Case Study: An Integrated Airport Security Planning Approach Using Simulated Annealing and Minimum Cost Flow

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Abstract. This research develops an integrated optimization framework for monthly rostering of airport ground security personnel. The approach combines a Simulated Annealing metaheuristic with a Minimum Cost Flow based staffing assessment to efficiently evaluate coverage and guide the search. Using a real-world dataset from airport security operations, the framework addresses the practical complexity of simultaneously constructing shifts and assigning them to employees while satisfying labor regulations, contractual constraints and employee preferences.

Initial rosters are generated through greedy construction heuristics and subsequently improved using neighborhood moves that modify assignments across multi-day blocks and refine shift characteristics such as timing, duration, and break placement. The Minimum Cost Flow formulation matches available employees to skill demand in each period, enabling fast evaluation of under- and overstaffing across the planning horizon.

For the dataset of the practical case study, the resulting rosters achieve staffing coverage above 99% with less than 1% overstaffing. Overtime remains controlled: roughly 3% of employees work overtime, with average overtime per working employee below 0.5 hours. External staffing is limited to around 6%. Sensitivity analyses illustrate how rosters change when different KPIs are prioritized.

Keywords: Employee Scheduling · Case Study · Simulated Annealing

1 Introduction

The airport security industry benefits greatly from automated and optimized scheduling. This research presents a case in which ORTEC, a leading provider of workforce scheduling optimization software, developed an approach to improve the monthly rostering process for airport ground security personnel. The aim was to design a framework that efficiently allocates staff resources while accounting for the operational complexities inherent to airport security work.

Airport security consists of predefined activities that must be staffed throughout the day, with personnel demand specified per half-hour period and known three months in advance. These activities vary in required staffing levels and can only be performed by employees who hold the appropriate skills. Once the monthly staffing requirements are known, the security company must design shifts and assign them to employees while balancing multiple objectives and satisfying multiple constraints.

In long-term planning, the assignment of employees to specific activities within their shifts is not yet considered. Instead, the objective is to create shift configurations and shift demands that cover the total staffing demand for each skill in every half-hour period. These requirements are obtained by aggregating the demands of all activities that require the same skill. A roster that meets these aggregated skill demands will, by extension, cover the underlying activities. To accomplish this, the rostering problem involves determining feasible shift configurations, each starting at any half-hour and lasting between 4 and 9.5 hours, and assigning them to employees. Because employees may possess multiple skills, they can cover different skill requirements within the same shift, though only one skill can be covered at a time. This flexibility enables closer alignment between staffing levels and fluctuating demand.

The roster must satisfy several types of constraints. First, all schedules must comply with labor rules based on the Dutch Working Hours Act (ATW). These include requirements on daily and weekly rest, restrictions on Sunday and night work, limitations on consecutive night shifts, and mandatory breaks for longer shifts. All employees must satisfy these rules for the roster to be feasible. Second, contractual requirements specify total weekly hours and allowable shift lengths. Across a month, an employee may not exceed 120% of their contracted hours, with the excess counted as overtime. Each assigned shift must lie within the contract's minimum and maximum lengths. Finally, employee preferences are modeled as soft constraints. Employees may request days on or off and may indicate preferred lengths of consecutive shift sequences. While these preferences may be violated, doing so reduces overall solution quality.

Data Case Study The case study covers a 28-day planning horizon and a workforce of 657 employees, of whom 487 are internal. Employees hold an average of 2.3 skills, drawn from a set of 7 unique skills. Total skill demand over the horizon equals 22,510 working hours. Figure 1 shows the mean demand per half-hour period, calculated across all 28 days for each skill. Demand starts at period 8 (04:00–04:30) and falls to zero after period 43 (21:30–22:00), fluctuating throughout the day with morning and evening peaks and a minor bump early in the afternoon.

