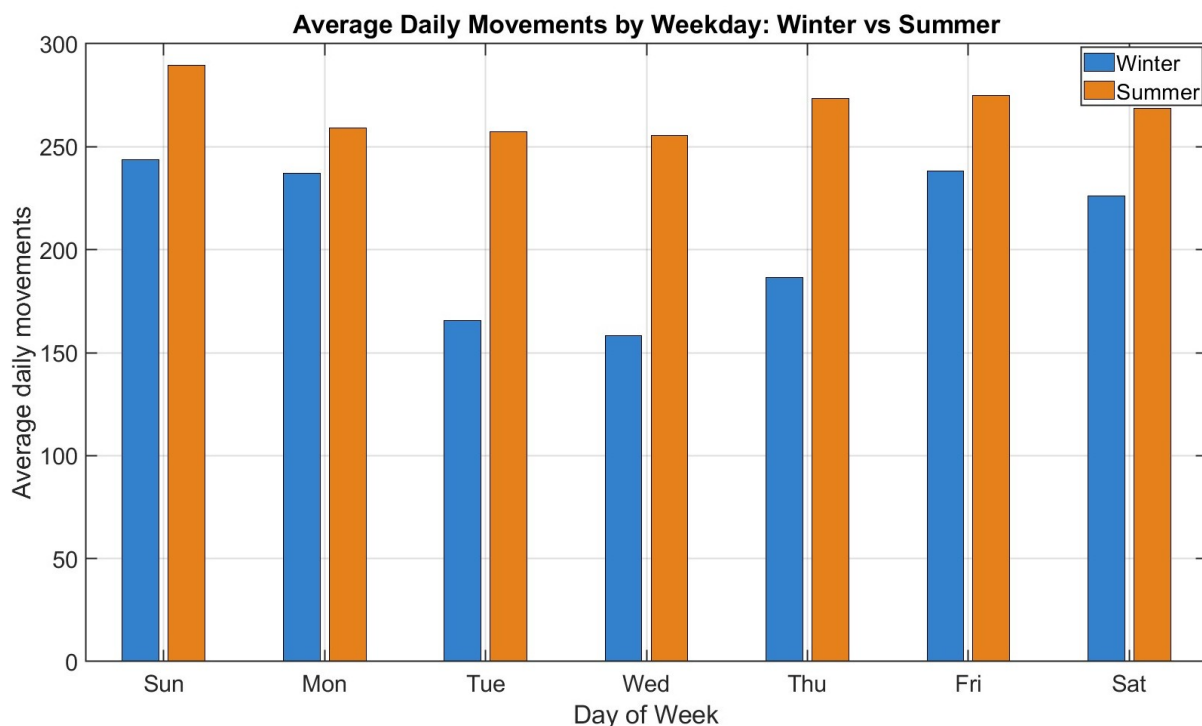


Figure 5.1: Average daily runway movements by weekday in winter and summer at BGY.

Across both seasonal profiles (Figures 5.2 and 5.3), traffic is distributed over most of the operating day rather than forming a single sharp peak. The clearest common features are a sustained build-up from the early morning, marked variability in the number of movements per 30-minute slot throughout the day on every weekday, and consistently low activity overnight. In winter, movements begin to rise rapidly after about 06:00 on all weekdays, with a broad morning shoulder extending into late morning and early afternoon,

followed by a gradual decline after roughly 21:00. Summer shows the same general pattern but with higher intensities across the active period and more pronounced late-evening activity, particularly between 19:00 and 22:00. The 00:00–05:00 window remains weakly populated in both seasons, confirming very low movement rates and providing a clear low-traffic opportunity for inspection activities.

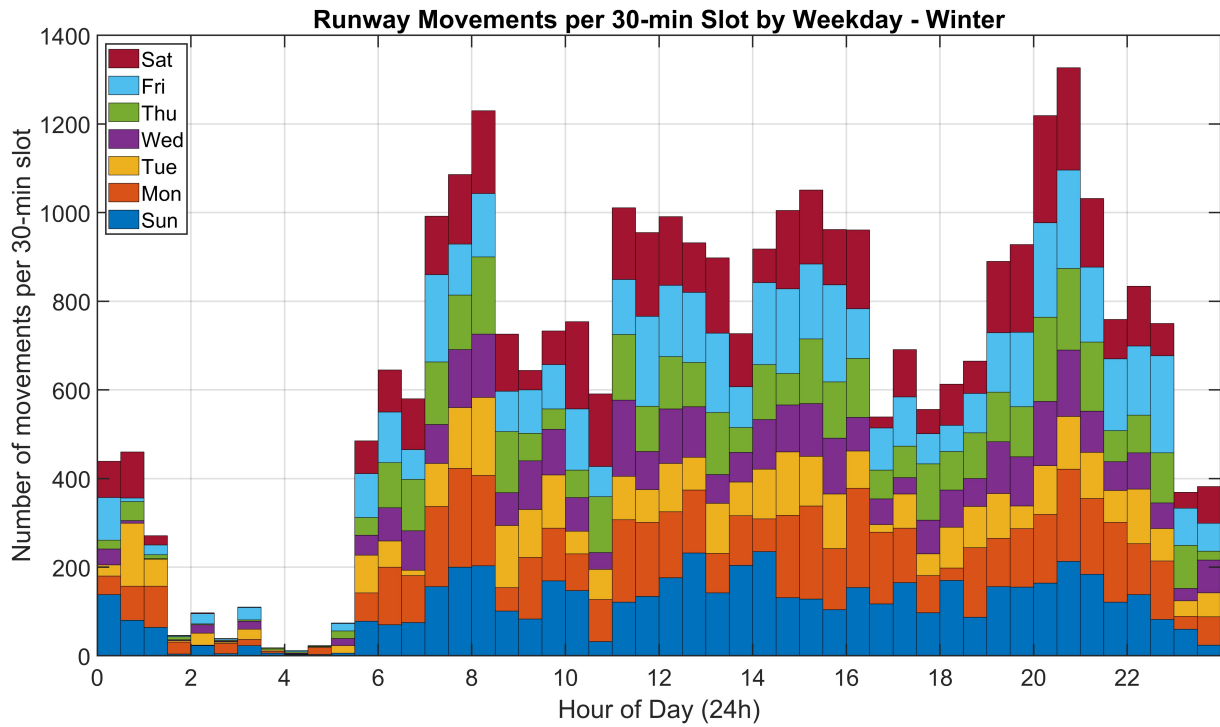


Figure 5.2: Total number of runway movements per 30-minute slot by weekday during the entire winter season; stacked bars show each weekday's contribution.

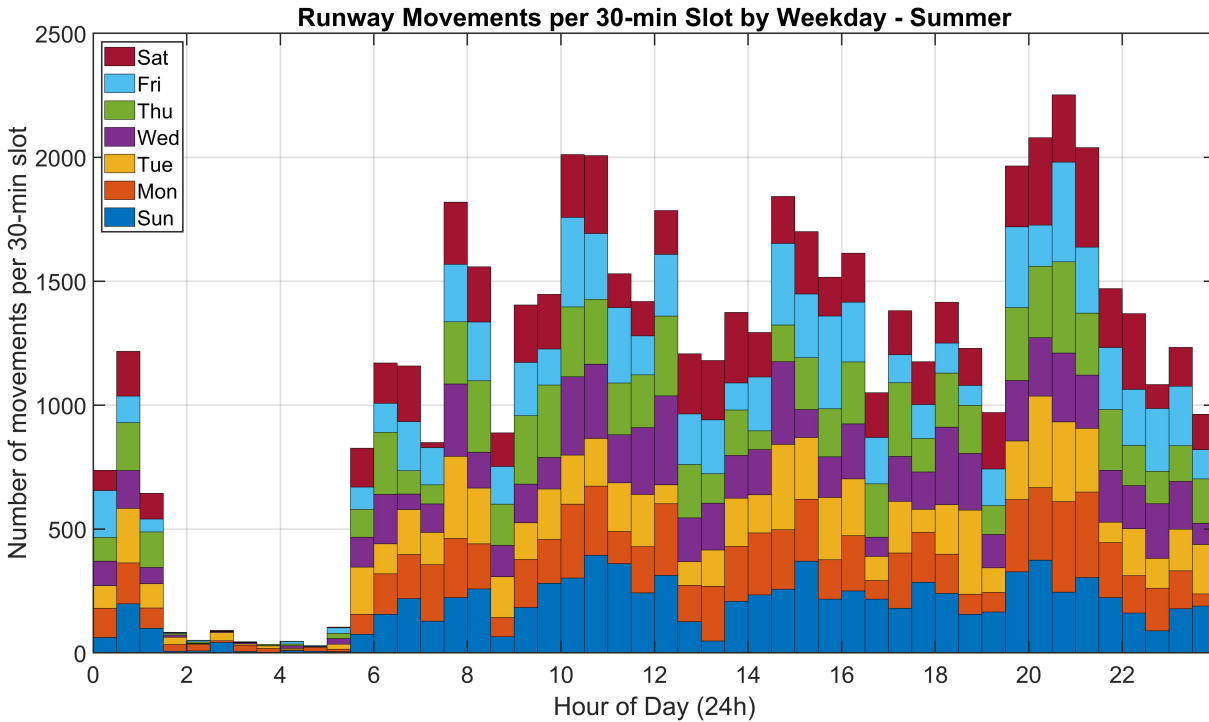


Figure 5.3: Total number of runway movements per 30-minute slot by weekday during the entire summer season; stacked bars show each weekday’s contribution..

Table 5.1 identifies specific 5-minute time slots sustaining high movement density, derived from the same underlying data as the 30-minute profiles in Figures 5.2 and 5.3. Winter operations show only 2 peak slots on Wednesdays and 5 on Sundays with 3 or more average movements per 5-minute interval, while summer operations demonstrate significantly more congestion with 9 peak slots on Wednesdays and 19 on Sundays. This reflects the seasonal increase in traffic concentration and its impact on inspection scheduling windows.

Table 5.1: Peak time slots sustaining ≥ 3 average movements per 5-minute interval on representative weekdays.

Season	Day	Peak Time Slots (≥ 3 avg movements)
Winter	Wednesday	07:50, 20:00
Winter	Sunday	07:25, 08:00, 12:40, 14:20, 21:45
Summer	Wednesday	07:45, 10:05, 10:20, 10:45, 12:20, 13:40, 18:00, 19:55, 21:00
Summer	Sunday	00:45, 06:00, 07:45, 09:50, 11:00, 11:25, 11:45, 12:10, 12:15, 14:15, 15:00, 15:10, 15:30, 17:40, 19:30, 20:00, 20:15, 21:00, 23:00

Seasonal comparison reveals differential growth patterns across weekdays. Wednesday traffic increased 61% from winter (158 movements/day, 9 movements/hour) to summer (255 movements/day, 14 movements/hour), while Sunday traffic increased only 19% from winter (244 movements/day, 14 movements/hour) to summer (290 movements/day, 16 movements/hour). This indicates that traditionally quiet days experience proportionally greater summer congestion, compressing inspection windows that were previously available during low-traffic periods. The seasonal effect is more pronounced on off-peak days, requiring inspection schedules to accommodate tighter constraints during summer Wednesdays than winter Sundays.

Peak period analysis quantifies temporal concentration of movements (Figures 2.2 and 2.3). Combined morning (06:00-09:00) and evening (18:00-21:00) peaks account for 34.0% of winter movements and 30.8% of summer movements, despite representing only 33.3% of the 18-hour operating day. Winter morning peaks average 11 movements/hour while evening peaks reach 12 movements/hour. Summer shows similar morning activity (12 movements/hour) but intensified evening operations (16 movements/hour), reflecting increased tourist arrivals. These concentrated periods create 86 extra movements on winter Sundays compared to Wednesdays, and 34 extra movements during summer Sundays, necessitating flexible inspection scheduling to accommodate weekly variability.

The overnight window (01:00-05:00) provides consistent low-traffic opportunities for extended inspections. This 5-hour period accounts for only 4.7% of winter movements and 5.3% of summer movements, with average rates of 2 movements/hour (winter) and 3 movements/hour (summer). This sustained low-density window enables runway inspections without significant operational disruption. Conversely, peak periods sustaining 11-16 movements/hour restrict inspection activities to rapid coordination with ATC during inter-movement gaps.

5.2.2. Aircraft Movement Characteristics

Taxi times establish the temporal footprint for runway and taxiway occupancy, directly determining when inspection activities can access the manoeuvring area. Departing aircraft averaged 10 minutes from parking stand to takeoff, while arrivals averaged 5 minutes from landing to parking stand assignment. This 2:1 asymmetry reflects pre-departure procedures including engine start, pushback coordination, and taxi queue management versus the expedited runway vacating prioritized for arrivals. Both departure and arrival operations impact runway inspection availability as aircraft occupy the runway environment during their respective phases, while ring inspections are primarily constrained by

departing traffic traversing the taxiway network.

Movement density analysis reveals the distribution of operational intensity across the daily operating period. Winter operations show a peak-to-off-peak ratio of 1.03, indicating relatively uniform traffic distribution throughout active hours with modest concentration during traditional peak windows. Summer operations demonstrate a peak-to-off-peak ratio of 0.89, suggesting that increased midday traffic during tourist season actually flattens the typical bimodal pattern, creating more consistent occupancy throughout daytime operations. This shift has significant implications for inspection scheduling: winter schedules can exploit pronounced off-peak calmness, while summer schedules must accommodate sustained moderate-density traffic with fewer extended low-activity windows.

The temporal spacing between consecutive movements quantifies natural inspection opportunities within the traffic flow. Inter-movement gaps suitable for ring inspections (≥ 30 minutes including buffer times) occur more frequently during winter operations when overall traffic density is lower. Summer operations compress these gaps, particularly during midday periods that historically provided inspection windows. The concentration of high-density 5-minute slots (Table 5.1) during summer operations—9 slots on Wednesdays versus 2 in winter—illustrates this compression effect. Extended runway inspections requiring short closures with ATC coordination remain feasible primarily during the overnight window (00:00-05:00) - which no inspections occur either way due to airport operation regulations - and sporadic midday calmness, with summer midday opportunities significantly reduced compared to winter availability.

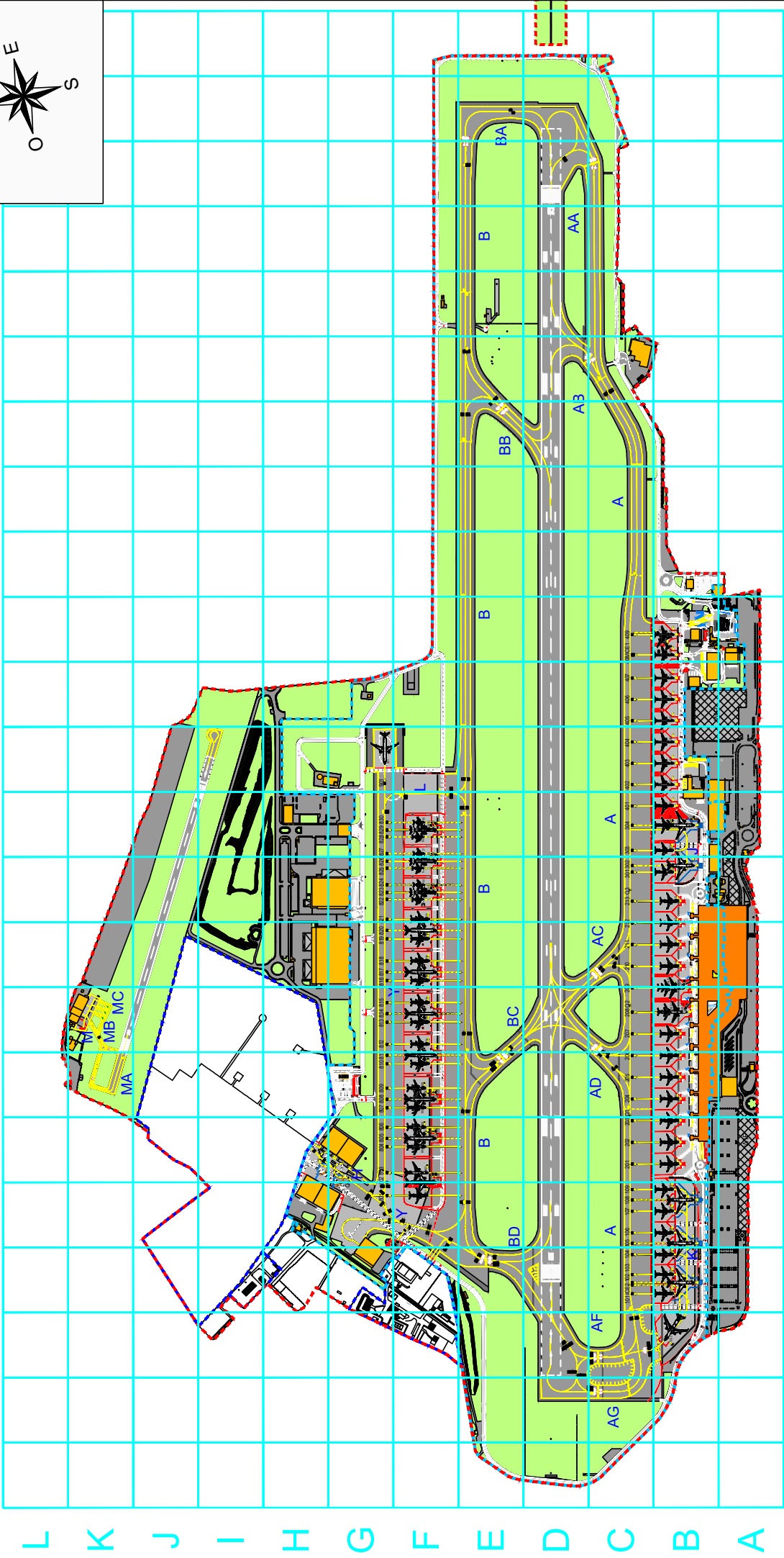
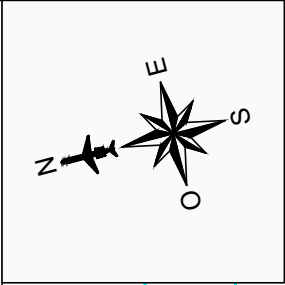
Flow patterns demonstrate systematic temporal clustering that inspection schedules must accommodate. Morning operations (06:00-09:00) generate departure-heavy traffic as aircraft positioned overnight begin daily rotations, creating sustained taxiway and runway occupancy that restricts ring and runway inspection route access. Evening operations (18:00-21:00) show arrival concentration as aircraft complete final daily rotations, impacting runway availability but clearing taxiways more rapidly.

5.3. Flight-Wildlife Correlation Analysis

5.3.1. Wildlife Monitoring System and Activity Patterns

Wildlife hazard monitoring at BGY employs a GPS-enabled mobile application system used by airside inspectors during all inspection activities. The application automatically records observation time and location using a grid-based coordinate system (refer to figure on page 48), while inspectors manually input environmental conditions and mark

wildlife locations on an interactive airport map. Each observation is assigned a risk coefficient through an automated algorithm that considers species type, quantity, location, and behavioral patterns. Medium and high-risk detections trigger mandatory re-inspection protocols and immediate ATC notification for potential hazard mitigation.



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

The dataset encompasses 1,363 wildlife observations from January 1, 2023 through October 28, 2025, with 464 observations during the winter season (Oct 27, 2024 - Mar 29, 2025) and 899 observations during summer (Mar 30 - Oct 25, 2025). This 94% increase in summer observations reflects heightened wildlife activity during warmer months and increased inspection frequency during peak operational periods. Wildlife strikes totaled 316 incidents across the complete study period, with 34 winter strikes and 74 summer strikes during the analyzed seasons, representing a 118% seasonal increase that parallels the elevated observation frequency.

5.3.2. Spatial and Risk Distribution

Spatial analysis reveals concentrated wildlife activity in specific airport zones (Figure 5.4). Grassy areas (“Erba”) account for 81.0% of winter observations (376 detections) and 81.1% of summer observations (729 detections), representing the primary wildlife habitat zone requiring continuous monitoring. Airborne observations (“In volo”) constitute 6.0% of winter and 9.9% of summer detections, indicating increased bird activity during warmer months. Critical operational zones show lower but significant activity: manoeuvring areas (4.5% winter, 3.6% summer), perimeter zones (3.2% winter, 3.0% summer), and runway environments (2.2% winter, 0.8% summer). The decreased runway observations during summer (10 winter detections to 7 summer) despite higher overall activity likely reflects either higher traffic density deterring wildlife presence or compressed inspection windows limiting detection opportunities.

