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A Dose of Optimization: Radiologist Scheduling at Brooke Army Medical Center

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Abstract: The Radiology Department at the 959th Clinical Support Squadron spends 260 work hours and $97,500 annually on manual scheduling. A senior radiologist spends five hours weekly assigning approximately 33 daily shifts across 10 departments at Brooke Army Medical Center and Wilford Hall. Unplanned absences further complicate the process, requiring frequent schedule adjustments. To reduce this burden, we developed a mathematical program using mixed-integer optimization to automate shift assignments while considering radiologist preferences, certifications, location constraints, and departmental coverage needs. We evaluate outcomes using metrics such as time efficiency and adaptability. Initial testing demonstrates a significant reduction in scheduling time, improved responsiveness to staffing changes, and increased alignment with radiologist preferences. This approach minimizes manual intervention and enhances operational resilience. Our method offers a scalable solution for other Department of Defense and civilian medical facilities, with potential to optimize resource utilization, and reduce recurring costs across complex healthcare systems.

Keywords: Scheduling, medical facilities, optimization

1. Introduction

The Department of Radiology at the 959th Clinical Support Squadron, located at Brooke Army Medical Center (BAMC), provides comprehensive imaging services to service members and their dependents nationwide. As one of the largest military medical centers in the United States, BAMC plays a critical role in supporting the health and readiness of the armed forces, making the efficiency of its operations a matter of national importance. Radiology is a medical discipline that utilizes advanced imaging techniques to diagnose and treat medical conditions without the need for invasive procedures. These imaging modalities include X-rays, fluoroscopy, MRI, CT scans, ultrasound, mammography, and nuclear medicine, all of which are vital for early and accurate diagnosis. Efficient scheduling within the Department of Radiology ensures optimal patient care, maximizes the use of expensive imaging equipment, and minimizes physician burnout. For this project, we worked directly with the 959th Clinical Support Squadron, who was interested in improving the current scheduling process. Currently, the by-hand scheduling process requires approximately 260 hours annually across two sites, consuming valuable time from senior subspecialty-trained physicians with an estimated market value of $350–$400 per hour. The cost of schedule curation is roughly $91,000–$104,000 per year. The new program aims to reduce scheduling time by 25%, saving approximately 65 hours annually, equivalent to $22,750–$26,000 in time value. Additionally, the program will enable quicker and easier adjustments, further enhancing operational efficiency and allowing physicians to focus on higher-value tasks.

1.1 Problem Statement

Currently, scheduling at BAMC is challenging and time consuming. Additionally, accommodating last-minute changes is especially challenging and often leads to scheduling disruptions. Thus, the department seeks to improve its radiology scheduling process to facilitate the creation of weekly schedules in advance.

1.2 Related Work

A significant body of research has been dedicated to the optimization of physician and nurse scheduling worldwide. Recent studies often employ advanced and complex optimization techniques, such as genetic algorithms, as demonstrated by Alharbi and AlQahtani (2017). The application of a genetic algorithm, coupled with a cost matrix, is used to solve optimization problems involving multiple variables. In their study, the authors address a range of factors in addition to scheduling optimization, including cost functions, work patterns, and days off. This approach highlights the flexibility and speed of genetic algorithms in handling multiple constraints and creating efficient schedules. While cost analysis is not a primary concern for the BAMC radiologist scheduling project, the underlying concept of using algorithms to optimize constraints and minimize manual workload is directly applicable.

Other research has explored physician scheduling using mathematical and heuristic approaches to balance constraints, preferences, and operational demands. Gunawan and Lau (2013) developed a mathematical model that incorporates a variety of physician duties, including shifts, training, and other responsibilities, while prioritizing physician preferences and constraints. Their heuristic algorithm provides a robust framework for addressing scheduling challenges in dynamic environments. This is particularly relevant as the BAMC project seeks to incorporate radiologist work types (e.g., radiology shifts, administrative duties, or leave) in a manner analogous to balancing preferences.

Bruni and Detti (2014) present a flexible Mixed Integer Linear Programming (MILP) model, highlighting its adaptability to real-world scenarios by integrating rest periods, shift coverage, and annual leave. Their use of a Branch-and-Cut procedure underscores the utility of mathematical programming in creating schedules that can accommodate changing rules and conditions.

Carter and Lapierre (2001) emphasize the significance of incorporating physician work-life balance into scheduling, showcasing constraints like mandatory rest periods and clustering off-days. Their findings reveal that scheduling methodologies must align with institutional needs while supporting physician well-being. BAMC radiologists' schedules, although simpler with full-day shifts and limited variability, could benefit from this perspective by ensuring fair distribution of workload and adherence to individual leave requests.

Similarly, Beaulieu et al. (2000) discuss the advantages of mathematical programming in physician scheduling, contrasting cyclic and non-cyclic approaches. Their use of a multi-objective integer programming model achieved substantial efficiency gains by reducing manual scheduling time from a week to a day. This highlights the potential of algorithmic methods to enhance both speed and quality in scheduling -- a goal shared by BAMC's initiative.