2 Methodology

This research addresses the integrated monthly rostering problem in which shifts must be constructed and assigned to employees while satisfying labor regulations, contractual constraints, and employee preferences. We solve this problem using a Simulated Annealing (SA) metaheuristic, where solution quality is evaluated through a staffing assessment step that matches scheduled employees to skill demand using a Minimum Cost Flow (MCF) formulation.

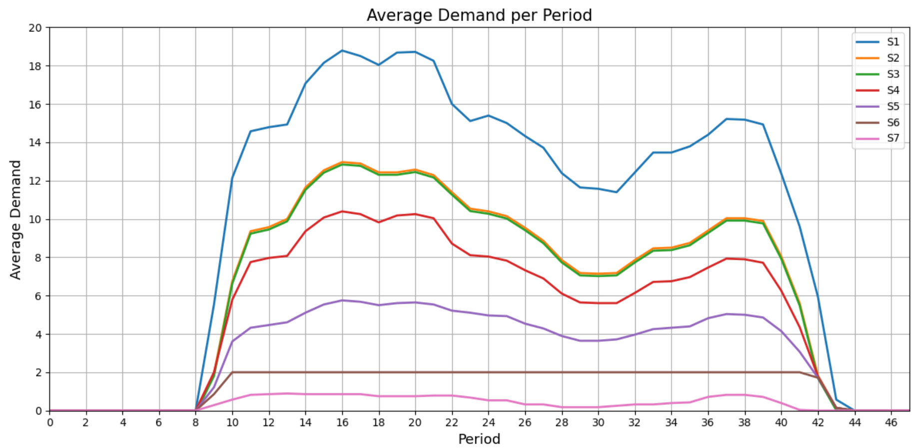

Fig. 1: Mean demand per half-hour period (periods 0–47) for each skill, averaged across all 28 days of the planning horizon.

The solution method is integrated in the sense that it searches directly in the space of complete rosters rather than separating shift generation and shift assignment into sequential steps. The search is initialized with a feasible roster produced by a greedy construction procedure. In this construction phase, employees are scheduled one-by-one using a fixed sorting order that prioritizes internal employees and preserves flexibility by keeping scarce and multi-skilled employees available for later decisions. For each employee, the heuristic assigns shifts only when they cover unmet demand and remain feasible with respect to all hard constraints; for longer shifts, the break position is chosen such that it yields the lowest penalty.

SA then improves this initial roster using two complementary move classes. Assignment searchers change who works which shifts: they swap x-day blocks between two employees (vertical swap), swap two non-overlapping x-day blocks within a single employee schedule (horizontal swap), or replace an employee's x-day block with a single uniform shift type, including days off (change move). Shift searchers refine existing shifts by moving the break, shifting the entire shift one period earlier or later, or extending/shortening the shift by one period at either the start or the end.

Staffing assessment is recomputed after roster changes by matching available employees to skill demand in each period. By combining demand slots and employees with identical skills, this Assignment Problem can be formulated as a Minimum Cost Flow problem and solved using the Cost-Scaling Push-Relabel algorithm [1], which is in practice substantially faster on sparse graphs than the Hungarian Method [2]. Solving the flow model yields the implied under- and overstaffing per skill and period, which is then used to evaluate roster quality throughout the search.

3 Results

The algorithm delivers high-quality solutions according to the defined key performance indicators. Results show excellent staffing coverage above 99%, with controlled over-staffing of less than 1%. Overtime is managed effectively, with about 3% of employees working overtime and average overtime per working employee under 0.5 hours, while taking into account employee preferences for work schedules and preferred working block lengths. Use of external staff is kept at an appropriate level around 6% to support internal capacity when necessary. Furthermore, we did a sensitivity analysis to compare rosters where one of the indicators like under-staffing, over-staffing, overtime, external staffing, or preferences, is valued higher. This shows that the framework is also interesting for other companies and datasets where prioritization is different.
In conclusion, the framework produces practical, high-quality rosters that meet coverage requirements while balancing operational needs with employee preferences. It offers a scalable and adaptable solution for airport security operations and can be applied to other industries requiring continuous staffing, providing a strong foundation for further improvement and real-world implementation.

References

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