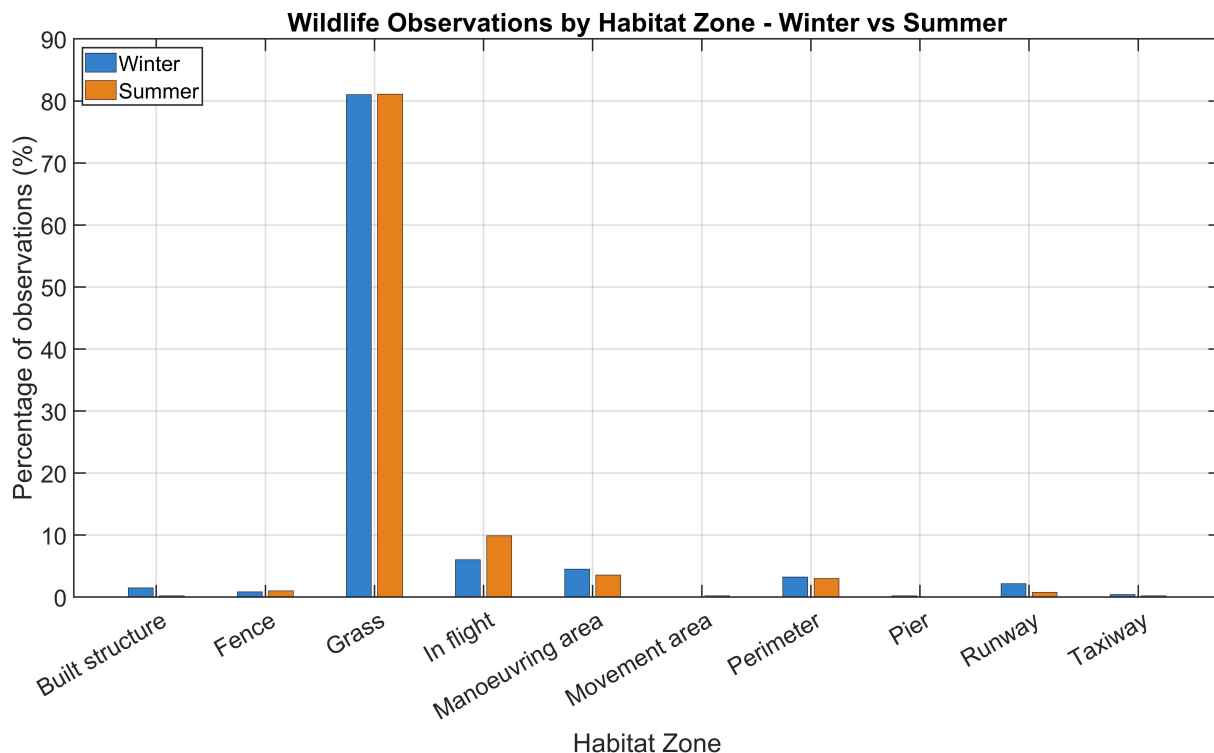


Figure 5.4: Wildlife observation distribution by airport habitat zones in winter and summer.

Risk coefficient distribution demonstrates predominantly low-level wildlife activity with occasional high-risk encounters. Winter observations show 74.1% low risk (coefficient <0.05), 18.3% medium risk (0.05-0.15), and 7.5% high risk (>0.15), while summer demonstrates 89.0% low, 7.3% medium, and 3.7% high risk encounters. The shift toward lower-risk observations in summer (74.1% to 89.0% low-risk) despite doubled strike incidents (34 to 74) suggests that increased inspection frequency during high-traffic periods captures more routine wildlife presence, while the absolute count of high-risk encounters remains consistent (35 winter vs. 33 summer). Maximum recorded risk coefficients remained under the BRI_2 of 0.5 (section 3.5.2) in both seasons, meeting ENAC requirements. The continuous spectrum of risk values enables nuanced inspection prioritization rather than binary hazard classification.

5.3.3. Temporal Patterns and Flight Operation Overlap

Hourly wildlife activity patterns reveal distinct temporal clustering with significant seasonal variations. Winter wildlife activity (Figure 4.11) peaks at 09:00 with 65 observations, while summer activity (Figure 4.12) peaks at 11:00 with 105 observations. Dawn periods (06:00-08:00) account for 6.9% of winter observations (32 detections) but 15.9% of sum-

mer observations (143 detections), while dusk periods (18:00-20:00) increase from 3.2% in winter (15 observations) to 11.8% in summer (106 observations). This pronounced summer dawn/dusk activity aligns with avian behavioral patterns during extended daylight hours and warmer temperatures, with combined dawn/dusk periods representing 27.7% of summer wildlife presence compared to only 10.1% in winter.

Critical overlap between high-traffic flight operations and wildlife activity creates compound risk windows requiring prioritized inspection attention (Figure 5.5). Flight peak periods (06:00-09:00 and 18:00-21:00) coincide with 23.5% of winter wildlife observations (109 detections) and 36.6% of summer observations (329 detections). Summer overlap is particularly pronounced, with dawn flight departures (06:00-09:00 averaging 11.8 flight movements/hour) occurring simultaneously with 192 wildlife observations (21.4% of summer total). Similarly, evening flight arrivals (18:00-21:00 averaging 15.7 movements/hour) align with 137 wildlife detections (15.2%). Medium and high-risk wildlife encounters (risk coefficient ≥ 0.5) during these flight peak windows totaled 12 in winter and 19 in summer, representing periods where both collision probability and operational disruption potential are maximized.

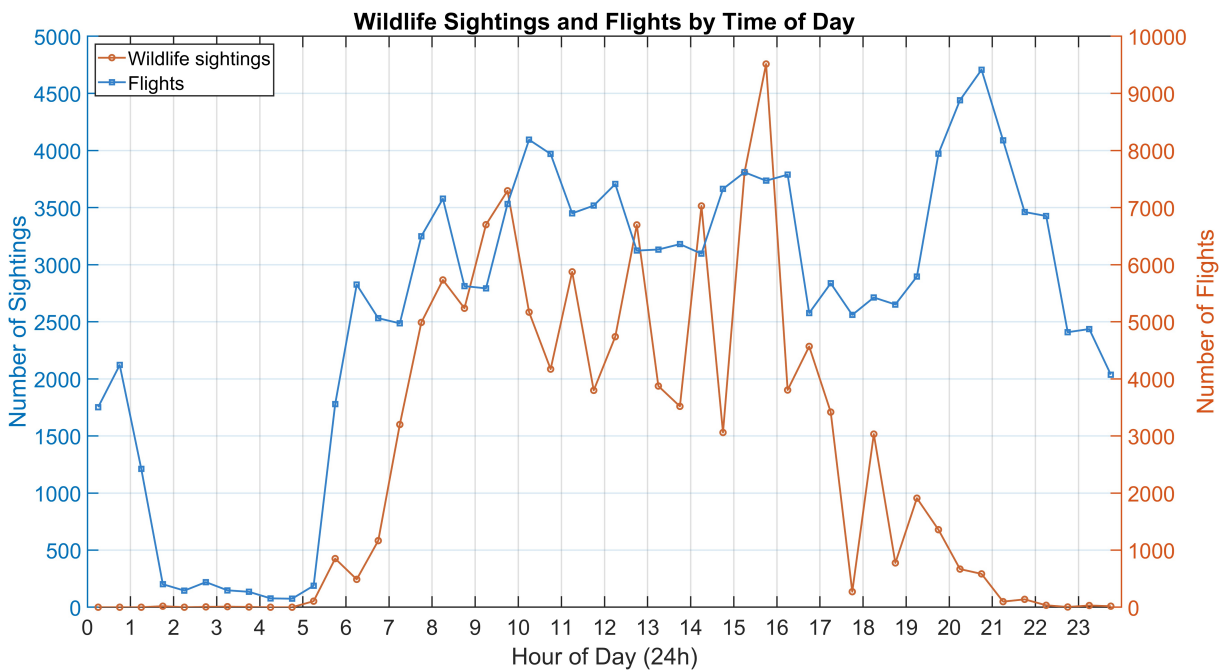


Figure 5.5: Wildlife sightings and flight movements at BGY by time of day (30-minute intervals), highlighting periods of peak temporal overlap between wildlife activity and scheduled operations.

Conversely, overnight periods (01:00-05:00) demonstrate minimal wildlife activity mirroring low flight traffic (Figure 5.5), with only 7 winter observations (1.5%) and 7 summer

observations (0.8%), as previously regulations called for inspections during these hours. This temporal alignment of low traffic and low wildlife presence during overnight hours validates the Milan Bergamo operations regulations of completing mandatory inspections right before and right after the night period.

5.3.4. Critical Intervention Period Identification

Integration of flight movement density and wildlife activity patterns identifies time-specific risk profiles requiring tailored inspection strategies. Summer morning operations (07:00-11:00) emerge as the highest-risk period, sustaining elevated flight traffic (11-14 movements/hour from Chapter 2), peak wildlife presence (318 observations, 35.4% of summer total), and compressed inspection windows. Winter mid-morning periods (08:00-10:00) similarly concentrate both flight and wildlife activity with 119 observations (25.6% of winter total), though at lower absolute magnitudes than summer operations.

Dawn and dusk periods warrant mandatory inspection designation due to convergent operational and biological factors. These periods exhibit heightened wildlife activity (22.8% of summer observations, 10.1% of winter) and correspond with visual detection challenges from low sun angles and transitional lighting conditions. The summer dawn period (06:00-08:00) combines 143 wildlife observations, 12 average flight movements/hour, and reduced visibility—creating compounded hazard conditions that justify ENAC’s mandatory dawn inspection requirements referenced in Chapter 6’s optimization constraints.

Midday periods (11:00–15:00) exhibit distinct seasonal behavior. In winter, 159 observations (34.3%) occur under moderate flight traffic, whereas summer records 218 observations (24.2%) with slightly reduced intensity relative to peak hours. These windows therefore represent feasible inspection opportunities, where wildlife monitoring remains important while coordination constraints are less restrictive than during morning and evening peaks.

Empirical overlap analysis shows that 36.6% of summer wildlife observations occur during periods exceeding 11 flight movements per hour, with 3.2% of all observations (19 of 329 summer peak detections) classified as medium- or high-risk encounters coinciding with peak operations. This correlation motivates the risk-weighted inspection scheduling approach developed in Chapter 7, which jointly accounts for operational disruption and safety criticality. Furthermore, the 118% increase in wildlife strikes from winter (34) to summer (74), despite only a 94% rise in observations, indicates that compressed high-density summer traffic elevates strike probability beyond simple exposure effects, reinforcing the need to prioritize inspections during these critical overlap windows.

6 | Scheduling Problem Formulation

6.1. Problem Definition

The objective of inspection scheduling at Milan Bergamo Airport is to maximize inspection coverage while minimizing disruption to flight operations. BGY aims to conduct inspections while experiencing the least number of interruptions by ATC. ENAC compliance requires a minimum of 14 inspections per day with at least one of each kind of inspection [7].

SACBO operates as a mediator between ENAC and ENAV, balancing competing regulatory priorities. If ENAC could, they would require only runway inspections to maximize safety monitoring in high-risk areas. Conversely, if ENAV could, they would eliminate runway inspections entirely to avoid operational disruptions. SACBO works to create a schedule that meets ENAC requirements while finding the balance between ENAC and ENAV for the best possible operational schedule.

The scheduling framework operates over a single operational day discretized into 5-minute time slots from 0 to 287, accommodating three inspection types: runway, ring, and perimeter (Inspection routes located on pages 2, 3, and 4). This schedule must avoid the night hours, as inspections are not completed during this time. For BGY, the night period is defined as 01:30 to 05:00, though the algorithm is flexible and allows the user to modify this time window. Inspections must also not begin during shift changes, nor within 30 minutes before the end of a shift, nor within 10 minutes after the start of a shift. This ensures that every worker does not exceed their assigned shift duration, and has a buffer time to settle into the start of their shift. At BGY, shift changes occur at 07:00, 15:00, and 23:00, creating three eight-hour shifts.

To maintain safety as a priority and minimize the interruption of an inspection by ATC as much as possible, runway and ring inspections follow additional movement-based constraints. The runway inspection can be interrupted when both the runway and the taxiway

are occupied by either arrivals or departures. The algorithm examines each 5-minute slot and its neighborhood—in this case, one slot to the left and one slot to the right of the selected slot. The algorithm checks whether the slot or its neighbors contain two or more movements. Both the movement threshold and the number of adjacent slots to examine are user-configurable inputs. This concept is also applied to ring inspection constraints, except the algorithm only considers departures, as departures predominantly affect ring inspections due to their extended taxiway occupancy time.

During ring and runway inspections, the inspector must call ATC to obtain permission to enter the taxiway and again to enter the runway when needed. Depending on the ATC controller, the inspector may be instructed to hold before entering the taxiway, permitted to proceed only when no other aircraft occupy the taxiway, or cleared to move at a safe distance behind taxiing aircraft. The movement-based constraints described previously—minimum movement thresholds for runway inspections and minimum departure thresholds for ring inspections—are designed to minimize the frequency with which ATC instructs BCU inspectors to hold, thereby reducing inspection delays and interruptions.

This problem formulation establishes the operational and regulatory framework within which feasible inspection schedules must be constructed. The mathematical representation of these constraints and the solution methodology are detailed in Chapters 6 and 7, respectively.

6.2. Mathematical Model

The inspection scheduling problem is formulated as a constraint-satisfaction model operating over discrete time intervals. This approach utilizes a greedy heuristic that prioritizes inspection types based on operational criticality while satisfying hard constraints related to temporal feasibility, movement thresholds, and resource availability. This section defines the decision variables, objective function, and constraint structure that govern the scheduling algorithm. A complete nomenclature table mapping mathematical symbols to MATLAB implementation variables is provided in E.

6.2.1. Decision Variables

The algorithm operates on implicit binary decision variables of the form:

$$x_{t,i} \in \{0, 1\} \quad \forall t \in \{0, 1, \dots, 287\}, \quad i \in \{1, 2, 3\}$$

where $x_{t,i} = 1$ indicates that an inspection of type i begins at time slot t , and $x_{t,i} = 0$ otherwise. The inspection type index i corresponds to:

- $i = 1$: Runway inspection
- $i = 2$: Ring inspection
- $i = 3$: Perimeter inspection

Time slot t represents a 5-minute discrete interval within the operational day, indexed from 0 (00:00) to 287 (23:55). The 5-minute discretization was selected because more than 99% of flights at BGY are scheduled to arrive or depart during such intervals, and because inspection durations are no more than 25 minutes in length, this level of detail allows the algorithm to evaluate candidate slots efficiently with manageable data volumes per slot.

6.2.2. Objective Function

The objective of the scheduling problem is to maximize total inspection coverage across three operational zones while respecting user-defined limits and operational constraints. Unlike traditional multi-objective formulations that balance competing objectives through weighted sum or Pareto-optimal approaches, this model employs a greedy priority-based heuristic that reflects the relative criticality of each inspection type.

All three inspection types are operationally important for wildlife hazard management at BGY. The runway inspection is the most critical, as the runway is the highest-risk zone where wildlife strikes are most likely to occur during takeoff and landing operations. The ring inspection is the second most critical, as it covers the two taxiways (A and B) at BGY, ensuring no wildlife is present in areas where aircraft taxi in and out. The third inspection, the perimeter inspection, monitors the airport's outer boundaries to detect wildlife approaching or migrating toward the manoeuvring area, allowing for early intervention before animals enter high-risk zones.

Given these inspection criticalities, the algorithm assigns fixed priority scores p_i to each inspection type:

1. Runway inspections: $p_1 = 3$ (most critical)
2. Ring inspections: $p_2 = 2$ (medium criticality)
3. Perimeter inspections: $p_3 = 1$ (least critical)

The objective is not to maximize the absolute number of runway inspections at the ex-

pense of ring and perimeter coverage, but rather to maximize runway inspection frequency within user-specified bounds while ensuring that all three inspection types achieve minimum required coverage. This formulation prevents degenerate solutions in which the algorithm schedules only runway inspections, which would leave taxiway and perimeter zones unmonitored and violate ENAC's requirement for at least one inspection of each type per day.

The greedy selection process operates as follows: the algorithm first identifies all feasible start times for each inspection type based on temporal, movement-based, and overlap constraints (detailed in Section 7.6). Each feasible candidate is assigned its corresponding priority score p_i . The algorithm then iterates through candidates in descending score order, selecting the highest-priority feasible inspection at each iteration and updating the occupied time slot mask M_{occupied} to prevent overlaps. This process continues until no additional feasible candidates remain or all inspection types have reached their user-defined maximum limits $n_{\text{max},i}$.

The greedy approach was selected instead of an exact mathematical programming method for several reasons. First, it offers the level of computational speed needed for real-time or near-real-time scheduling, the more candidate start times, the longer it takes to run. Second, the greedy heuristic is easier for BCU operators to interpret: they can see how inspections are prioritized and can adjust user-configurable settings (such as minimum inspection counts $n_{\text{min},i}$ and maximum inspection counts $n_{\text{max},i}$) without needing detailed knowledge of optimization theory. Third, field observations and discussions with BCU personnel showed that their operational preferences, such as avoiding many consecutive inspections of the same type, are more naturally expressed as minimum gap requirements between inspections than as a weighted penalty that subtracts from the objective function.

6.2.3. Constraints

The scheduling algorithm incorporates multiple constraint categories that reflect temporal restrictions, inspection-specific operational requirements, movement-based feasibility conditions, and regulatory mandates. These constraints are enforced through binary masks and feasibility checks during the greedy candidate selection process.

Temporal Constraints

The operational day is divided into 288 discrete time slots, each representing a five-minute interval, indexed from 0 to 287. Within this structure, certain time periods forbid inspections to start due to operational or regulatory limitations.

Night no-inspection period. Inspections may not begin during the airport night hours, defined by user-configurable input T_{night} , which is converted to slot indices $t_{\text{night_start}}$ and $t_{\text{night_end}}$. At BGY this period is set to 01:30–05:30 (slots 18–66), though the algorithm allows the user to change these hours for different operational contexts.

Shift change buffers. To prevent scenarios in which inspectors would exceed their assigned shift duration and to provide adequate preparation time for the first inspection during a shift, inspections may not begin within Δt_{end} slots before a shift ends or within Δt_{start} slots after a shift starts. At BGY, shift transitions occur at 07:00, 15:00, and 23:00. The buffer parameters are set to $\Delta t_{\text{end}} = 6$ slots (30 minutes) and $\Delta t_{\text{start}} = 2$ slots (10 minutes).

These temporal restrictions are encoded in a binary mask $M_{\text{forbidden}}$ of length 288, where $M_{\text{forbidden}}(t) = 1$ indicates that slot t is forbidden for inspection initiation. The algorithm allows the user to change these values for different operational contexts.

Inspection-Specific Duration and Buffer Constraints

Each inspection type i has a defined body duration d_i representing the time required to complete the inspection route, and a post-inspection buffer b_i representing the minimum separation time before another inspection can begin. This buffer provides the inspector time for any repeat inspection, wildlife deterrence actions, or waiting for ATC approval before entering manoeuvring areas. These parameters are user-configurable and set as follows at BGY:

- Runway: $d_1 = 2$ slots (10 minutes), $b_1 = 9$ slots (45 minutes)
- Ring: $d_2 = 5$ slots (25 minutes), $b_2 = 9$ slots (45 minutes)
- Perimeter: $d_3 = 5$ slots (25 minutes), $b_3 = 6$ slots (30 minutes)

When an inspection of type i is scheduled to begin at slot t , the algorithm blocks slots $[t, t + d_i + b_i - 1]$ in the global occupancy mask M_{occupied} , preventing any subsequent inspection from overlapping this body-plus-buffer window. This ensures that only one inspection occurs at a time, respecting the staffing constraint that there is only one inspector per shift.

Movement-Based Feasibility Constraints

To minimize the likelihood of ATC interrupting inspections, runway and ring inspections are subject to movement threshold constraints based on historical flight data.