Altogether, these studies provide a wealth of approaches and considerations for physician scheduling. While the BAMC radiologist scheduling problem does not necessitate the complexity of some of these methods, we can draw from their insights to develop an integer program that balances efficiency and practicality. Integrating lessons from genetic algorithms, preference-based modeling, and flexibility in scheduling rules can ensure that the solution is both robust and adaptable to the needs of the hospital.

2. Data and Methodology

This scheduling project leverages a curated dataset provided by radiologists of Brooke Army Medical Center (BAMC), ensuring that the model reflects the practical realities of current operations. The dataset contains critical information necessary for effective schedule generation, including radiologists' names, primary work locations (either BAMC or the affiliated Wilford Hall Ambulatory Surgical Center (WH)), fellowship specialties (if applicable), their top three preferred specialty areas, and their qualifications for working in pediatrics, cardiology, and mammography. These attributes form the basis for ensuring that scheduled assignments align with both clinical demands and individual expertise. No additional data collection efforts are required, as variables such as compensation rates, hours worked, and employee satisfaction measures are outside the defined scope of this project. Likewise, the scheduling of nuclear medicine rotations and certain specialized emergency room shifts falls beyond the project's boundaries. Nevertheless, the model must incorporate constraints to account for pre-existing assignments in these excluded areas, ensuring that individuals already committed to nuclear medicine or emergency shifts are properly excluded from standard duty rosters. Furthermore, the algorithm must dynamically adjust for personal unavailability due to factors such as scheduled leave, official travel, mandated crew-rest periods, or other operational commitments. Incorporating these real-world constraints ensures that the resulting schedules are not only feasible but also robust to the common disruptions experienced in a high-tempo clinical environment.

2.1 Optimization Formulation

Sets and Subsets

- S is the set of shifts.
- D is the set of days.
- R is the set of radiologists.

Parameters

- $\underline{\delta}_r$ and $\overline{\delta}_r$ are the minimum and maximum number of days radiologist r works weekly, respectively.
- c_r is 1 if radiologist r is qualified to work cardiology, 0 otherwise.
- m_r is 1 if radiologist r is qualified to work mammography, 0 otherwise.
- p_r is 1 if radiologist r is qualified to work pediatrics, 0 otherwise.
- α_{rd} is 1 if radiologist r is available to work on day d, 0 otherwise.
- c_{sr} is radiologist r's preference to work shift s. A value of n indicates alignment with the radiologist's nth section preference at their primary location. A value of 5 represents a shift within radiologist r's top three section preferences, but not at their primary location. A value of 10 represents a shift that is not among radiologist r's top three section preferences.

Decision Variable

- $x_{sdr} \in \{0,1\}$ is 1 if shift s is filled by radiologist r on day d, 0 otherwise.

Integer Programming Formulation

$$minimize \sum_{r}^{R} \sum_{s}^{S} c_{sr} \cdot x_{sdr} \qquad (1)$$

Subject to:

$$\sum_{r}^{R} x_{sdr} = 1 \qquad \forall s, d \qquad (2)$$

$$\underline{\delta}_r \leq \sum_{s}^{S} \sum_{d}^{D} x_{sdr} \leq \overline{\delta} \qquad \forall r \qquad (3)$$

$$\sum_{s}^{S} x_{sdr} \leq \alpha_{rd} \qquad \forall r, d \qquad (4)$$

$$x_{sdr} \leq c_r \qquad \forall d, r \qquad (5)$$

$$x_{sdr} \leq m_r \qquad \forall d, r \qquad (6)$$

$$x_{sdr} \leq p_r \qquad \forall d, r \qquad (7)$$

Formulation Description

- (1) The objective minimizes the sum of preference numbers across all radiologists.
- (2) Radiologists can only be scheduled for one shift per day.
- (3) Radiologists must work the minimum number of days but cannot exceed the maximum number of days per week.
- (4) Only radiologists available for work on a given day are scheduled.
- (5) Radiologists must be qualified to be assigned to the cardiology section.
- (6) Radiologists must be qualified to be assigned to the mammography section.
- (7) Radiologists must be qualified to be assigned to the pediatrics section.

2.2 Methodology

To create a weekly schedule that satisfies all constraints while allowing flexibility in priority adjustments, an integer programming (IP) approach was adopted using PuLP, a Python-based linear and mixed-integer programming solver. By formulating the scheduling program as a math program and solving it with optimization, we're able to generate a solution that satisfies all scheduling requirements while maximizing the schedule quality, as measured by provider preferences. Integer programming (IP) is a mathematical technique used to optimize an objective function subject to a set of linear equality and inequality constraints, with the additional requirement that some or all decision variables must take integer values. IP is particularly useful in problems involving discrete decisions, such as scheduling, allocation, and resource management, where fractional solutions are not feasible or meaningful.

The IP model incorporates several key inputs, including availability, which ensuring that only providers who are available during a given time slot are scheduled; workload constraints, which limit the number of shifts assigned per provider per week; section preferences, which account for individual provider preferences for specific departments; qualifications, ensuring that providers are assigned only to sections where they are certified to work; and primary location, which reflects a provider's default or preferred workplace.