Runway movement threshold constraint. A runway inspection may only begin at slot t if the total number of aircraft movements (arrivals plus departures) in slot t and its adjacent slots does not exceed a user-defined threshold. Let w_1 define the adjacency window size and τ_1 define the movement threshold. Then a runway inspection is feasible at slot t only if:

$$\max_{s \in [t-w_1, t+w_1]} m(s) \leq \tau_1$$

where $m(s)$ denotes the total number of arrivals and departures scheduled in slot s . At BGY, default parameters are $w_1 = 1$ (examining one slot before and after the candidate slot) and $\tau_1 = 2$ movements. Slots violating this constraint are marked in the binary mask $M_{1,\text{mov}}$.

Additionally, the runway inspection body itself (duration $d_1 = 2$ slots) must contain no more than a specified movement threshold $\tau_{1,\text{body}}$ within its duration. At BGY, this is set to $\tau_{1,\text{body}} = 0$, requiring that both slots of the runway inspection body contain no scheduled aircraft movements.

Ring departure threshold constraint. Ring inspections are constrained based solely on departure counts $m_{\text{dep}}(s)$, as departing aircraft occupy taxiways for extended periods during taxi-out and queue formation. A ring inspection may only begin at slot t if the number of departures in slot t and its adjacent slots does not exceed threshold τ_2 . Formally, with adjacency window w_2 :

$$\max_{s \in [t-w_2, t+w_2]} m_{\text{dep}}(s) \leq \tau_2$$

Default parameters are $w_2 = 2$ slots and $\tau_2 = 2$ departures. Violating slots are marked in the binary mask $M_{2,\text{dep}}$.

No perimeter constraints. Perimeter inspections occur outside the manoeuvring area and therefore are not subject to movement-based constraints.

Forced Inspection Requirements

To ensure runway coverage during high-risk periods, the algorithm mandates three runway inspections at specific times, which are placed before the greedy candidate selection phase:

Pre-night runway inspection. One runway inspection must begin within w_{pre} slots before the night closure period starts. The algorithm searches backward from $t_{\text{night_start}}$ to identify the latest feasible start time satisfying runway movement constraints.

Post-night runway inspection. One runway inspection must begin within w_{post} slots after the night closure period ends. The algorithm searches forward from $t_{\text{night_end}}$ to identify the earliest feasible start time. No separate forced dawn inspection is required, as this post-night inspection typically occurs during dawn hours when wildlife activity is naturally elevated.

Dusk runway inspection. One runway inspection should begin within $\pm w_{\text{dusk}}$ slots of a user-specified dusk time t_{dusk} , as wildlife activity typically increases during twilight periods. The algorithm performs a bidirectional search (forward first, then backward) to find the nearest feasible start time.

At BGY, default window parameters are $w_{\text{pre}} = 4$, $w_{\text{post}} = 4$, and $w_{\text{dusk}} = 4$ slots. If no feasible start time exists within the specified window, the algorithm issues a warning, finds the next feasible slot if any, and continues execution.

Minimum Gap Constraints

To prevent redundant consecutive inspections of the same type and to promote schedule diversity, the user may specify a minimum gap g_i (in hours) between consecutive inspections of type i . This constraint emerged from field observations with BCU operators, who noted that scheduling multiple identical inspections in rapid succession yields diminishing returns in wildlife detection, except during peak traffic windows.

The minimum gap is converted to slots as $g_i^{\text{slots}} = \lfloor g_i \times 12 \rfloor$ (where 12 slots = 1 hour). When evaluating a candidate inspection of type i starting at slot t , the algorithm rejects the candidate if any previously scheduled inspection of type i began at slot t' such that $|t - t'| < g_i^{\text{slots}}$.

An enhanced version of this constraint ensures that the minimum gap accounts for the full duration and buffer of the previous inspection, preventing cases where inspections are separated by the gap duration but still overlap in their buffer periods. Specifically, if a previous inspection of type i began at slot t_{prev} , a new inspection of type i may only begin at slot t if:

$$t - t_{\text{prev}} \geq g_i^{\text{slots}} + d_i + b_i + 1$$

This formulation was introduced to address pathological cases observed on low-traffic days (e.g., December 25, 2024, with only 44 movements), where the algorithm scheduled seven consecutive runway inspections followed by multiple ring inspections and no perimeter inspections. By enforcing minimum gaps that account for body and buffer durations, the algorithm produces more balanced schedules that distribute inspection types throughout the operational day.

Cardinality Constraints

Each inspection type i must satisfy user-defined minimum and maximum cardinality bounds:

$$n_{\min,i} \leq \sum_{t=0}^{287} x_{t,i} \leq n_{\max,i}$$

ENAC regulations require at least one inspection of each type per day ($n_{\min,1}, n_{\min,2}, n_{\min,3} \geq 1$) and a total of at least 14 inspections across all types. These cardinality bounds are fully configurable, allowing BCU operators to adjust them based on daily operational goals and expected traffic levels. At BGY, typical cardinality bounds are set to $n_{\min,1} = 4$ and $n_{\max,1} = 7$ for runway inspections, with ring and perimeter bounds configured to ensure the total inspection count satisfies the 14-inspection minimum while providing scheduling flexibility.

The greedy algorithm enforces these bounds during candidate selection: once an inspection type reaches its maximum count $n_{\max,i}$, no further candidates of that type are accepted, even if they have the highest priority score p_i among remaining candidates. For runway inspections specifically, BGY operators prioritize strict enforcement of the upper bound, they consider it critical to never exceed $n_{\max,1} = 7$ runway inspections, as excessive runway closures directly reduce the number of feasible ring and perimeter inspections. However, the algorithm is permitted to fall short of the minimum bound $n_{\min,1} = 4$ if it cannot find four feasible runway inspection windows that satisfy all spacing and buffer constraints. This asymmetric treatment of bounds reflects the operational reality that scheduling too many runway inspections is more disruptive than scheduling too few, since ring and perimeter inspections provide coverage when opportunities for runway inspections are limited.

7 | Greedy Algorithm for Inspection Scheduling

7.1. Algorithm Overview

After the mathematical model formulation presented in Chapter 6, this chapter details the implementation of the greedy algorithm used to solve this airside inspection scheduling problem. As mentioned in 6, the algorithm is designed to create an inspection schedule based on the priority of the three inspections with scores of $p_1 = 3$ for runway inspection, $p_2 = 2$ for ring inspection, $p_3 = 1$ for perimeter inspection, ensuring that the most critical inspections are scheduled first when feasible and when constraints permit. The greedy approach creates solutions iteratively by selecting the highest-priority feasible candidate at each step without backtracking. The following sections describe the implementation of the scheduling algorithm in MATLAB, including data processing, constraint mask creation, force inspection placement, and the core greedy selection loop that generates the feasible inspection schedules for a selected day.

7.2. Data Pre-processing

Historical flight data from January 1, 2023 to October 26, 2025 was extracted from the SACBO database. The dataset included scheduled date, scheduled time, actual flight date, actual flight time (time chocks were removed or placed), time aircraft took off or landed, actual taxi time, assigned stand, flight type (arrival or departure), runway used, aircraft model (common name, IATA, and ICAO designations), flight number, origin/destination, and delay information if applicable.

The data was filtered using MATLAB's `isoutlier` function based on actual taxi time, calculated as the absolute value of the difference between takeoff/landing time and the time chocks were removed/placed. The `isoutlier` function "returns a logical array whose elements are true when an outlier is detected in the corresponding element... By default, an outlier is a value that is more than three scaled median absolute deviations from the

median" [12]. Taxi times were used as the filtering criterion because aircraft at BGY typically require 5 minutes to taxi in and 10 minutes to taxi out. These durations are critical when evaluating movement counts per slot for runway inspections or departure counts per slot for ring inspections. Taxi times exceeding typical values may result from operational delays, database errors, or situations where chocks were removed prior to takeoff but subsequently replaced.

Following outlier removal, the data was further filtered to include only aircraft parking at Class C stands. BGY operates five stand categories (A, B, C, D, and E), but approximately 97% of arriving and departing aircraft utilize Class C stands. Aircraft using other stand categories were excluded from the analysis.

Each scheduled flight was assigned to a 5-minute time slot ranging from 0 to 287, based on its scheduled time (slot 0 corresponds to 00:00, slot 287 to 23:55). For flights scheduled at times not divisible by 5 minutes, the floor function was applied to determine the appropriate slot assignment. The 5-minute discretization was selected because it accurately represents airport operations: inspections require 10-25 minutes to complete, and flights typically operate on schedules with departure/arrival times divisible by 5 minutes. The algorithm also accounts for edge cases where an inspection scheduled near the end of the operational day, including its duration and buffer, may extend into the following day.

The *occupied_slots* array stores movement counts for each 5-minute interval, which forms the bases for all constraint evaluations and feasibility checks.

7.3. User-Defined Parameters

Table 7.1 reports the variables in the scheduling algorithm that a user must define prior to running the code along with the values that are currently adopted at Milan Bergamo Airport. Detailed descriptions of each symbol and its corresponding MATLAB implementation variable are provided in Appendix E.

Table 7.1: User-configurable scheduling parameters and BGY default values

MATLAB field	BGY value
shift_start_hours	[7, 15, 23]
shift_end_hours	[15, 23, 7]
no_inspection_night	[1, 30, 5, 30]
closing_open_slots	4
opening_open_slots	4
shift_start_buffer_slots	2
shift_end_buffer_slots	6
dusk_hour	21
dusk_minute	40
dusk_neighborhood_slots	4
dusk_search_window_slots	4
runway_inspection_duration_slots	2
runway_post_inspection_buffer_slots	9
runway_min_user	6
runway_max_user	6
runway_mov_threshold	0
adj_movement_threshold	2
adj_movement_window_slots	1
ring_inspection_duration_slots	5
ring_post_inspection_buffer_slots	9
ring_min_user	1
ring_max_user	∞
adj_departure_threshold_ring	2
adj_departure_window_slots	2
perimeter_inspection_duration_slots	5
perimeter_inspection_buffer_slots	6
perimeter_min_user	1
perimeter_max_user	∞
runway_min_gap_hours	0
ring_min_gap_hours	0
perimeter_min_gap_hours	0

7.4. Constraint Mask Construction

This section shows how the temporal and movement-based constraints from Chapter 6 section 6.2.3 are applied as binary masks in MATLAB. Each mask contains 288 elements in a boolean array - "an array consisting of elements, each of which can be either True or False" [5] - where 'True' means a slot is forbidden for an inspection to begin due to specific operational constraints.

7.4.1. Night Period and Shift Buffer Mask

The forbidden time slot mask $M_{\text{forbidden}}$ includes the temporal constraints from section 6.2.3. This mask does not allow inspections to begin during night hours (01:30-05:30 at BGY) and within buffer zones around shift changes (07:00, 15:00, and 23:00 at BGY).

Algorithm 7.1 Night Period and Shift Buffer Mask Construction

```

1 Initialize no_inspection_mask with 288 slots, all set to false
2 night_start_slot ← 18
3 night_end_slot ← 66
4 for slot = night_start_slot to night_end_slot do
5     Mark no_inspection_mask(slot) as forbidden (true)
6 end for
7 shift_start_slots ← [84, 180, 276]
8 shift_start_buffer_slots ← 2
9 for each shift_start in shift_start_slots do
10     buffer_end ← min(shift_start + shift_start_buffer_slots, 288)
11     for slot = shift_start to buffer_end do
12         Mark no_inspection_mask(slot) as forbidden (true)
13     end for
14 end for
15 shift_end_slots ← [180, 276, 84]
16 shift_end_buffer_slots ← 6
17 for each shift_end in shift_end_slots do
18     buffer_start ← max(1, shift_end - shift_end_buffer_slots + 1)
19     for slot = buffer_start to shift_end do
20         Mark no_inspection_mask(slot) as forbidden (true)
21     end for
22 end for
23 return no_inspection_mask

```

Algorithm 7.1 first marks all 5-minute slots for the night period (slots 18-66) as forbidden, then iterates through the three shift times to add the specified buffer constraints. Shift

start buffers does not allow inspections to begin in the first 10 minutes of each shift, while shift end buffers do not allow inspections to begin within 30 minutes from the end of a shift.

7.4.2. Runway Movement Mask

The runway adjacency mask $M_{1,\text{mov}}$ includes the movement-based constraint from section 6.2.3. This mask does not allow a runway inspection to begin at slot t if slot t or any neighboring slot within window w_1 contains $\geq \tau_1$ movements.

Algorithm 7.2 Runway Movement Adjacency Mask Construction

```

1 Initialize adjacent_movement_mask with 288 slots, all set to false
2 adj_movement_threshold  $\leftarrow$  2
3 adj_movement_window_slots  $\leftarrow$  1
4 for slot = 0 to 287 do
5   Set blocking  $\leftarrow$  false
6   for offset = -adj_movement_window_slots to +adj_movement_window_slots do
7     neighbor  $\leftarrow$  slot + offset
8     if neighbor < 0 then
9       movements  $\leftarrow$  occupied_slots_prev(neighbor + 288)
10    else if neighbor > 287 then
11      movements  $\leftarrow$  occupied_slots_next(neighbor - 288)
12    else
13      movements  $\leftarrow$  occupied_slots(neighbor)
14    end if
15    if movements  $\geq$  adj_movement_threshold then
16      Set blocking  $\leftarrow$  true
17      break
18    end if
19  end for
20  if blocking is true then
21    Mark adjacent_movement_mask(slot) as forbidden (true)
22  end if
23 end for
24 return adjacent_movement_mask

```

Algorithm 7.2 examines each slot and its neighborhood across three days (previous, current, next) to handle the cases that occur around midnight. For each candidate slot, if any slot within the adjacency window (± 1 slot defined at BGY) contains two or more movements (user-defined at BGY), the candidate is marked as forbidden. This constraint is meant to reduce the likelihood that ATC will interrupt an inspection for a large period of time due to a high volume of traffic.

7.4.3. Ring Departure Mask

The ring departure mask $M_{2,dep}$ includes the departure constraint for the ring inspection from section 6.2.3. This mask does not allow a ring inspection to begin at slot t if slot t or any neighboring slot within window w_2 contains $\geq \tau_2$ departures.

Algorithm 7.3 Ring Departure Adjacency Mask Construction

```

1 Initialize adjacent_departure_mask_ring with 288 slots, all set to false
2 adj_departure_threshold_ring  $\leftarrow$  2
3 adj_departure_window_slots  $\leftarrow$  2
4 for slot = 0 to 287 do
5   Set blocking  $\leftarrow$  false
6   for offset = -adj_departure_window_slots to +adj_departure_window_slots do
7     neighbor  $\leftarrow$  slot + offset
8     if neighbor < 0 then
9       departures  $\leftarrow$  occupied_dep_prev(neighbor + 288)
10    else if neighbor > 287 then
11      departures  $\leftarrow$  occupied_dep_next(neighbor - 288)
12    else
13      departures  $\leftarrow$  occupied_dep(neighbor)
14    end if
15    if departures  $\geq$  adj_departure_threshold_ring then
16      Set blocking  $\leftarrow$  true
17      break
18    end if
19  end for
20  if blocking is true then
21    Mark adjacent_departure_mask_ring(slot) as forbidden (true)
22  end if
23 end for
24 return adjacent_departure_mask_ring

```

Unlike the runway movement mask which counts all movements (arrivals and departures), the ring mask (algorithm 7.3) only considers departures. This is because arriving aircraft clear taxiways quickly, having minimal impact on ring inspections, while aircraft taxiing out occupy the runway for approximately 10 minutes which has a much larger impact on ring inspections. The adjacency window value is user defined, and can be changed at the operation departments discretion.

7.5. Force Inspection Placement

This section shows how the three mandatory (if feasible) runway inspections are implemented as defined in section 6.2.3. These include the pre-night, post-night, and dusk runway inspections. These inspections are placed before the execution of the greedy algorithm, ensuring that the runway is free of wildlife after a large wave of movements, before a large wave of movements (typically around dawn), and around dusk when there is a large number of active wildlife.

7.5.1. Post-Night Runway Inspection

A post-night inspection must begin within $w_{\text{post}} = 4$ slots after the night period ends (section 6.2.3). This portion of the code searches forward from slot 66 (05:30) for the first feasible slot (hopefully within the desired w_{post}).

Algorithm 7.4 Post-Night Runway Inspection Placement

```

1 opening_open_slots  $\leftarrow$  4
2 night_end_slot  $\leftarrow$  66
3 runway_inspection_duration_slots  $\leftarrow$  2
4 runway_post_inspection_buffer_slots  $\leftarrow$  9
5 runway_mov_threshold  $\leftarrow$  0
6 search_start  $\leftarrow$  night_end_slot + 1
7 search_end  $\leftarrow$  night_end_slot + opening_open_slots
8 forced_post_inspection_slot  $\leftarrow$  none
9 for slot = search_start to search_end do
10   if slot > 286 then
11     continue
12   end if
13   inspection_end  $\leftarrow$  slot + runway_inspection_duration_slots - 1
14   Check if all slots from slot to inspection_end are not forbidden in no_inspection_mask
15   Check if all slots from slot to inspection_end are not blocked in adjacent_movement_mask
16   Check if total movements in [slot, inspection_end]  $\leq$  runway_mov_threshold
17   if all conditions are satisfied then
18     Set forced_post_inspection_slot  $\leftarrow$  slot
19     buffer_end  $\leftarrow$  min(287, slot + runway_inspection_duration_slots +
        runway_post_inspection_buffer_slots - 1)
20     for t = slot to buffer_end do
21       Mark occupied_mask_all(t) as blocked (true)
22     end for
23     break
24   end if
25 end for
26 return forced_post_inspection_slot

```

Algorithm 7.4 satisfies the mandatory post-night hours (before a wave of high movement) and coincides with dawn in which wildlife activity is high. If no feasible slot exist within w_{post} slot window, a warning pop up appears and the code continues to run, and alternative inspection times are places where feasible.

7.5.2. Pre-Night Runway Inspection

A pre-night inspection must begin within $w_{\text{post}} = 4$ slots before the night period starts (section 6.2.3). This portion of the codes searches backward from slot 18 (01:30) for the latest feasible slot.

Algorithm 7.5 Pre-Night Runway Inspection Placement

```

1 closing_open_slots  $\leftarrow$  4
2 night_start_slot  $\leftarrow$  18
3 runway_inspection_duration_slots  $\leftarrow$  2
4 runway_mov_threshold  $\leftarrow$  0
5 search_end  $\leftarrow$  night_start_slot - 1
6 search_start  $\leftarrow$  max(0, night_start_slot - closing_open_slots -
   runway_inspection_duration_slots + 1)
7 forced_pre_inspection_slot  $\leftarrow$  none
8 for slot = search_end down to search_start do
9   if slot  $\geq$  night_start_slot - 1 or slot  $>$  286 then
10    continue
11   end if
12   inspection_end  $\leftarrow$  slot + runway_inspection_duration_slots - 1
13   Check if all slots from slot to inspection_end are not forbidden in no_inspection_mask
14   Check if all slots from slot to inspection_end are not blocked in adjacent_movement_mask
15   Check if total movements in [slot, inspection_end]  $\leq$  runway_mov_threshold
16   if all conditions are satisfied then
17     Set forced_pre_inspection_slot  $\leftarrow$  slot
18     for t = slot to inspection_end do
19       Mark occupied_mask_all(t) as blocked (true)
20     end for
21     break
22   end if
23 end for
24 return forced_pre_inspection_slot

```

In algorithm 7.5 only the runway inspection body duration (2 slots) is marked as occupied, the post-inspection buffer is allowed to overlap with the night period.

7.5.3. Dusk Runway Inspection

The dusk inspection must begin within $\pm w_{\text{dusk}} = 4$ slots of the specified dusk time (section 6.2.3) The code searches forward first, then backward.

Algorithm 7.6 Dusk Runway Inspection Placement

```

1 dusk_slot ← user-specified dusk time in slots
2 dusk_search_window_slots ← 4
3 runway_inspection_duration_slots ← 2
4 runway_post_inspection_buffer_slots ← 9
5 runway_mov_threshold ← 0
6 forced_dusk_inspection_slot ← none
7 for offset = 0 to dusk_search_window_slots do
8   test_slot ← dusk_slot + offset
9   if  $0 \leq \text{test\_slot} \leq 286$  then
10    inspection_end ← test_slot + runway_inspection_duration_slots - 1
11    Check if all slots from test_slot to inspection_end are not forbidden
12    Check if all slots from test_slot to inspection_end are not blocked
13    Check if total movements  $\leq$  runway_mov_threshold
14    if all conditions are satisfied then
15      Set forced_dusk_inspection_slot ← test_slot
16      break
17    end if
18  end if
19 end for
20 if forced_dusk_inspection_slot = none then
21   for offset = 1 to dusk_search_window_slots do
22     test_slot ← dusk_slot - offset
23     if  $0 \leq \text{test\_slot} \leq 286$  then
24       inspection_end ← test_slot + runway_inspection_duration_slots - 1
25       Check if all slots from test_slot to inspection_end are not forbidden
26       Check if all slots from test_slot to inspection_end are not blocked
27       Check if total movements  $\leq$  runway_mov_threshold
28       if all conditions are satisfied then
29         Set forced_dusk_inspection_slot ← test_slot
30         break
31       end if
32     end if
33   end for
34 end if
35 if forced_dusk_inspection_slot  $\neq$  none then
36   buffer_end ← min(287, forced_dusk_inspection_slot +
    runway_inspection_duration_slots + runway_post_inspection_buffer_slots - 1)
37   for  $t = \text{forced\_dusk\_inspection\_slot}$  to buffer_end do
38     Mark occupied_mask_all( $t$ ) as blocked (true)
39   end for
40 end if
41 return forced_dusk_inspection_slot

```

The search in algorithm 7.6 prioritizes the slots at or immediately after the target dusk time before searching backward. This reflects the observation that wildlife activity increases after the dusk time. All runway feasibility constraints are taken into account.

7.6. Greedy Inspection Selection Algorithm

This section shows how the greedy algorithm is implemented to select the 'best' inspection candidates. The algorithm creates a list of all feasible inspection candidates, sorts them by a priority score ($p_1 = 3$, $p_2 = 2$, $p_3 = 1$), and iteratively selects candidates that satisfy overlap, cardinality, and minimum gap constraints defined in section 6.2.3.

7.6.1. Generation of Candidates

The algorithm first identifies all of the time slots where each inspection type can begin, following all constraints. This candidate generation step examines every 5-minute slot in the selected day and applies inspection type feasibility checks based on the constraint masks created in section 7.4. The output of this step is a list of candidate inspection, each tagged with its start time, end time, inspection type, and priority score.

Table 7.2 shows an example of the candidate list structure generated for July 4, 2025.

Table 7.2: Example candidate inspection list generated for July 4, 2025 (slots 5–16)

Start Slot	End Slot	Inspection Type	Priority Score
...			
5	9	Ring	2
5	9	Perimeter	1
6	10	Ring	2
6	10	Perimeter	1
7	11	Ring	2
7	11	Perimeter	1
8	9	Runway	3
8	12	Ring	2
8	12	Perimeter	1
9	10	Runway	3
9	13	Ring	2
9	13	Perimeter	1
10	14	Ring	2
10	14	Perimeter	1
11	15	Ring	2
11	15	Perimeter	1
12	13	Runway	3
15	16	Runway	3
16	17	Runway	3
...			
Candidate Generation Summary:			
Feasible runway inspection starts: 10			
Feasible ring inspection starts: 67			
Feasible perimeter inspection starts: 192			
Total feasible candidates: 269			

Runway Inspection Candidates

Runway inspection candidates are selected by checking each slot against three conditions: temporal feasibility which are not in `no_inspection_mask`, movement-based feasibility which are not in `adjacent_movement_mask`, and that the selected slot has no scheduled movements (`runway_mov_threshold = 0`). Each of the candidates are assigned a priority

score of 3, reflecting a high criticality for runway inspections, as shown in algorithm 7.7.

Algorithm 7.7 Generate Runway Inspection Candidates

```

1 Initialize empty candidate list candidates  $\leftarrow []$ 
2 runway_inspection_duration_slots  $\leftarrow 2$ 
3 runway_mov_threshold  $\leftarrow 0$ 
4 for slot = 0 to 287 - runway_inspection_duration_slots + 1 do
5   inspection_end  $\leftarrow$  slot + runway_inspection_duration_slots - 1
6   Set is_feasible  $\leftarrow$  true
7   if any slot in [slot, inspection_end] is forbidden in no_inspection_mask then
8     Set is_feasible  $\leftarrow$  false
9   end if
10  if any slot in [slot, inspection_end] is blocked in adjacent_movement_mask then
11    Set is_feasible  $\leftarrow$  false
12  end if
13  if total movements in [slot, inspection_end] > runway_mov_threshold then
14    Set is_feasible  $\leftarrow$  false
15  end if
16  if is_feasible is true then
17    Create candidate c with:
18      c.start  $\leftarrow$  slot
19      c.end  $\leftarrow$  inspection_end
20      c.type  $\leftarrow$  1
21      c.score  $\leftarrow$  3
22    Add c to candidates
23  end if
24 end for
25 return candidates

```

Ring Inspection Candidates

Ring inspection candidates are selected by checking each slot against three conditions: temporal constraints which are not in **no_inspection_mask**, departure constraints which are not in **adjacent_departure_mask_ring**, and the global occupancy mask to avoid any conflicts with the forced runway inspections that had already been placed. Ring inspections receive a priority score of 2, indicating medium criticality, as shown in algorithm 7.8.

Algorithm 7.8 Generate Ring Inspection Candidates

```

1 ring_inspection_duration_slots  $\leftarrow$  5
2 for slot = 0 to  $287 - \text{ring\_inspection\_duration\_slots} + 1$  do
3   inspection_end  $\leftarrow$  slot + ring_inspection_duration_slots - 1
4   Set is_feasible  $\leftarrow$  true
5   if any slot in [slot, inspection_end] is forbidden in no_inspection_mask then
6     Set is_feasible  $\leftarrow$  false
7   end if
8   if any slot in [slot, inspection_end] is blocked in adjacent_departure_mask_ring then
9     Set is_feasible  $\leftarrow$  false
10  end if
11  if any slot in [slot, inspection_end] is already occupied in occupied_mask_all then
12    Set is_feasible  $\leftarrow$  false
13  end if
14  if is_feasible is true then
15    Create candidate c with:
16      c.start  $\leftarrow$  slot
17      c.end  $\leftarrow$  inspection_end
18      c.type  $\leftarrow$  2
19      c.score  $\leftarrow$  2
20    Add c to candidates
21  end if
22 end for
23 return candidates

```

Perimeter Inspection Candidates

Perimeter inspection candidates only face temporal constraints which are not found in `no_inspection_mask`, nor occupancy constraints, because perimeter inspections occur outside the movement area and are not subject to traffic-based restrictions. The perimeter inspection candidates are assigned a priority score of 1, meaning it is the least critical compared to the other two inspections, and plays a part in mitigating wildlife migration towards the more critical areas, as shown in algorithm 7.9.

Algorithm 7.9 Generate Perimeter Inspection Candidates

```

1  perimeter_inspection_duration_slots  $\leftarrow$  5
2  for slot = 0 to 287 - perimeter_inspection_duration_slots + 1 do
3      inspection_end  $\leftarrow$  slot + perimeter_inspection_duration_slots - 1
4      Set is_feasible  $\leftarrow$  true
5      if any slot in [slot, inspection_end] is forbidden in no_inspection_mask then
6          Set is_feasible  $\leftarrow$  false
7      end if
8      if any slot in [slot, inspection_end] is already occupied in occupied_mask_all then
9          Set is_feasible  $\leftarrow$  false
10     end if
11     if is_feasible is true then
12         Create candidate c with:
13             c.start  $\leftarrow$  slot
14             c.end  $\leftarrow$  inspection_end
15             c.type  $\leftarrow$  3
16             c.score  $\leftarrow$  1
17         Add c to candidates
18     end if
19 end for
20 return candidates

```

7.6.2. Greedy Selection with Constraint Enforcement

After all feasible candidates have been identified and marked with priority scores, the greedy inspection selection algorithm (algorithm 7.10) sorts the complete candidate list in descending order by the priority score. This ensure that runway inspections are considered first, followed by ring inspections, and lastly perimeter inspections. The algorithm then iterates through the sorted list , evaluating each candidate against the following constraints: no overlap, user-defined cardinality limits, and the user-defined minimum gap requirement. Only the candidates that satisfy all constraints are accepted into the final schedule.

The no overlap constraint ensures that no two inspections occupy the same time slots including both the inspection body and buffer durations. The cardinality limit constraint enforces the user-defined maximum inspection counts, preventing the algorithm from scheduling an excessive number of inspections of any single type. The minimum gap constraint requires a minimum temporal separation between consecutive inspections of the same type, accounting for the entire duration of the body and buffer of the previous inspection.

When a candidate is accepted, the algorithm updates the global occupancy mask to block

all affected time slots and then it adds one to the counter for that inspection type. This greedy approach does not backtrack or reconsider previous selections, ensuring computational efficiency while producing schedules that prioritize high-criticality inspections and satisfy all operational constraints.

Algorithm 7.10 Greedy Selection Loop with Constraint Enforcement

```

1 Sort candidates in descending order by score
2 runway_count  $\leftarrow$  number of forced runway inspections already placed
3 ring_count  $\leftarrow$  0
4 perimeter_count  $\leftarrow$  0
5 runway_max_user  $\leftarrow$  7
6 ring_max_user  $\leftarrow$   $\infty$ 
7 perimeter_max_user  $\leftarrow$   $\infty$ 
8 for each candidate c in sorted candidates do
9   if c.type = 1 then
10     duration  $\leftarrow$  runway_inspection_duration_slots
11     buffer  $\leftarrow$  runway_post_inspection_buffer_slots
12     min_gap_slots  $\leftarrow$  runway_min_gap_slots
13     current_count  $\leftarrow$  runway_count
14     max_count  $\leftarrow$  runway_max_user
15   else if c.type = 2 then
16     duration  $\leftarrow$  ring_inspection_duration_slots
17     buffer  $\leftarrow$  ring_post_inspection_buffer_slots
18     min_gap_slots  $\leftarrow$  ring_min_gap_slots
19     current_count  $\leftarrow$  ring_count
20     max_count  $\leftarrow$  ring_max_user
21   else
22     duration  $\leftarrow$  perimeter_inspection_duration_slots
23     buffer  $\leftarrow$  perimeter_inspection_buffer_slots
24     min_gap_slots  $\leftarrow$  perimeter_min_gap_slots
25     current_count  $\leftarrow$  perimeter_count
26     max_count  $\leftarrow$  perimeter_max_user
27   end if
28   start_slot  $\leftarrow$  c.start
29   buffer_end  $\leftarrow$  min(287, start_slot + duration + buffer - 1)
30   if any slot in [start_slot, buffer_end] is marked as occupied in occupied_mask_all then
31     continue to next candidate
32   end if
33   if current_count  $\geq$  max_count then
34     continue to next candidate
35   end if
36   if min_gap_slots > 0 then
37     Find all previously selected inspections of type c.type in selected
38     Store their start slots in same_type_starts
39     if same_type_starts is not empty then
40       time_since_last  $\leftarrow$  start_slot - max(same_type_starts)
41       required_gap  $\leftarrow$  min_gap_slots + duration + buffer + 1
42       if time_since_last < required_gap then
43         continue to next candidate
44       end if
45     end if
46   end if
47   Add c to selected inspections
48   Mark all slots in [start_slot, buffer_end] as occupied in occupied_mask_all
49   if c.type = 1 then
50     runway_count  $\leftarrow$  runway_count + 1
51   else if c.type = 2 then
52     ring_count  $\leftarrow$  ring_count + 1
53   else
54     perimeter_count  $\leftarrow$  perimeter_count + 1
55   end if
56 end for
57 return selected

```

Table D.9 shows an example of the final schedule structure generated for July 4, 2025. Status signifies if it was forced, meaning mandatory or a normal greedy selected inspection. On this particular day, two of the forced inspections could not be found within the specified slot constraints.

Table 7.3: Final inspection schedule generated for July 4, 2025

Inspection ID	Start Slot	End Slot	Start Time	Type	Status
1	0	4	00:00	Ring	Normal
2	16	17	01:20	Runway	Forced - Pre-night
3	67	71	05:35	Perimeter	Normal
4	89	93	07:25	Ring	Normal
5	103	107	08:35	Perimeter	Normal
6	115	116	09:35	Runway	Normal
7	126	130	10:30	Perimeter	Normal
8	144	148	12:00	Ring	Normal
9	158	162	13:10	Ring	Normal
10	183	187	15:15	Perimeter	Normal
11	202	203	16:50	Runway	Normal
12	213	217	17:45	Perimeter	Normal
13	226	227	18:50	Runway	Normal
14	237	241	19:45	Perimeter	Normal
15	248	252	20:40	Perimeter	Normal
16	259	263	21:35	Perimeter	Normal
17	284	285	23:40	Runway	Normal

Schedule Summary:

Runway inspections: 5

Ring inspections: 4

Perimeter inspections: 8

Total inspections: 17

8 | Algorithm Validation, Testing, and Results

Figure 8.1 shows a visualization of the final inspection schedule for July 4, 2025 (Table D.9), overlaid with flight data (blue) and constraint masks (further details found below). This visualization confirms the algorithm's correct integration of all constraints while demonstrating the distribution of the inspections scheduled throughout the day.

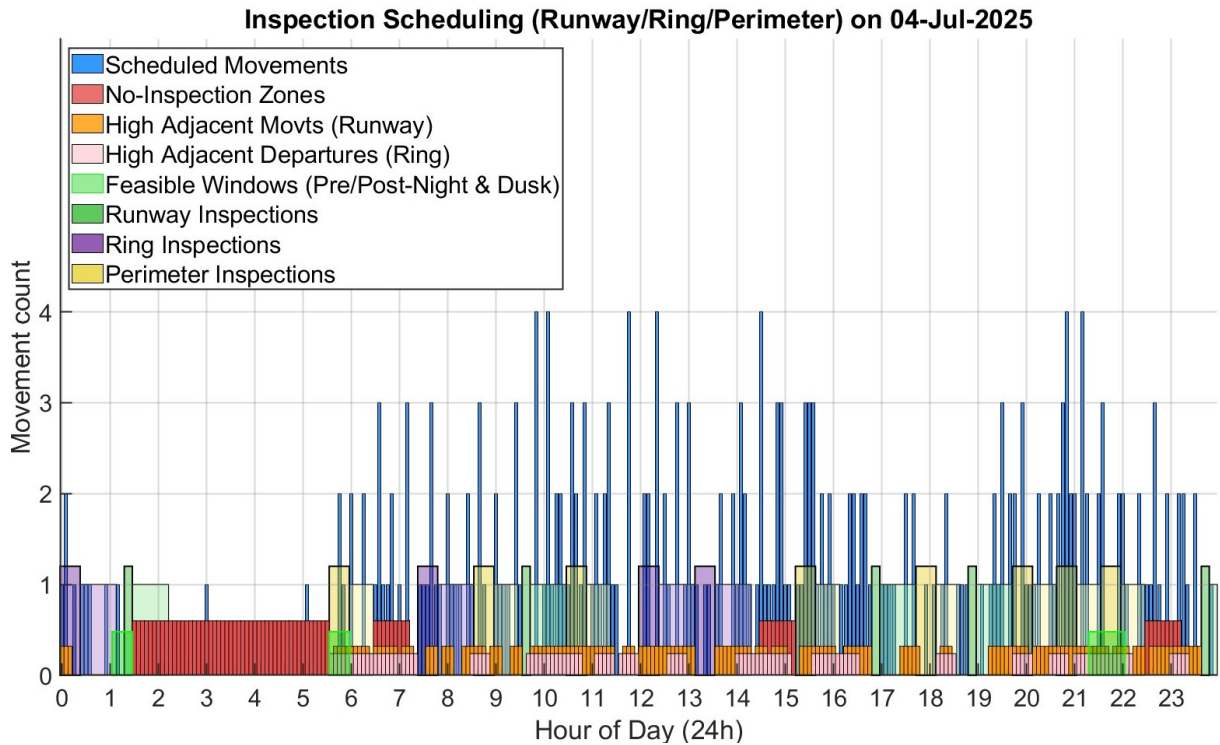


Figure 8.1: Distribution of scheduled inspections by time of day.

The figure illustrates all the constraints applied by the scheduling algorithm:

No-Inspection Zones (Red): The red shaded region between 01:30 and 05:30 shows the night period during which no inspections are permitted. The other red shaded regions, appearing around 06:30-07:30, 14:30-15:30, and 22:30-23:30, represent the shift start and

end times and their buffer periods.

High Adjacent Movements - Runway (Orange): The orange shaded slots are where runway inspections are constrained by the adjacency movement threshold (set to 2 movements in adjacent slots). Concentrated orange regions correspond to periods of high traffic.

High Adjacent Departures - Ring (pink): The pink shaded slots are where ring inspections are constrained by the adjacency departure threshold (set to 2 departures in adjacent slots). Concentrated pink regions corresponding to periods of high numbers of departures.

Feasible Windows for Forced Inspections (Bright Green Shading): Bright green shaded regions represent the pre-night, post-night and dusk forced inspection windows. If a runway inspection is placed in one of these windows, the algorithm was able to find a feasible solution.

Inspections (Green, Purple, Yellow): Runway, ring, and perimeter inspection schedules are visually represented in the figure with the colors green, purple, and yellow, respectively. The taller of the two blocks per inspection represent the duration of the inspection itself, while the shorter of the two blocks represents the inspection buffer time.

Figure 8.1 shows algorithm correctness for a single day (July 4, 2025) using the BGY default parameters displayed in table 7.1. This baseline validation confirms that all constraint enforcement mechanisms function correctly under typical summer traffic conditions. The algorithm's robustness and adaptability across varying operational scenarios including high traffic peak days, low-traffic periods, and alternative parameter configurations- require broader testing. Chapter 8.2 supports this validation by applying the algorithm to multiple days spanning winter and summer seasons, testing sensitivity to parameter variations (movement thresholds, adjacency windows, cardinality limits), and evaluating schedule quality under diverse traffic profiles.

8.1. Inspection Distribution and Operational Impact

Runway Inspection Timing: The five runway inspections (green) occur in low-traffic windows spread throughout the day. This reflects the algorithm's ability to prioritize feasibility over temporal distribution when movement constraints limit the number of available slots.

Ring and Perimeter Coverage: Ring inspections (purple) and perimeter inspections

(yellow) are distributed throughout the day where moderate to high traffic occurs. This also reflects the algorithm’s ability to prioritize feasibility over temporal distribution when movement constraints limit the number of available slots. The algorithm correctly avoids long sequences of the same inspection type for a typical traffic day.

Buffer Zones: The figure confirms that no two inspection blocks overlap, validating the correct enforcement of the constraint related to no overlapping in the periods where inspection body and buffer durations are already placed. Some inspections begin immediately after the previous inspections buffer time, while others have some downtime due to slots where constraints forbid any type of inspection.

The visual timeline representation, Figure 8.1 (July 4, 2025), continues to validate the algorithm based on the scheduled flights (blue), by showing it correctly places runway inspections in slots with the least amount of traffic and ring and perimeter inspections in slots with moderate to high amounts of traffic, prioritizing safety. It achieves ENAC compliance of ≥ 14 minimum inspections in a day and ≥ 1 of each type of inspection, as shown in Table D.9, while adapting to traffic patterns to minimize ATC interruption duration.

8.2. Dataset Description

The algorithm was validated using flight data from BGY spanning over a 3 year period. Historical flight data covers January 1, 2023 through October 25, 2025, while future flight data covers October 26, 2025 to March 28, 2026. This dataset encompasses both summer seasons (defined from the start of daylight saving time to its end) and winter seasons (defined from the end of daylight saving time to its start), aligning with SACBO’s operation cycles and seasonal traffic patterns.

Traffic intensity was determined by using standard percentiles applied to daily runway movements (T):

```
lowQ  = prctile(T, 25);    % 25th percentile (Low traffic)
highQ = prctile(T, 75);    % 75th percentile (High traffic)
```

Days with $T \leq \text{lowQ}$ were classified as “Low” traffic, $T \geq \text{highQ}$ as “High” traffic, and remaining days as “Medium” traffic. Seasonal medians were:

```
Historical Winter = 223 movements/day
```

```
Historical Summer = 267 movements/day
```

```
Future Winter = 269 movements/day
```

Days that highly deviated from the seasonal median were excluded from the test set to maintain the typical representation of operation at BGY. For example, December 25, 2024 recorded only 44 runway movements—80% below the Historical Winter median, possibly due to the holidays, and is atypical of normal winter operations. Similarly, future winter extremes (62 movements on December 25, 2025; 332 movements on December 19, 2025) represent special cases that rarely have an affect on inspection scheduling.