The objective function minimizes the total preference score, but since lower scores represent better preferences (with 1 being the most preferred and 10 being the least), this effectively means we are maximizing radiologist satisfaction. By assigning shifts in a way that results in the lowest total preference score, the model ensures that radiologists receive their most desired shifts as frequently as possible. By formulating the scheduling problem as an IP, the solution optimizes assignments while ensuring feasibility. This approach enhances scalability and adaptability, enabling seamless modifications to constraints and preferences as operational requirements evolve.

Since there are times during the year when staffing is low, there may not be enough radiologists to cover all of the required shifts (i.e., there are no feasible solutions). In practice, a single radiologist will simultaneously cover multiple shifts during these times. For our model, to ensure a feasible solution exists, we added ghost providers (i.e., artificial placeholder providers) to fill slots in the case of an infeasible solution. These ghost providers, if required to satisfy a feasible solution, display instances where a radiologist will need to be double-booked for the day.

To incorporate the primary location constraint, each radiologist was assigned a designated work site, and a penalty was applied in the objective function if they were scheduled outside their primary location. This allows for flexible scheduling during times of limited staffing while still discouraging unnecessary reassignment. The scheduling model operates within a military clinical environment where providers follow a standard Monday through Friday schedule, and weekends are not worked. This simplifies the need for additional constraints related to consecutive workdays or rest periods. All constraints were manually encoded using PuLP in an interpretable way, making it easy to adjust the model logic to fit different operational contexts or evolving scheduling needs.

2.3 Implementation and Advantages

The optimization scheduling model was implemented in Python, a versatile and widely used programming language. This decision was intentional, by choosing Python, we ensured that the model could be executed on free and accessible platforms like Google Colab. This eliminates the need for paid software or advanced computing environments, making the tool more practical for real-world use by hospital administrators or scheduling coordinators.

The scheduling process begins with a comma-separated values (CSV) file, which contains structured information on each radiologist's name, specialty, and daily availability. Each row in the dataset corresponds to an individual radiologist, and the columns include identifiers for name, specialty, and a binary availability indicator (1 for available, 0 for unavailable) across a predefined scheduling horizon. This structure allows users to easily specify constraints such as unavailability on specific days, which the model uses to dynamically adjust the pool of assignable personnel during the optimization process.

This optimization model offers several benefits:

- **Feasibility**: Algorithm guarantees that every schedule it generates is feasible, adhering to all hard constraints such as required coverage, daily limits per radiologist, and specialty-based assignments.
- **Flexibility**: The model is designed to be responsive to changes. Administrators can easily modify the input spreadsheet to reflect real-time availability, staffing updates, or changes in department needs. The model adapts accordingly without requiring a complete rewrite or reconfiguration.
- **Efficiency**: Manual scheduling is often time-consuming and error-prone. This automated model streamlines the process, significantly reducing the time and effort required to generate a full week of assignments.

- **Equitability**: Preference-based considerations were integrated into the model. Radiologists' preferred sections and work locations are respected whenever possible, promoting fairness and job satisfaction while still satisfying operational demands.
- **Accessibility**: This tool runs entirely in Python using an open-source, linear programming modeler (PuLP) and is compatible with multiple IDEs, making it routine to implement and replicate. Users with minimal technical experience can upload the spreadsheet, run the code, and generate a new schedule without additional training.

This approach aligns with BAMC's requirements by delivering a practical, adaptable, and efficient scheduling solution tailored to the specific needs of its radiology department. The CSV file is easy to modify, allowing for ease in adjustments to the list of providers and their availability.

3. Results

Initial estimates following model completion suggest that generating a weekly schedule requires approximately 30 minutes. To validate this assumption, test cases were conducted using a simulated list of available radiologists for a given week. The scheduling product was then applied to these lists to assess its efficiency. Validation by multiple operators confirmed that the optimized model could generate a complete weekly schedule in under eight minutes.

This improvement reduces the annual scheduling effort to approximately seven hours, a significant decrease from the baseline of 260 hours. As a result, the tool is projected to cut scheduling time by 97.3%, yielding annual savings of $94,900 on average. These results surpass the original efficiency and cost-saving goals. Furthermore, preliminary user feedback suggests that this scheduling tool will outperform the current system used by the BAMC Department of Radiology, providing a more effective and streamlined solution.

4. Conclusions and Future Research

Medical scheduling is a complex and time-intensive task. Developing a tool to streamline the scheduling process for medical professionals can save significant time and money for medical facilities. After extensive research, an integer programming model was identified as the most effective approach for optimizing the weekly schedule, with implementation carried out using Python. The primary objective—creating a scheduling tool that is both flexible and easy to implement while adhering to all constraints—was successfully achieved.

Although this scheduling tool was designed specifically for a radiology department, applications could be extended to other medical departments and facilities within the Department of Defense (DoD), as many of these facilities operate under similar constraints. Additionally, expanding its application beyond DoD medical facilities is feasible by incorporating constraints relevant to civilian healthcare settings, such as weekly work-hour limits. Scaling this tool beyond the BAMC Radiology Department presents a realistic and practical opportunity for broader implementation.

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