The days used to test and generate, reported in table 8.1, were selected for their operational representativeness. One representative day was selected from each traffic intensity category (Low, Medium, High) across all three seasons, for a total of **9 test days**. Medium traffic days were prioritized as they represent approximately 50% of operational days and align with seasonal medians. Low and high traffic test day selections represent the least extreme cases within their percentile ranges (closest to median among the classified Low/High days), to verify that the algorithm performs correctly under different traffic conditions without focusing on pathological extremes.

Table 8.1: Selected Test Days for Algorithm Validation

Season	Date	Day of Week	Total Movements	Traffic Class	Deviation from Median	% of Seasonal Days
Historical Winter	Feb 21, 2025	Fri	223	Medium	0	~50%
	Jan 22, 2025	Wed	125	Low*	−98	~25%
	Dec 22, 2024	Sun	265	High*	+42	~25%
Historical Summer	Apr 10, 2025	Thu	267	Medium	0	~50%
	May 10, 2025	Sat	234	Low*	−33	~25%
	Jun 29, 2025	Sun	299	High*	+32	~25%
Future Winter	Jan 16, 2026	Fri	269	Medium	0	~50%
	Jan 21, 2026	Wed	136	Low*	−133	~25%
	Dec 22, 2025	Mon	321	High*	+52	~25%

*Least extreme case within percentile range (closest to median among Low/High classified days).

The greedy inspection scheduling algorithm was created and tested in MATLAB R2024a on the 9 representative test days listed in table 8.1. The average computation time was less than 5 seconds per day on a standard workstation, which demonstrates operational feasibility for real-time daily planning by the BCU.

8.3. Manual Schedule Baseline

SACBO’s operations department currently defines inspection schedules for every winter and summer aviation season. These schedules are designed using forecasted flight schedules and are then applied identically to every day in the season, despite actual variability in the actual flight program. The resulting static schedules, such as the Winter 2025-2026 and Summer 2025 schedules reported in tables 8.2 and 8.3, do not adapt to day-to-day changes in traffic, which can lead to mismatches between inspection timing and runway occupancy and, consequently, to suboptimal inspection coverage. Due to operational changes within SACBO, the inspection types in these legacy schedules do not exactly match the current inspection categories used in this work.

Table 8.2: Winter 2025–2026 Manual Schedule

Start Time	Type	Route	Example Duration
01:50	Runway	Runway	01:50–02:00
05:20	Runway	Runway	05:20–05:30
06:20	Perimeter	Perimeter	06:20–06:43
07:25	Perimeter	Perimeter	07:25–07:48
08:30	Perimeter	Perimeter	08:30–08:53
09:55	Runway	Runway	09:55–10:05
11:10	Ring	Alfa/Bravo	11:10–11:35
12:30	Perimeter	Perimeter	12:30–12:53
13:55	Ring	Alfa/Bravo	13:55–14:20
15:10	Ring	Alfa/Bravo	15:10–15:35
16:10	Perimeter	Perimeter	16:10–16:33
17:05	Runway	Runway	17:05–17:15
18:20	Ring	Alfa/Bravo	18:20–18:45
19:30	Perimeter	Perimeter	19:30–19:53
20:50	Perimeter	Perimeter	20:50–21:13
22:10	Perimeter	Perimeter	22:10–22:33
23:40	Runway	Runway	23:40–23:50

Applied identically every winter day, regardless of actual traffic patterns.

Table 8.3: Summer 2025 Manual Schedule

Start Time	Type	Route	Example Duration
01:35	Runway	Runway	01:35–01:45
03:20	Ring	Alfa/Bravo	03:20–03:45
04:50	Runway	Runway	04:50–05:00
06:10	Perimeter	Perimeter	06:10–06:23
07:15	Ring	Alfa/Bravo	07:15–07:40
08:35	Ring	Alfa/Bravo	08:35–09:00
09:45	Perimeter	Perimeter	09:45–10:08
11:10	Perimeter	Perimeter	11:10–11:33
12:25	Ring	Alfa/Bravo	12:25–12:50
13:35	Runway	Runway	13:35–13:45
14:25	Ring	Alfa/Bravo	14:25–14:50
15:30	Perimeter	Perimeter	15:30–15:53
16:40	Runway	Runway	16:40–16:50
17:40	Perimeter	Perimeter	17:40–18:03
18:50	Ring	Alfa/Bravo	18:50–19:15
20:00	Perimeter	Perimeter	20:00–20:23
21:05	Perimeter	Perimeter	21:05–21:28
22:00	Ring	Alfa/Bravo	22:00–22:25
23:30	Runway	Runway	23:30–23:40

Applied identically every summer day, regardless of actual traffic patterns.

8.4. ENAC Regulatory Compliance

For validation, four metrics were considered: total daily runway movements, number of feasible start slots, theoretical maximum number of possible inspections, and the number of inspections actually scheduled by the greedy algorithm. Across all 9 representative test days, the algorithm produced schedules that satisfied ENAC requirements, which confirms correct constraint implementation and robust performance across various days with different traffic volumes. Table 8.4 summarizes the results, showing 100% compliance even on days with very limited availability of feasible start slots.

Table 8.4: Runway Inspection Validation: 9 Representative Test Days

Season	Date	Movements	Feasible Starts	Max Possible	Greedy Achieved	ENAC Min	Status
Historical Winter	21-Feb-2025	223	22	8	6	6	✓
	22-Jan-2025	125	62	12	6	6	✓
	22-Dec-2024	265	12	8	6	6	✓
Historical Summer	10-Apr-2025	267	12	6	6	6	✓
	10-May-2025	234	16	8	6	6	✓
	29-Jun-2025	299	13	6	6	6	✓
Future Winter	16-Jan-2026	269	18	9	6	6	✓
	21-Jan-2026	136	53	15	6	6	✓
	22-Dec-2025	321	13	6	6	6	✓

100% ENAC compliance; average feasible starts: 24.2; high-traffic days averaged 12.7 feasible starts.

These results demonstrate that all regulatory constraints are satisfied, that the greedy algorithm achieves the ENAC minimum on every test day, and that it remains effective over a wide range of traffic volumes (125–321 movements).

8.4.1. Detailed Example: April 10, 2025

Figure 8.2 reports the schedule generated for 10 April 2025, a medium-traffic day with 267 movements. Flight movements are shown in blue, movement density in orange and pink, forbidden inspection start slots in red, while runway, ring, and perimeter inspections are displayed in green, purple, and yellow, respectively. Although only 12 start slots were feasible for runway inspections, the algorithm scheduled 6 of them, exactly meeting ENAC requirements.

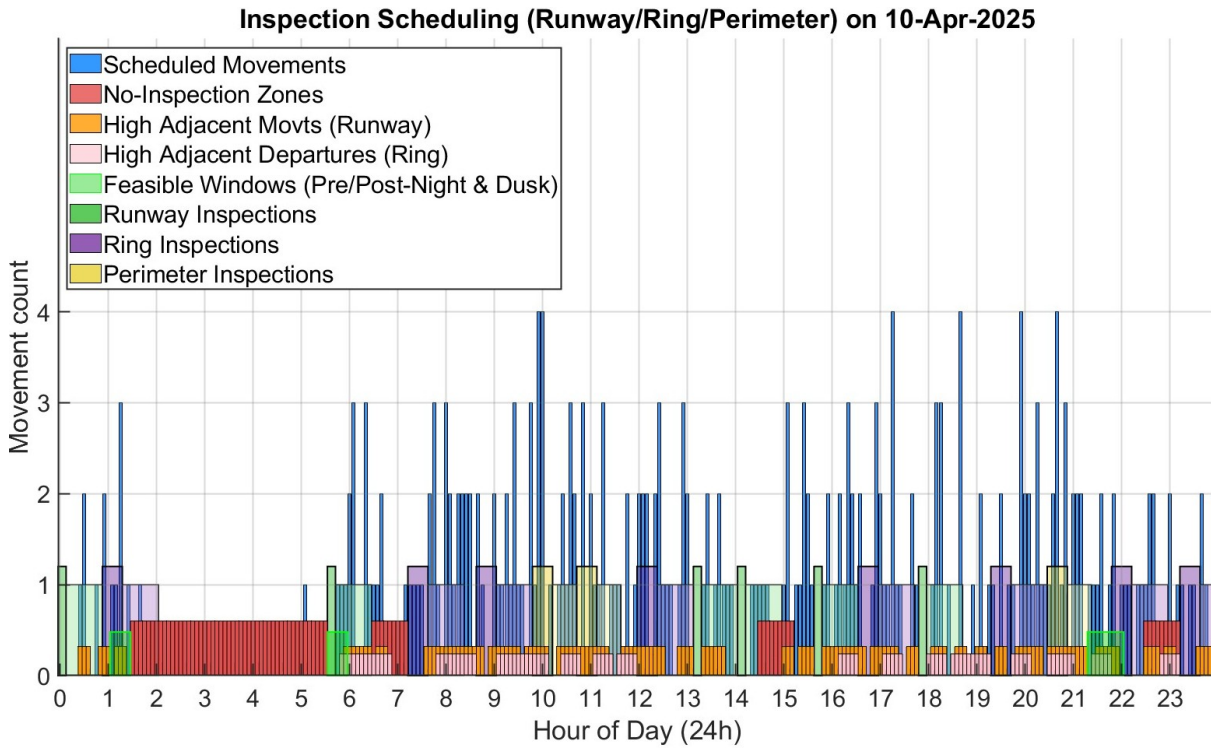


Figure 8.2: Runway occupancy and inspection schedule for April 10, 2025 (267 movements).

Table 8.5 lists the detailed inspection schedule for 10 April 2025. It confirms that all inspections are located in the closest feasible slots that do not violate any constraints. In total, 17 inspections (6 runway, 7 ring, 4 perimeter) are scheduled, with only one forced post-night inspection due to the unavailability of earlier feasible slots.

Table 8.5: Inspection Schedule: April 10, 2025 (17 total inspections)

ID	Start Slot	End Slot	Start Time	Type	Status
1	0	1	00:00	Runway	Normal
2	11	15	00:55	Ring	Normal
3	67	68	05:35	Runway	Forced post-night
4	87	91	07:15	Ring	Normal
5	104	108	08:40	Ring	Normal
6	118	122	09:50	Perim.	Normal
7	129	133	10:45	Perim.	Normal
8	144	148	12:00	Ring	Normal
9	158	159	13:10	Runway	Normal
10	169	170	14:05	Runway	Normal
11	188	189	15:40	Runway	Normal
12	199	203	16:35	Ring	Normal
13	214	215	17:50	Runway	Normal
14	232	236	19:20	Ring	Normal
15	246	250	20:30	Perim.	Normal
16	262	266	21:50	Ring	Normal
17	279	283	23:15	Ring	Normal

6 runway + 7 ring + 4 perimeter = 17 total; all inspections feasible.

8.4.2. Algorithm Performance Across Different Traffic Intensities

High-traffic days (265–321 movements) exhibit a relatively small number of feasible start slots (on average approximately 13 per day), yet in all such cases the algorithm was able to meet both ENAC and SACBO requirements without violating any constraint. Low-traffic days (125–234 movements) have a much higher number of feasible start slots (between 16 and 62 slots in the test set), but even in these conditions the algorithm never exceeded the user-defined upper limits on the number of inspections for each type. Full visualizations and schedules for all 9 test days are reported in Appendix D.

8.5. Complete Season Analysis

Apart from the 9 representative test days, the algorithm code was adapted into a function and executed over all days in the historical winter season (154 days), historical summer

season (210 days), and future winter season (154 days). The results are summarized in Table 8.6.

Table 8.6: ENAC Compliance Across Full Seasons (Runway Inspections, Min=4)

Season	Total Days	Meets ENAC	Max Possible < ENAC	Compliance %
Historical Winter	154	154	0	100.0%
Historical Summer	210	205	5	97.6%
Future Winter	154	139	15	90.3%
Total	518	498	20	96.1%

Historical Winter: During this season, there was 100.0% compliance, this shows that there were a sufficient number of slots available for all inspections to be scheduled and meet ENAC and SACBO requirements. This is because during this winter season there was a lower number of traffic.

Historical Summer: During this season, there was 97.6% compliance, there were only 5 days out of 210 days that had too many constraints and the algorithm was not able to find enough feasible solutions to meet the minimum requirement.

Future Winter: During this season, there was 90.3% compliance, there were 15 days out of 154 that did not meet the user-defined minimum inspection requirement. As the years come, the number of flights scheduled in a day at SACBO increases. The higher number of movements, the less the chance of the algorithm meeting the user-defined minimum, meaning some user-defined constraints must be relaxed while still meeting all regulations.

High-movement days (more than 280 movements) show a marked reduction in feasible start slots, from approximately 18 on average across the season to around 9 on the most congested days. In all cases, the greedy algorithm consistently utilizes the available capacity, which supports the accuracy of the constraint modeling and the effectiveness of the approach under BGY's current operating conditions.

8.6. Manual Schedule Versus Algorithmic Schedule

The manually created schedules for Summer 2025 (Table 8.3) and Winter 2025–2026 (Table 8.2) are static daily schedules used through the length of that season, regardless of the real time traffic at BGY. Summer manually created schedule includes 19 inspections (6 runway, 7 ring, 6 perimeter), while Winter includes 17 inspections (6 runway, 5 ring, 6 perimeter). Inspection durations range from 10 minutes for runway to 25 minutes for

ring and 23 minutes for perimeter. The summer 2025 schedule was created before SACBO decided that no inspections would take place during night/early morning hours and before the exact routes per inspection type were changed, therefore it is slightly different from what is used today.

On the other hand, the schedules created using the greedy algorithm for those listed in Table 8.4 show dynamic optimization based on actual traffic patterns. These schedules adapt inspection timing to minimize conflicts with peak traffic periods (refer to Appendix D for all 9 schedules and their schedule visualizations).

Both the manual and algorithmic approaches aim at maintaining ENAC compliance, with a minimum of 14 inspections per day (including at least one of each type), but the algorithmic approach is more aware of the traffic while the manual schedules risk peak-hour overlaps. In practice, the operator in charge of inspections retains the authority to adjust individual inspection times in real time, while still following the proposed schedule closely enough to guarantee that all minimum requirements are satisfied.

8.7. Sensitivity Analysis

To assess the robustness of the greedy scheduling algorithm and the impact of key operational parameters, a sensitivity analysis was carried out at two complimentary levels. At the seasonal level, all days in the Historical Winter, Historical Summer, and Future Winter datasets were used to study how different runway inspection requirement bounds (minimum/maximum number of inspections per day) affect feasibility and regulatory compliance over complete seasons. At the daily level, the 9 representative test days introduced in Table 8.1 (six historical and three future days spanning low, medium, and high traffic intensities) were used to analyze the effect of movement thresholds, temporal constraints and delay robustness, and scenario-based parameter interactions in greater detail.

8.7.1. Inspection Requirement Bounds (Min/Max)

The first set of sensitivity analyses focuses on the minimum and maximum number of runway inspections required per day. Three configurations were evaluated across all days of the Historical Winter (154 days), Historical Summer (210 days), and Future Winter (154 days) seasons:

- **Unconstrained ($0-\infty$):** No lower or upper bound on the number of runway inspections. This configuration reveals the theoretical inspection capacity imposed solely by operational constraints (night period, shift buffers, movement adjacency,

and separation rules).

- **Baseline (4–7):** A minimum of 4 and a maximum of 7 runway inspections per day. This setting corresponds to SACBO’s current operational practice and was used as the reference configuration in Chapter 8.2.
- **Strict (6–6):** Exactly 6 runway inspections per day (minimum and maximum both equal to 6). This configuration tests the feasibility of enforcing a fixed, tighter coverage requirement under varying traffic conditions.

For each season and configuration, the following indicators were computed: number of days meeting the ENAC minimum, number of infeasible days where the maximum achievable inspections fell below the minimum requirement, overall compliance percentage, and average number of runway inspections scheduled by the greedy algorithm. The results are summarized in Table 8.7.

Table 8.7: Seasonal sensitivity to runway inspection requirement bounds

Season	Total Days	Meets ENAC	Fails	Compliance	Avg Achieved	Configuration
Historical Winter	154	154	0	100.0%	9.7	Unconstrained (0– ∞)
	154	154	0	100.0%	6.8	Baseline (4–7)
	154	150	4	97.4%	6.0	Strict (6–6)
Historical Summer	210	210	0	100.0%	6.4	Unconstrained (0– ∞)
	210	200	10	95.2%	5.9	Baseline (4–7)
	210	140	70	66.7%	5.5	Strict (6–6)
Future Winter	154	154	0	100.0%	8.2	Unconstrained (0– ∞)
	154	139	15	90.3%	6.4	Baseline (4–7)
	154	133	21	86.4%	5.6	Strict (6–6)

“Fails” indicates days where the maximum achievable number of runway inspections is lower than the minimum required.

Under the unconstrained configuration (0– ∞), the algorithm achieved 100% compliance in all three seasons, confirming that the model operational constraints alone do not create infeasibility. In this regime, the greedy heuristic utilizes all available feasible slots, with an average of 9.7 runway inspections per day in Historical Winter, 6.4 in Historical Summer, and 8.2 in Future Winter, reflecting the different traffic intensities and gap structures of each season.

With baseline configuration (4–7), Historical Winter maintained 100.0% compliance (154 days out of 154 days), indicating that for this lower-traffic season there are always sufficient

feasible slots to schedule at least 4 runway inspections. Historical Summer compliance decreased to 95.2% (10 failures out of 210 days) and Future Winter decreased to 90.3% (15 failures out of 154 days), where some high-traffic days did not provide enough feasible start slots to meet the minimum requirement despite the algorithm filling all available capacity. On those failing days, the average number of runway movements was approximately 280 in Historical Summer and 292 in Future Winter, substantially higher than the corresponding seasonal averages, which supports the interpretation that infeasibility is driven by exceptionally congested traffic patterns rather than by shortcomings of the algorithm.

The strict configuration (6–6) was the most restrictive and exhibited the lowest compliance, especially in higher-traffic seasons. Historical Winter still achieved 97.4% compliance, with only 4 infeasible days out of 154, while Historical Summer dropped to 66.7% compliance, with 70 failures out of 210 days, and Future Winter to 86.4%, with 21 failures out of 154 days. Failure days under the strict configuration again correspond to particularly busy traffic conditions: in Historical Winter they averaged 254 movements, and in Historical Summer and Future Winter around 280 and 292 movements, respectively, values that leave very few feasible gaps for inspections once night periods, shift buffers, and movement-adjacency rules are enforced. In these cases, the algorithm typically schedules the maximum possible number of inspections (around 3–4 on average) but cannot reach the strict minimum of 6, indicating that the constraint set is physically infeasible for those days.

Overall, this analysis shows that the greedy algorithm robustly utilizes available capacity and that infeasibilities arise from the interaction between tight inspection bounds and high traffic, rather than from algorithmic limitations. The baseline configuration (4–7) emerges as a reasonable compromise: it preserves 100% seasonal compliance in Historical Winter and maintains high compliance in Historical Summer and Future Winter, whereas the strict configuration (6–6) is overly demanding on many high-traffic days and may not be realistic as a fixed operational requirement going forward. In practice, SACBO operators retain the ability to loosen or tighten these bounds to adapt to evolving traffic conditions and operational priorities, while the most critical requirement from the operations department remains to guarantee at least one runway inspection per day and never exceed the maximum allowed limit, targets that were satisfied 100% of the time in all tested configurations.

8.7.2. Movement Thresholds

The second set of sensitivity analyses focuses on how conservative movement-based rule for runway inspections and departure-based rule for ring inspections affect the schedules generated on the 9 representative test days from Table 8.1. All other parameters are kept fixed. Three configurations were considered:

- **Very constrained:** runway adjacency threshold = 1 movement, window = 1 slot; ring departure threshold = 1, window = 2 slots.
- **Baseline:** runway adjacency threshold = 2 movements, window = 1 slot; ring departure threshold = 2, window = 2 slots.
- **Least constrained:** runway adjacency threshold = 3 movements, window = 1 slot; ring departure threshold = 3, window = 2 slots.

Where runway adjacency threshold and ring departure threshold mean the number of movements/departures cannot be equal to or greater than the value indicated in the current/adjacent slots. The window slot value is to indicate how many slots to refer to adjacent to the current slot.

These settings progressively relax the movement thresholds while leaving the slot structure and all other constraints unchanged. For each configuration, the algorithm was run on the 6 historical and 3 future winter test days, and the resulting counts of runway, ring, and perimeter inspections were recorded.

Tables 8.8, 8.9, and 8.10 report the inspection counts for all 9 representative days under the three movement-threshold configurations.

Table 8.8: Movement thresholds sensitivity: baseline configuration (runway adj.=2, ring adj.=2)

Date	Season	Movements	Runway	Ring	Perimeter	Total
21-Feb-2025	Hist Winter	223	7	4	5	16
22-Jan-2025	Hist Winter	125	7	7	2	16
22-Dec-2024	Hist Winter	265	7	5	5	17
10-Apr-2025	Hist Summer	267	6	8	3	17
10-May-2025	Hist Summer	234	7	4	5	16
24-Jun-2025	Hist Summer	268	7	6	3	16
16-Jan-2026	Fut Winter	269	7	3	7	17
21-Jan-2026	Fut Winter	136	7	8	2	17
22-Dec-2025	Fut Winter	321	6	5	6	17

Under the baseline movement thresholds, all 9 representative days meet the ENAC requirement on total inspections (at least 14) and contain at least one inspection of each type (runway, ring, and perimeter). Runway inspections are consistently at or close to the upper bound (6–7 per day) across historical and future seasons, while ring and perimeter inspections fill the remaining feasible slots, yielding between 16 and 17 total inspections per day. This indicates that the baseline adjacency thresholds are sufficiently conservative to protect inspections from traffic conflicts, yet flexible enough to maintain a balanced mix of inspection types over low, medium, and high traffic conditions in both historical and future winter contexts.

Table 8.9: Movement thresholds sensitivity: least constrained configuration (runway adj.=3, ring adj.=3)

Date	Season	Movements	Runway	Ring	Perimeter	Total
21-Feb-2025	Hist Winter	223	7	8	2	17
22-Jan-2025	Hist Winter	125	7	9	0	16
22-Dec-2024	Hist Winter	265	7	9	1	17
10-Apr-2025	Hist Summer	267	7	9	0	16
10-May-2025	Hist Summer	234	7	9	0	16
24-Jun-2025	Hist Summer	268	7	7	2	16
16-Jan-2026	Fut Winter	269	7	9	2	18
21-Jan-2026	Fut Winter	136	7	10	0	17
22-Dec-2025	Fut Winter	321	7	8	1	16

When movement thresholds are relaxed (least constrained configuration), the algorithm consistently increases the number of ring inspections across almost all days and seasons, often at the expense of perimeter inspections, while keeping runway inspections saturated at their upper bound (7 per day). For several historical and future days, perimeter inspections are completely suppressed (22-Jan-2025, 10-Apr-2025, 10-May-2025, 21-Jan-2026), and the schedule consists almost entirely of runway and ring inspections. Despite this, the total number of inspections per day remains high (16–18), so the ENAC minimum on total inspections is always satisfied, but the operational requirement of having at least one inspection of each type is no longer guaranteed for all 9 days.

Table 8.10: Movement thresholds sensitivity: very constrained configuration (runway adj.=1, ring adj.=1)

Date	Season	Movements	Runway	Ring	Perimeter	Total
21-Feb-2025	Hist Winter	223	3	0	16	19
22-Jan-2025	Hist Winter	125	7	2	8	17
22-Dec-2024	Hist Winter	265	2	1	17	20
10-Apr-2025	Hist Summer	267	2	0	18	20
10-May-2025	Hist Summer	234	3	1	13	17
24-Jun-2025	Hist Summer	268	3	0	15	18
16-Jan-2026	Fut Winter	269	3	1	15	19
21-Jan-2026	Fut Winter	136	7	0	12	19
22-Dec-2025	Fut Winter	321	1	1	17	19

Under the very constrained configuration, any slot with at least one movement in the current or adjacent slots is blocked for runway and ring inspections, making these inspection types much harder to place, especially on high-traffic days. The algorithm responds by scheduling many more perimeter inspections, which are not affected by the departure-based ring constraint, or movement-based runway constraint, leading to totals as high as 19–20 inspections on several days. However, on both historical and future days, the number of runway inspections can drop sharply (down to 1 or 2 on some high-traffic winter and summer days), and ring inspections are sometimes eliminated entirely (e.g. 21-Feb-2025, 10-Apr-2025, 24-Jun-2025, 21-Jan-2026), so that some schedules no longer contain all three inspection types, despite meeting and often exceeding the ENAC minimum on total inspections.

Across all 9 representative days and all three movement-threshold configurations, the algorithm always satisfies the ENAC requirement of at least 14 inspections per day, but

only the baseline configuration consistently produces schedules that contain at least one of each inspection type (runway, ring, perimeter). Both the least constrained and very constrained settings result in days where one inspection type is entirely absent: in the least constrained case, perimeter inspections are frequently omitted, whereas in the very constrained case, ring inspections (and in some cases runway inspections) become rare or nearly disappear. This illustrates that movement thresholds primarily affect the composition of the schedule by type rather than its total capacity, and that the baseline thresholds provide a good compromise between safety margins and type balance across historical and future traffic conditions.

The inspection type imbalances observed under non-baseline movement thresholds are partly a consequence of the greedy scoring and the absence of spacing between same-type inspections. Runway and ring inspections have higher scores than perimeter inspections, so when they are feasible they tend to be selected repeatedly. With all minimum gap parameters set to zero:

```
runway_min_gap_hours    = 0;
ring_min_gap_hours      = 0;
perimeter_min_gap_hours = 0;
```

the algorithm may place several inspections of the same type back-to-back whenever allowed by movement thresholds and buffers, rather than inserting a different inspection type in between.

A practical way to mitigate this and improve inspection type balance, without changing ENAC or user-defined minima, is to introduce a minimum spacing between same-type inspections:

```
config.runway_min_gap_hours    = X_runway;
config.ring_min_gap_hours      = X_ring;
config.perimeter_min_gap_hours = X_perimeter;
```

Here, `X_runway`, `X_ring`, and `X_perimeter` are user-defined parameters (in hours) that set the minimum time that must elapse from the start of a runway, ring, or perimeter inspection before another inspection of the same type may begin. These minimum-gap parameters force the algorithm to consider the next-best inspection type for subsequent feasible slots instead of repeatedly selecting the same type whenever possible. To be effective, gap values must be chosen larger than the corresponding inspection duration plus buffer, expressed in hours. For example, if a ring inspection has a body of 25 minutes and a buffer of 45 minutes (70 minutes total), then `ring_min_gap_hours` should

be set greater than approximately 1.2 hours; this prevents a second ring inspection from immediately following the buffer and reduces sequences of consecutive ring inspections.

By appropriately tuning these minimum gap parameters, SACBO can encourage more even alternation between inspection types and reduce the likelihood of schedules that, although compliant with ENAC's total inspection requirement, omit one of the inspection types. This provides a simple and interpretable lever for controlling the diversity of daily inspection plans alongside the movement-threshold settings.

8.7.3. Effect of Delays on Temporal Constraints and Robustness

Inspection schedules at SACBO are constructed in advance based solely on the published flight timetable, while actual take-off and landing times, hence delays, are only observed on the day of operation. To understand how these schedules behave when exposed to real delays, a dedicated robustness analysis was carried out for all days in the Historical Winter (27-Oct-2024 to 29-Mar-2025) and Historical Summer (30-Mar-2025 to 25-Oct-2025) seasons.

For each historical day, a single daily inspection schedule was first generated using scheduled movement times and the baseline configuration from Table 7.1. This produced a fixed schedule specifying, for each inspection, its type (runway, ring, perimeter) and planned start slot. Every schedule satisfies the ENAC requirement of 14 inspections per day.

The robustness of this fixed schedule was then evaluated against the actually realized time recorded. For each day, the actual movement times were converted into 5-minute slots and a new movement profile was computed, while the planned inspections were kept unchanged.

An inspection was classified as violated if, when using the realized movement profile, there were too many movements near its planned start time and the corresponding movement-adjacency limit was exceeded. In particular, a planned runway inspection was marked as violated if the number of updated movements in the window around its planned start exceeded the runway adjacent movement threshold, and a planned ring inspection was marked as violated if the number of updated departures around its planned start exceeded the ring adjacent departure threshold. Perimeter inspections were not subject to any checks in this analysis. This analysis directly captures situations where, for example, a runway inspection was planned during a period in which no movement occurs but is now unsafe because a departure that was scheduled a few slots earlier is now delayed into the inspection window.

Table 8.11 summarizes robustness metrics for Historical Winter and Historical Summer. For each season, it reports the average number of inspection violations per day and the fraction of days on which the pre-planned schedule remains conflict-free under realized delays.

Table 8.11: Robustness of pre-planned schedules under realized delays

Season	Avg. violated inspections per day	Days with no violations
Historical Winter	1.22	29.2%
Historical Summer	2.42	4.3%

On Historical Winter days, a plan built on scheduled movements experiences on average 1.22 inspections per day that are violated by delays, while 29.2% of winter days have no violations at all and the entire plan remains compatible with the realized traffic. Historical Summer days exhibit substantially higher sensitivity: the average number of violated inspections increases to 2.42 per day, and only 4.3% of summer days have no violations at all, reflecting the higher traffic intensity and tighter temporal gaps that leave less slack to absorb delays. In both seasons, having between 1-3 inspections violated per day is not catastrophic, as the majority of the planned inspections remain valid, and the total minimum requirement of 14 inspections per day continues to be satisfied across all days, but on many days, especially in the summer, several runway and ring inspections would need to be canceled, delayed, or anticipated when actual delays are taken into account.

The findings show that, realistic delays often push additional movements into the neighborhood of planned inspection windows, causing the movement-adjacency thresholds to be exceeded for a subset of inspections. From an operational perspective, this suggests that relying solely on a static schedule derived from scheduled times is insufficient, particularly in high-traffic periods. SACBO would benefit from periodically re-evaluating or partially rerunning the scheduling algorithm during the day as delays accumulate, in order to identify and repair violated inspections before execution rather than managing these conflicts when necessary.

9 | Conclusions and Future Developments

This thesis addressed the problem of automating airside wildlife inspection scheduling at Milan Bergamo Airport, where inspections are currently planned manually under tight operational and regulatory constraints. The main objective was to generate feasible daily inspection schedules that meet ENAC and SACBO requirements while minimizing interference with flight operations.

This work characterized wildlife presence and strike risk at BGY using multi-year observation and strike records, quantified seasonal and flight movement patterns within the day with a 5-minute resolution, and formulated a Greedy scheduling heuristic model that adheres to regulatory, operational, and risk-based constraints. It prioritizes runway over ring and perimeter inspections, integrates night, shift-buffer, and movement-based masks, and supports user-defined bounds on the number of inspections per day.

The algorithm was validated over complete historical summer and winter seasons, as well as a future winter season, achieving 100% ENAC compliance in the historical winter dataset, 95.2% in the historical summer under baseline configuration (4–7 runway inspections per day). In the more congested future winter dataset, compliance remained above 90% under baseline configuration, and infeasible days were concentrated on high-movement days with tighter constraints. Compared with SACBO’s static manual schedules, the algorithmic dynamic schedules adapt inspection timing to actual traffic, reducing conflicts with peak movement windows while maintaining the same or higher total number of inspections.

The results demonstrated that a greedy heuristic, when combined, with carefully constructed constraint masks and realistic data, is sufficient to produce inspection schedules that are both operationally feasible and compliant for a wide range of traffic conditions. For SACBO, the proposed approach offers an immediately usable prototype that can be integrated into the existing wildlife monitoring workflow to support planners and BCU operators, while preserving their authority to determine the risks of performing the inspec-

tion at the proposed time. The constraint-driven framework and algorithm are tailored to BGY but could potentially be implemented at other airports of similar or smaller scale. Larger airports would need additional development to account for specific airport factors like inspections routes, number of runways, and available operators.

Future developments for this work can proceed along several directions. First, connecting the scheduling algorithm to real-time flight information would allow hourly schedule updates that incorporate delays and last-minute changes without generating continuous, confusing shifts for operators. These updates could also be accompanied by a short explanation so that operators immediately understand why a time change occurred. Second, the schedule could be displayed simultaneously in the ATC tower, the BCU office, and on the mobile devices used during wildlife inspections, ensuring that all stakeholders share a consistent, up-to-date view of planned inspections in the manoeuvring areas. Monitoring its performance over time, would provide feedback to refine parameters and validate real-world impact. Lastly, extending this framework to multi-airport settings would allow a broader use, capturing airport-specific inspection routes, runway configurations, and staffing levels.

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A | Requirements and Constraints

Table A.1: Regulatory and operational requirements for wildlife inspections

Requirement / Constraint	Source
Airport operator must implement actions to prevent risks of impact between aircraft and wildlife	[7]
Wildlife risk assessment (Birdstrike Risk Index, BRI) must be calculated and monitored for each airport	[7]
Airport must maintain a Bird Control Unit (BCU) and adopt a formal wildlife prevention and control plan	[7]
Use of standardized Bird Strike Reporting Form (BSRF) and Bird Strike Monitoring Form (BSMF) is required	[7]
Annual wildlife strike report and wildlife hazard report must be produced by the airport operator	[7]
Presence and management of attractants in airport surroundings must be evaluated and mitigated	[7]
BCU must perform preventive (scheduled) wildlife monitoring inspections in airside	[17]
BCU must also perform corrective (on-request) inspections when wildlife presence or strikes are reported	[17]
Three programmed inspection types defined: runway, taxiways A/B (“ring”) and perimeter	[17]
Runway inspection must follow prescribed route along runway 10/28 (layout and checkpoints fixed)	[17]
Taxiway A/B and perimeter inspections must follow prescribed routes with specific checkpoints and observation points	[17]

Requirement / Constraint	Source
BCU must position initially at defined checkpoints (1 or 2) before starting runway/taxiway/perimeter monitoring	[17]
Before each runway/taxiway inspection, BCU must pre-coordinate with TWR and request entry to the manoeuvring area	[17]
BCU must maintain continuous radio contact with TWR during monitoring and report "runway free and clear of animals" at end	[17]
If an inspection is interrupted more than once by TWR, BCU must continue along perimeter route to the end-inspection point	[17]
Carcass or remains found must be collected, recorded and removed following a defined procedure	[17]
Wildlife observations, dispersal actions and events must be recorded in the dedicated software / forms	[17]
BCU staff must receive initial and recurrent training on wildlife, procedures and reporting	[17]
Environment and attractant monitoring (internal and external sources) is required	[17]
ENAC compliance requires a minimum of 14 inspections per day, with at least one of each inspection type (runway, ring, perimeter)	[17]
No inspections during night period; at BGY defined as 01:30–05:00 (user-configurable in algorithm)	[17]
No inspection may start during shift changes, nor within 30 minutes before shift end, nor within 10 minutes after shift start	[17]
BGY shift changes occur at 07:00, 15:00, and 23:00, creating three 8-hour shifts	[17]
Runway inspections must avoid slots (and neighbors) where total movements exceed a movement threshold (user-configurable)	[17]
Ring inspections must avoid slots where departures exceed a specified threshold (user-configurable)	[17]
Movement adjacency window and thresholds are user-configurable	[17]

Requirement / Constraint	Source
Perimeter inspections are not subject to traffic-based movement/departure constraints (occur outside movement area)	[17]
Priority ordering between inspection types: runway > ring > perimeter (scores 3, 2, 1)	[17]
User-defined minimum and maximum daily counts for each inspection type ($n_{\min,i}$, $n_{\max,i}$)	[17]
Minimum time gap between inspections of the same type (in slots/hours), including duration and post-inspection buffer	[17]
Forced runway inspections must be placed in pre-night, post-night and dusk windows (if feasible)	[17]
Global no-inspection mask combining night, shift buffers, and other forbidden slots	[17]
Global occupied-slots mask must prevent overlap of inspection body + buffer between any two inspections	[17]
Algorithm must always respect ENAC minimum requirements; if infeasible, day is flagged as "fails minimum requirement"	[17]
Monitoring radius for wildlife observations 13 km around runway	[17]
ENAC runway capacity 26 movements/h (06:00–22:59); 15 movements/h (23:00–05:59)	[17]
Runway inspection duration 10 minutes (2 slots)	[17]
Ring inspection duration 25 minutes (5 slots)	[17]
Perimeter inspection duration 25 minutes (5 slots)	[17]

B | Wildlife at BGY



Ardea alba
Great Egret



Ardea cinerea
Grey Heron



Chroicocephalus
ridibundus
Black Headed Gull



Columba livia
Rock Pigeon



Columba palumbus
Wood Pigeon



Falco tinnunculus
Common Kestrel



Lepus europaeus
European Hare



Sturnus vulgaris
Common Starling

Table B.1: Total wildlife sightings and animals involved in strikes by species (January 1, 2023 – October 28, 2025). Species are ordered by decreasing number of sightings.

Species	Sightings	Strike count
Pigeon	22912	19
Common Starling	13026	5
Carrion Crow	8693	0
Eurasian Magpie	3882	1
Barn Swallow	2426	9
Brown Hare	2091	39
Italian Sparrow	1662	2
Cattle Egret	1637	0
Wood Pigeon	1305	6
Spotless Starling	1131	0
Grey Heron	837	0
Common Kestrel	515	27
Black-headed Gull	178	0
Common Swift	146	1
Common Buzzard	80	1
European Rabbit	50	0
Common Pheasant	41	0
Blackbird	41	1
House Martin	35	0
Mallard	21	0
Eurasian Collared-Dove	18	0
Skylark	10	3
Duck	9	0
Cat	9	0
Wheatear	6	0
White Wagtail	5	0
Green Woodpecker	5	0
Tawny Owl	4	0
Northern Bald Ibis	4	0
Yellow Wagtail	3	0
Little Owl	3	0
Red Fox	3	0

Table B.1 – Continued from previous page

Species	Sightings	Strike count
Rook	2	0
Falcon sp.	2	0
Sacred Ibis	2	0
Great White Egret	1	0
Montagu's Harrier	1	0
Pallid Harrier	1	0
Western Marsh Harrier	1	0
Eurasian Woodcock	1	1
Peregrine Falcon	1	0
Western Marsh Harrier	1	0
Common Chaffinch	1	0
Grey Heron	0	2
Cattle Egret	0	4
White Wagtail	0	1
Barn Owl	0	0
Common Snipe	0	1
Greater Short-toed Lark	0	1
European Rabbit	0	10
Northwestern Crow	0	1
Carrion Crow	0	8
Black-headed Gull	0	5
Yellow-legged Gull	0	1
Tawny Owl	0	1
Lanner Falcon	0	1
Eurasian Hobby	0	1
Blue Rock Thrush	0	1
Unknown	0	34

C |

Class C Aircraft Types at
BGY

This appendix lists all Class C aircraft types included in the data filtering process for runway and ring inspection scheduling analysis. These aircraft represent approximately 97% of movements at BGY during the study period (January 1, 2023 to October 26, 2025).

Table C.1: Class C aircraft types at BGY (n=47)

Model	IATA	ICAO	Historical Count
AEROSPATIALE ALENIA ATR-72	AT7	AT72	626
AEROSPATIALE ALENIA ATR-42	AT4	AT45	2
AIRBUS 321-200 FREIGHTER	32X	A321	4
AIRBUS A220-300	223	BCS3	240
AIRBUS A318 SHARKLETS	31A	A318	16
AIRBUS A320 NEO	32N	A20N	1636
AIRBUS A320 SHARKLETS	32A	A320	11142
AIRBUS A321 NEO	32Q	A21N	10248
AIRBUS A321 SHARKLETS	32B	A321	170
AIRBUS INDUSTRIE A318	318	A318	22
AIRBUS INDUSTRIE A319	319	A319	4404
AIRBUS INDUSTRIE A320	320	A320	12693
AIRBUS INDUSTRIE A321	321	A321	7350
ANTONOV 26/30/32	AN6	AN26	8
ANTONOV AN-26	A26	AN26	18
ATR 72 FREIGHTER	ATF	AT72	22
ATR-42 FREIGHTER	ATZ	AT43	28
BOEING 737 MAX 8	7M8	B38M	79237
BOEING 737 MAX 9	7M9	B39M	18

Table C.1 – Continued from previous page

Model	IATA	ICAO	Historical Count
BOEING 737 PASSENGER	737	B737	12
BOEING 737-300 FREIGHTER	73Y	B733	12
BOEING 737-300 PASSENGER	733	B733	20
BOEING 737-400 FREIGHTER	73P	B734	6
BOEING 737-400 PASSENGER	734	B734	1116
BOEING 737-500 PASSENGER	735	B735	40
BOEING 737-700 PASSENGER	73G	B737	1498
BOEING 737-700 WINGLET	73W	B737	580
BOEING 737-800 FREIGHTER WIN.	73K	B738	14
BOEING 737-800 PASSENGER	738	B738	4787
BOEING 737-800 SCIMITAR WIN.	7S8	B738	100253
BOEING 737-800 WINGLET	73H	B738	49413
BOEING 737-900 PASSENGER	739	B739	4
BOMBARDIER CRJ 1000 NEXTGEN	CRK	CRJX	164
CANADAIR REGIONAL JET 900	CR9	CRJ9	18
DE HAVILLAND DHC-8 DASH 8	DH8	DH8A	6
DE HAVILLAND DHC-8 DASH 8-400	DH4	DH8D	514
EMBRAER 170	E70	E170	14
EMBRAER 175	E75	E75S	130
EMBRAER 190	E90	E190	726
EMBRAER 195	E95	E190	26
EMBRAER E195	195	E195	40
EMBRAER RJ135	ER3	E135	12
EMBRAER RJ135/145	ERJ	E145	2
EMBRAER RJ145	ER4	E145	86
FOKKER 100	FK1	F100	10
MCDONNELL DOUGLAS MD-82	M82	MD82	2
SAAB 2000	S20	SB20	6

D | Schedules and Their Visualizations

This appendix contains visual schedules and schedules themselves for the dates listed in Table 8.4, to further comprehend how the algorithm works and outputs the data.

In the following tables, it can be noted that CF stands for 'closest feasible'. This means the algorithm could not find a feasible start time for the inspection within the specified constraint, but was able to find the next most reasonable slot.

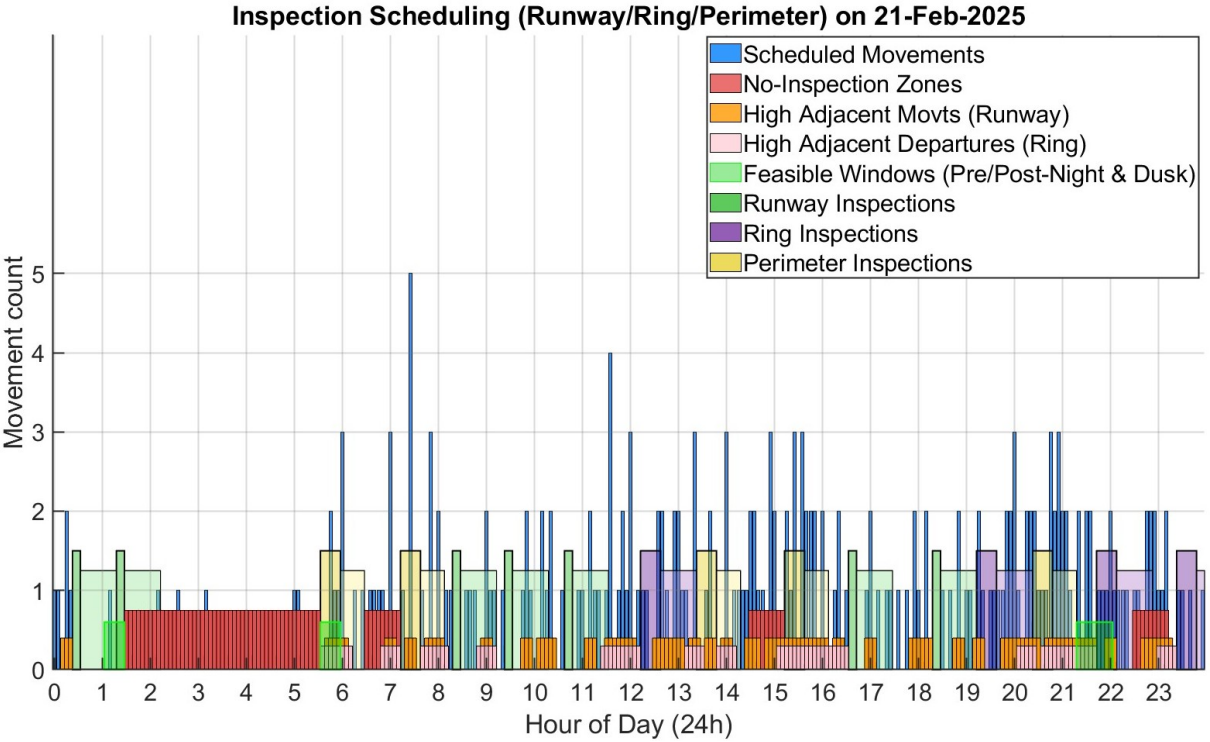


Figure D.1: Inspection schedule and coverage on 21 February 2025.

Table D.1: Final inspection schedule generated for February 21, 2025

Inspection ID	Start Slot	End Slot	Start Time	Type	Status
1	0	1	00:00	Runway	Normal
2	11	15	00:55	Ring	Normal
3	67	68	05:35	Runway	Forced - Post-night (CF)
4	87	91	07:15	Ring	Normal
5	104	108	08:40	Ring	Normal
6	118	122	09:50	Perimeter	Normal
7	129	133	10:45	Perimeter	Normal
8	144	148	12:00	Ring	Normal
9	158	159	13:10	Runway	Normal
10	169	170	14:05	Runway	Normal
11	188	189	15:40	Runway	Normal
12	199	203	16:35	Ring	Normal
13	214	215	17:50	Runway	Normal
14	232	236	19:20	Ring	Normal
15	246	250	20:30	Perimeter	Normal
16	262	266	21:50	Ring	Normal
17	279	283	23:15	Ring	Normal
Schedule Summary:					
Runway inspections: 6					
Ring inspections: 8					
Perimeter inspections: 3					
Total inspections: 17					

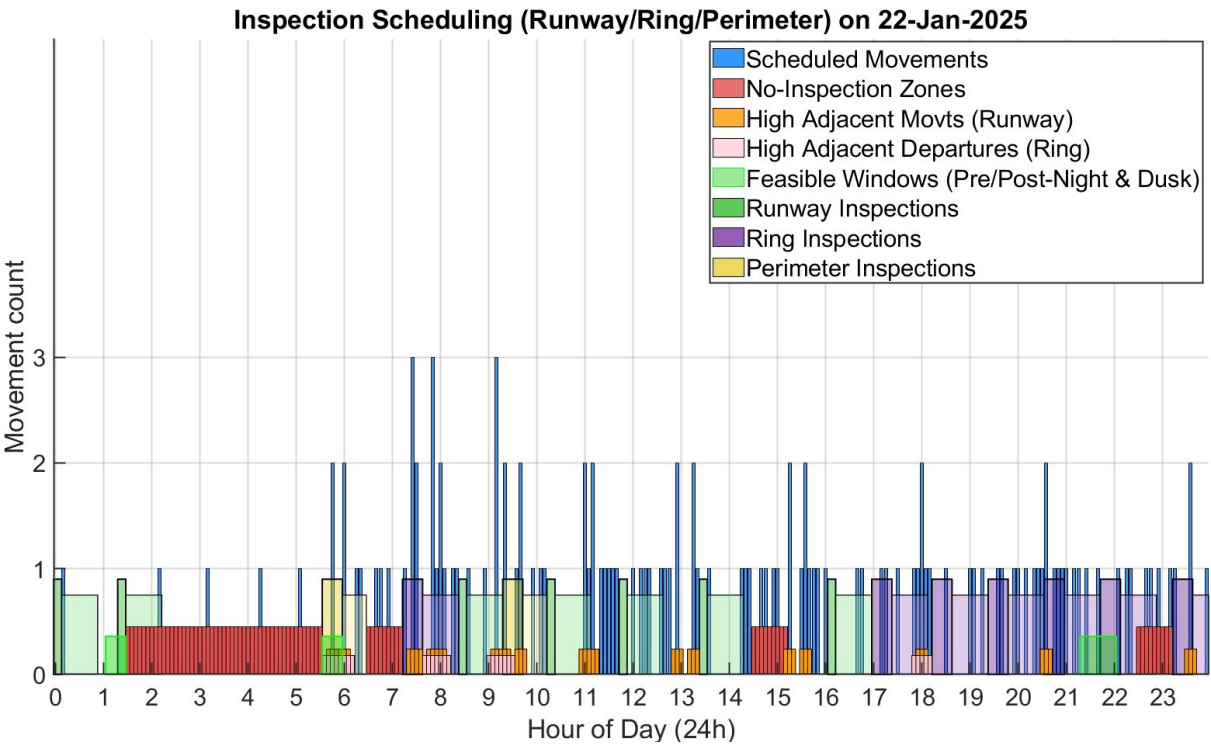


Figure D.2: Inspection schedule and coverage on 22 January 2025.

Table D.2: Final inspection schedule generated for January 22, 2025

Inspection ID	Start Slot	End Slot	Start Time	Type	Status
1	0	1	00:00	Runway	Normal
2	16	17	01:20	Runway	Forced - Pre-night (CF)
3	67	71	05:35	Perimeter	Normal
4	87	91	07:15	Ring	Normal
5	101	102	08:25	Runway	Normal
6	112	116	09:20	Perimeter	Normal
7	123	124	10:15	Runway	Normal
8	141	142	11:45	Runway	Normal
9	161	162	13:25	Runway	Normal
10	193	194	16:05	Runway	Normal
11	204	208	17:00	Ring	Normal
12	219	223	18:15	Ring	Normal
13	233	237	19:25	Ring	Normal
14	247	251	20:35	Ring	Normal
15	261	265	21:45	Ring	Normal
16	279	283	23:15	Ring	Normal
Schedule Summary:					
Runway inspections: 7					
Ring inspections: 7					
Perimeter inspections: 2					
Total inspections: 16					

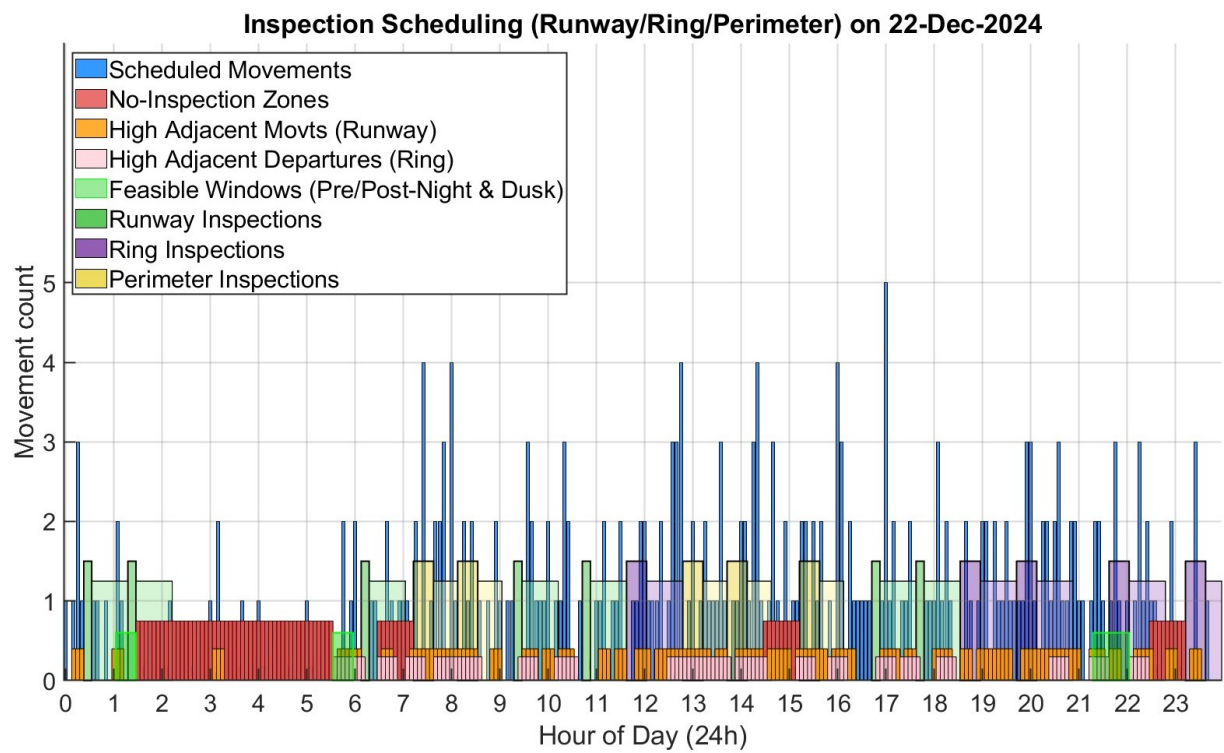


Figure D.3: Inspection schedule and coverage on 22 December 2024.

Table D.3: Final inspection schedule generated for December 22, 2024

Inspection ID	Start Slot	End Slot	Start Time	Type	Status
1	5	6	00:25	Runway	Normal
2	16	17	01:20	Runway	Forced - Pre-night (CF)
3	74	75	06:10	Runway	Normal
4	87	91	07:15	Perimeter	Normal
5	98	102	08:10	Perimeter	Normal
6	112	113	09:20	Runway	Normal
7	129	130	10:45	Runway	Normal
8	140	144	11:40	Ring	Normal
9	154	158	12:50	Perimeter	Normal
10	165	169	13:45	Perimeter	Normal
11	183	187	15:15	Perimeter	Normal
12	201	202	16:45	Runway	Normal
13	212	213	17:40	Runway	Normal
14	223	227	18:35	Ring	Normal
15	237	241	19:45	Ring	Normal
16	260	264	21:40	Ring	Normal
17	279	283	23:15	Ring	Normal
Schedule Summary:					
Runway inspections: 7					
Ring inspections: 5					
Perimeter inspections: 5					
Total inspections: 17					

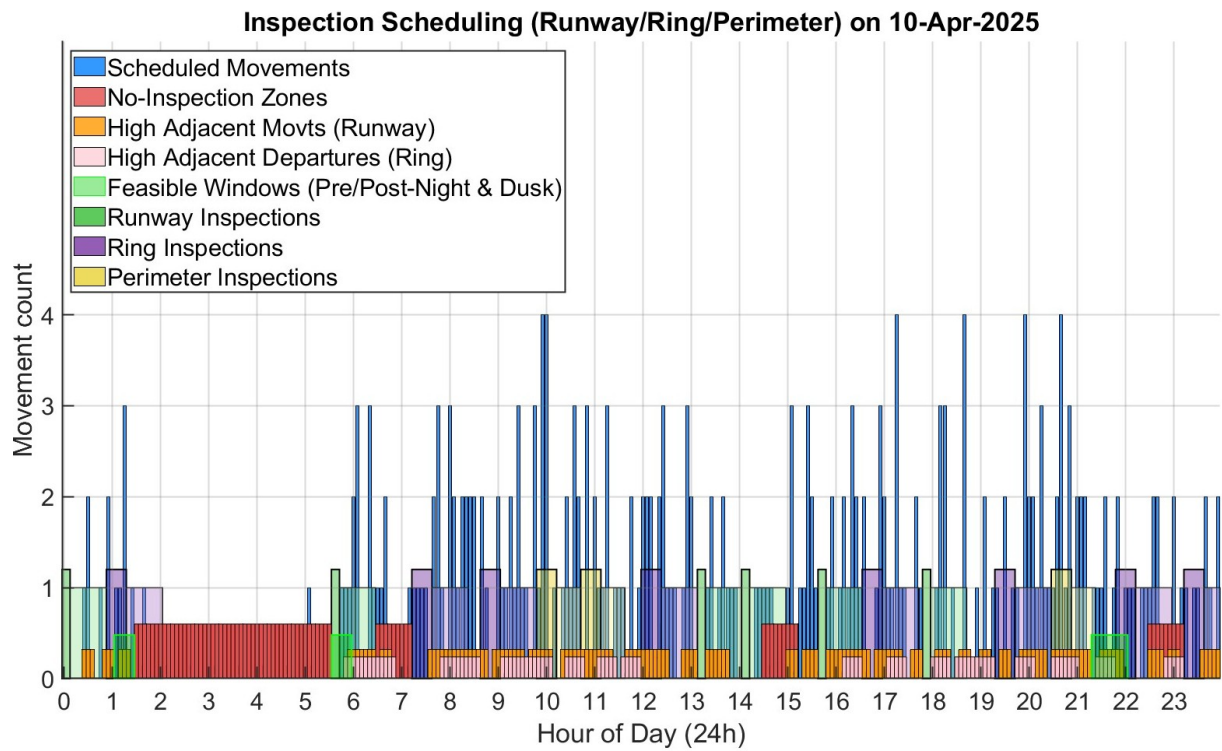


Figure D.4: Inspection schedule and coverage on 10 April 2025.

Table D.4: Final inspection schedule generated for April 10, 2025

Inspection ID	Start Slot	End Slot	Start Time	Type	Status
1	0	1	00:00	Runway	Normal
2	11	15	00:55	Ring	Normal
3	67	68	05:35	Runway	Forced - Post-night (CF)
4	87	91	07:15	Ring	Normal
5	104	108	08:40	Ring	Normal
6	118	122	09:50	Perimeter	Normal
7	129	133	10:45	Perimeter	Normal
8	144	148	12:00	Ring	Normal
9	158	159	13:10	Runway	Normal
10	169	170	14:05	Runway	Normal
11	188	189	15:40	Runway	Normal
12	199	203	16:35	Ring	Normal
13	214	215	17:50	Runway	Normal
14	232	236	19:20	Ring	Normal
15	246	250	20:30	Perimeter	Normal
16	262	266	21:50	Ring	Normal
17	279	283	23:15	Ring	Normal
Schedule Summary:					
Runway inspections: 6					
Ring inspections: 8					
Perimeter inspections: 3					
Total inspections: 17					

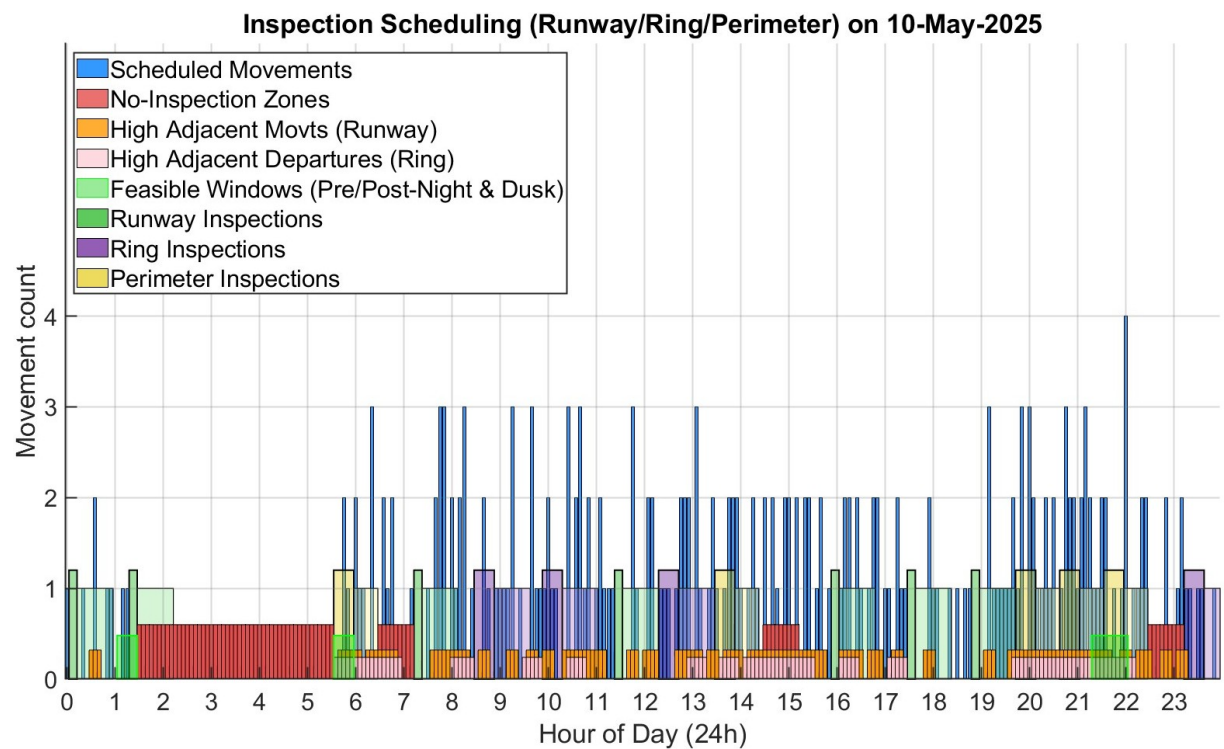


Figure D.5: Inspection schedule and coverage on 10 May 2025.

Table D.5: Final inspection schedule generated for May 10, 2025

Inspection ID	Start Slot	End Slot	Start Time	Type	Status
1	1	2	00:05	Runway	Normal
2	16	17	01:20	Runway	Forced - Pre-night (CF)
3	67	71	05:35	Perimeter	Normal
4	87	88	07:15	Runway	Normal
5	102	106	08:30	Ring	Normal
6	119	123	09:55	Ring	Normal
7	137	138	11:25	Runway	Normal
8	148	152	12:20	Ring	Normal
9	162	166	13:30	Perimeter	Normal
10	191	192	15:55	Runway	Normal
11	210	211	17:30	Runway	Normal
12	226	227	18:50	Runway	Normal
13	237	241	19:45	Perimeter	Normal
14	248	252	20:40	Perimeter	Normal
15	259	263	21:35	Perimeter	Normal
16	279	283	23:15	Ring	Normal
Schedule Summary:					
Runway inspections: 7					
Ring inspections: 4					
Perimeter inspections: 5					
Total inspections: 16					

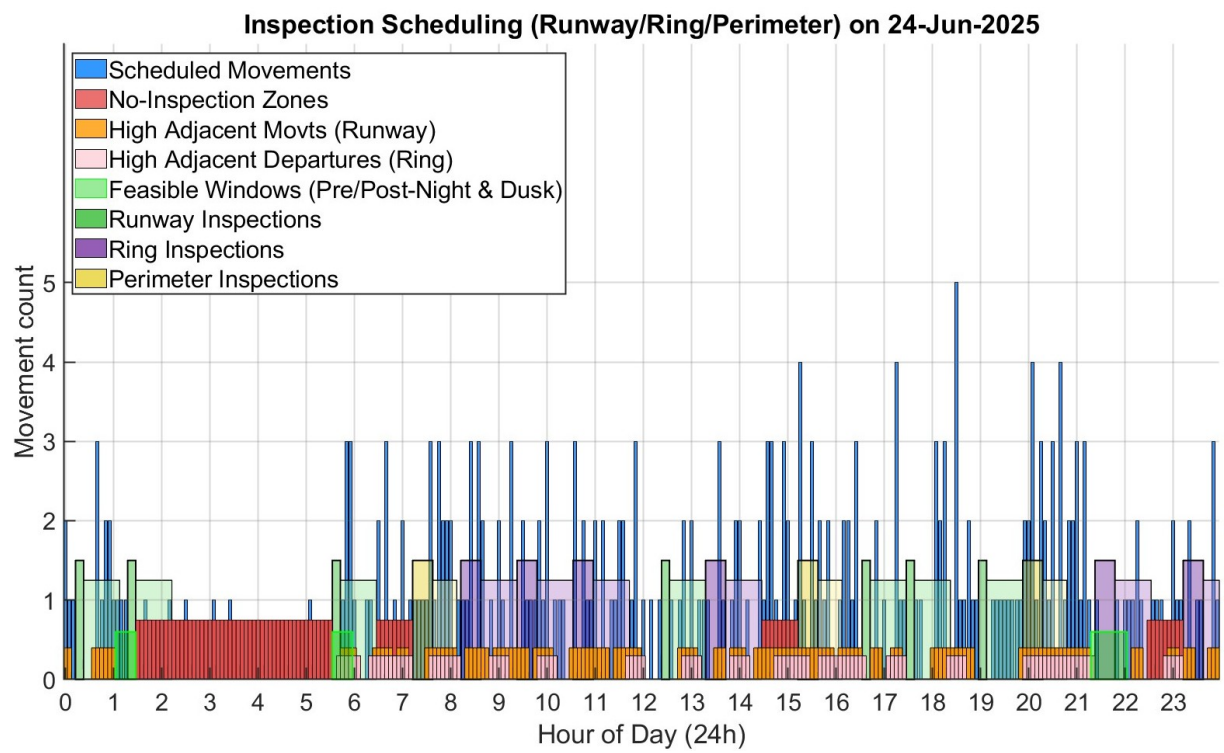


Figure D.6: Inspection schedule and coverage on 24 June 2025.

Table D.6: Final inspection schedule generated for June 24, 2025

Inspection ID	Start Slot	End Slot	Start Time	Type	Status
1	3	4	00:15	Runway	Normal
2	16	17	01:20	Runway	Forced - Pre-night (CF)
3	67	68	05:35	Runway	Forced - Post-night (CF)
4	87	91	07:15	Perimeter	Normal
5	99	103	08:15	Ring	Normal
6	113	117	09:25	Ring	Normal
7	127	131	10:35	Ring	Normal
8	149	150	12:25	Runway	Normal
9	160	164	13:20	Ring	Normal
10	183	187	15:15	Perimeter	Normal
11	199	200	16:35	Runway	Normal
12	210	211	17:30	Runway	Normal
13	228	229	19:00	Runway	Normal
14	239	243	19:55	Perimeter	Normal
15	257	261	21:25	Ring	Normal
16	279	283	23:15	Ring	Normal
Schedule Summary:					
Runway inspections: 7					
Ring inspections: 6					
Perimeter inspections: 3					
Total inspections: 16					

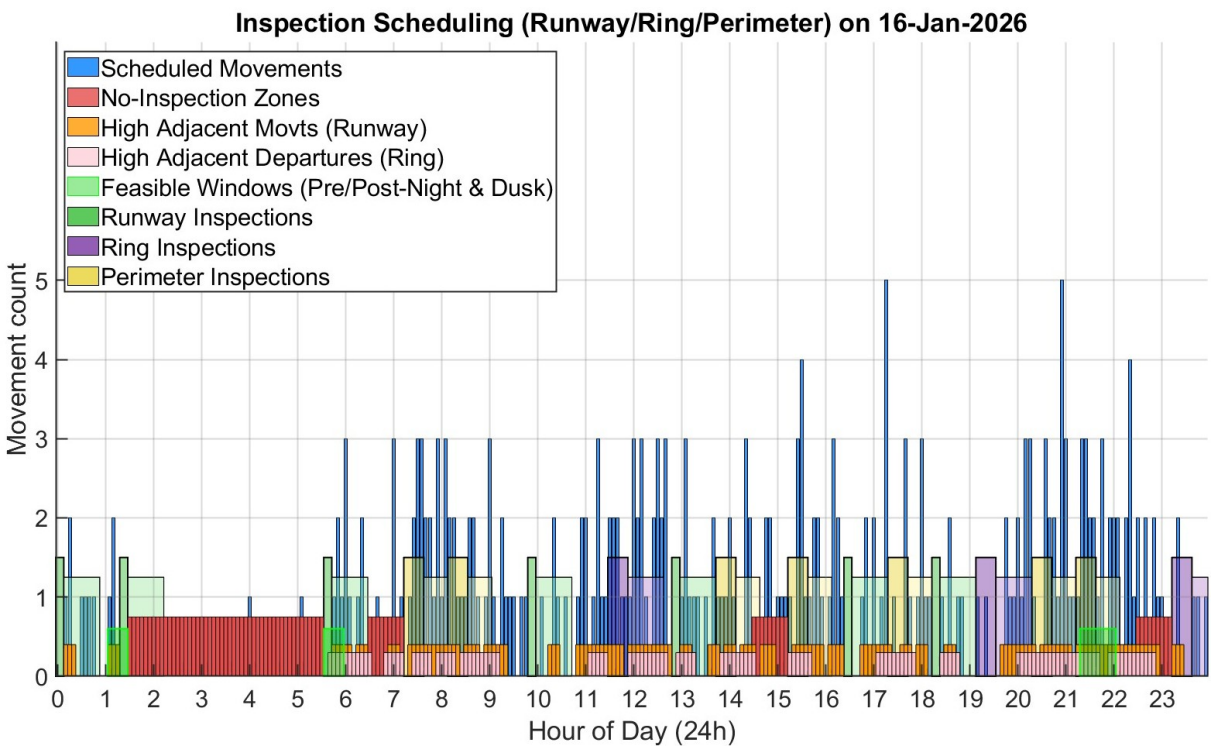


Figure D.7: Inspection schedule and coverage on 16 January 2026.

Table D.7: Final inspection schedule generated for January 16, 2026

Inspection ID	Start Slot	End Slot	Start Time	Type	Status
1	0	1	00:00	Runway	Normal
2	16	17	01:20	Runway	Forced - Pre-night (CF)
3	67	68	05:35	Runway	Forced - Post-night (CF)
4	87	91	07:15	Perimeter	Normal
5	98	102	08:10	Perimeter	Normal
6	118	119	09:50	Runway	Normal
7	138	142	11:30	Ring	Normal
8	154	155	12:50	Runway	Normal
9	165	169	13:45	Perimeter	Normal
10	183	187	15:15	Perimeter	Normal
11	197	198	16:25	Runway	Normal
12	208	212	17:20	Perimeter	Normal
13	219	220	18:15	Runway	Normal
14	230	234	19:10	Ring	Normal
15	244	248	20:20	Perimeter	Normal
16	255	259	21:15	Perimeter	Normal
17	279	283	23:15	Ring	Normal
Schedule Summary:					
Runway inspections: 7					
Ring inspections: 3					
Perimeter inspections: 7					
Total inspections: 17					

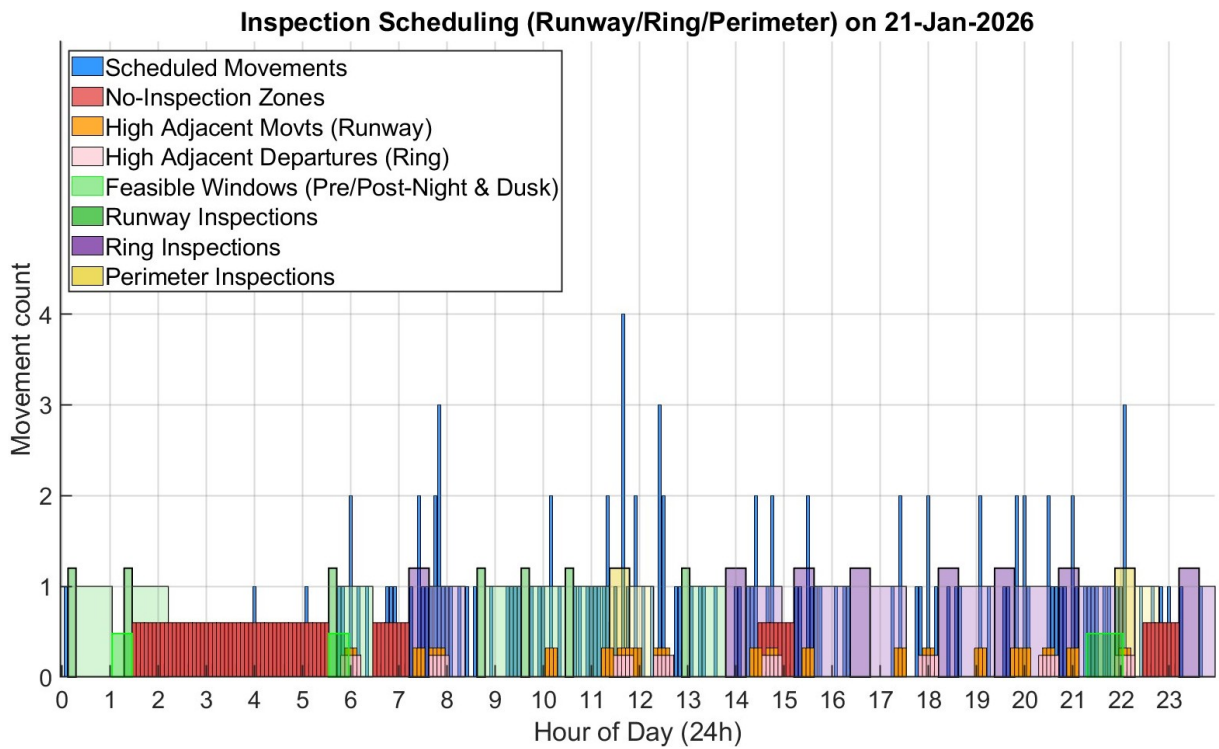


Figure D.8: Inspection schedule and coverage on 21 January 2026.

Table D.8: Final inspection schedule generated for January 21, 2026

Inspection ID	Start Slot	End Slot	Start Time	Type	Status
1	2	3	00:10	Runway	Normal
2	16	17	01:20	Runway	Forced - Pre-night (CF)
3	67	68	05:35	Runway	Forced - Post-night (CF)
4	87	91	07:15	Ring	Normal
5	104	105	08:40	Runway	Normal
6	115	116	09:35	Runway	Normal
7	126	127	10:30	Runway	Normal
8	137	141	11:25	Perimeter	Normal
9	155	156	12:55	Runway	Normal
10	166	170	13:50	Ring	Normal
11	183	187	15:15	Ring	Normal
12	197	201	16:25	Ring	Normal
13	219	223	18:15	Ring	Normal
14	233	237	19:25	Ring	Normal
15	249	253	20:45	Ring	Normal
16	263	267	21:55	Perimeter	Normal
17	279	283	23:15	Ring	Normal
Schedule Summary:					
Runway inspections: 7					
Ring inspections: 8					
Perimeter inspections: 2					
Total inspections: 17					

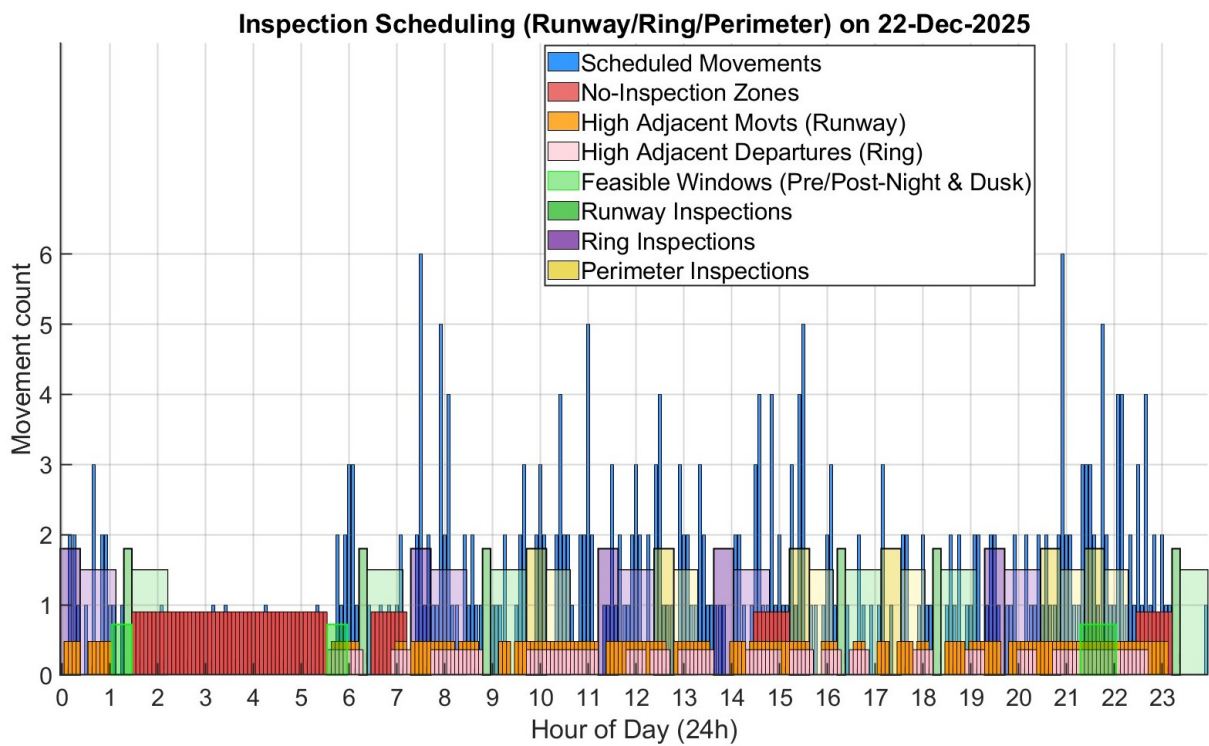


Figure D.9: Inspection schedule and coverage on 22 December 2025.

Table D.9: Final inspection schedule generated for December 22, 2025

Inspection ID	Start Slot	End Slot	Start Time	Type	Status
1	0	4	00:00	Ring	Normal
2	16	17	01:20	Runway	Forced - Pre-night (CF)
3	75	76	06:15	Runway	Normal
4	88	92	07:20	Ring	Normal
5	106	107	08:50	Runway	Normal
6	117	121	09:45	Perimeter	Normal
7	135	139	11:15	Ring	Normal
8	149	153	12:25	Perimeter	Normal
9	164	168	13:40	Ring	Normal
10	183	187	15:15	Perimeter	Normal
11	195	196	16:15	Runway	Normal
12	206	210	17:10	Perimeter	Normal
13	219	220	18:15	Runway	Normal
14	232	236	19:20	Ring	Normal
15	246	250	20:30	Perimeter	Normal
16	257	261	21:25	Perimeter	Normal
17	279	280	23:15	Runway	Normal
Schedule Summary:					
Runway inspections: 6					
Ring inspections: 5					
Perimeter inspections: 6					
Total inspections: 17					

E | List of Symbols

Symbol	Description	MATLAB Variable
$x_{t,i}$	Inspection type i starts at slot t	selected struct
t	Time slot index (0–287)	slot
i	Inspection type index (1, 2, 3)	type
s	General slot index	–
T_{night}	Night period input array	no_inspection_night
$t_{\text{night_start}}$	Night period start slot	night_start_slot
$t_{\text{night_end}}$	Night period end slot	night_end_slot
t_{dusk}	Dusk target slot	dusk_slot
t_{prev}	Previous inspection start slot	same_type_starts
d_i	Inspection duration (slots)	[type]_inspection_duration_slots
b_i	Post-inspection buffer (slots)	[type]_post_inspection_buffer_slots
Δt_{start}	Shift start buffer (slots)	shift_start_buffer_slots
Δt_{end}	Shift end buffer (slots)	shift_end_buffer_slots
w_r	Runway adjacency window (slots)	adj_movement_window_slots
τ_r	Runway movement threshold	adj_movement_threshold
$\tau_{r,\text{body}}$	Runway body movement limit	runway_mov_threshold
w_{rg}	Ring adjacency window (slots)	adj_departure_window_slots
τ_{rg}	Ring departure threshold	adj_departure_threshold_ring
$m(s)$	Total movements in slot s	occupied_slots(s+1)
$m_{\text{dep}}(s)$	Departures in slot s	occupied_dep(s+1)
w_{pre}	Pre-night window size (slots)	closing_open_slots
w_{post}	Post-night window size (slots)	opening_open_slots
w_{dusk}	Dusk window size (slots)	dusk_neighborhood_slots
g_i	Minimum gap (hours)	[type]_min_gap_hours
g_i^{slots}	Minimum gap (slots)	[type]_min_gap_slots
$n_{\text{min},i}$	Minimum inspections required	[type]_min_user
$n_{\text{max},i}$	Maximum inspections allowed	[type]_max_user
$M_{\text{forbidden}}$	Forbidden time slots mask (288×1)	no_inspection_mask

Symbol	Description	MATLAB Variable
$M_{r,\text{mov}}$	Runway high-movement mask (288×1)	<code>adjacent_movement_mask</code>
$M_{rg,\text{dep}}$	Ring high-departure mask (288×1)	<code>adjacent_departure_mask_ring</code>
M_{occupied}	Globally occupied slots mask (288×1)	<code>occupied_mask_all</code>
p_i	Priority score for type i	<code>score (3, 2, 1)</code>

F | List of Abbreviations

Symbol	Description
SACBO	Società per l'Aeroporto Civile di Bergamo – Orio al Serio S.p.A.
ENAC	Ente Nazionale per l'Aviazione Civile (Italian Civil Aviation Authority)
BSCI	Bird Strike Committee Italy
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
EASA	European Union Aviation Safety Agency
BGY	Il Caravaggio International Airport, Milan Bergamo (IATA code)
LIME	Milan Bergamo Airport (ICAO code)
BCU	Bird Control Unit
ATC	Air Traffic Control
GPS	Global Positioning System

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