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DESIGN AND IMPLEMENTATION OF AN AUTOMATED SCHEDULER FOR PHARMACISTS IN A LOCAL HOSPITAL

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To deliver adequate healthcare to the community, it is crucial to lower expenses and enhance the working environments for healthcare professionals, such as nurses, doctors, and pharmacists. Traditionally, pharmacists were not considered a significant component of the healthcare system, as their role primarily involved medication delivery. However, over the past few decades, the role of pharmacists has evolved significantly, making them a crucial and integral part of the healthcare staff due to their involvement in new missions. Consequently, the pharmacists' community must be considered within the broader healthcare system. Pharmacists now face new challenges, such as unbalanced workloads and burnout. This paper examines a case study involving pharmacists at a local hospital. Pharmacist scheduling was traditionally performed manually, a process that proved both time-consuming and error-prone. Moreover, the resulting schedules often failed to meet pharmacists' preferences, leading to dissatisfaction. A decision support system (DSS) for optimizing pharmacist scheduling in a hospital is developed in this paper. This DSS aims to automatically and efficiently generate well-balanced schedules that satisfy the pharmacists as much as possible. Balancing workload, considering pharmacist preferences, and meeting daily coverage requirements are challenging tasks that are difficult to accomplish manually without the assistance of a computer. Therefore, a mathematical model, specifically a Mixed Integer Programming (MIP) model, was developed to generate an optimal schedule for pharmacists. This model considers individual pharmacists' preferences, their ability to fulfill duties, workload balancing, and annual leave requirements. The model has been implemented, and a graphical user interface has been developed. This interface allows users to input the required number of pharmacists needed each month and their preferences, and also allows automatic generation of the schedules. An experimental study was conducted to evaluate the proposed DSS's performance. As a result of the automated schedules, overtime has been eliminated completely, and pharmacists' preferences have been accommodated. The proposed DSS automates pharmacist scheduling while considering human preferences and fairness criteria, offering a practical tool for hospital administrators to enhance efficiency and staff satisfaction.

Keywords: Pharmacists' Scheduling; Balanced Workload; Burnout; Integer Linear Program.

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1. INTRODUCTION

Pharmacists play a crucial and significant role in healthcare (Chagas *et al.*, 2023; Lichvar *et al.*, 2023; Watson *et al.*, 2023). Pharmacists are essential members of the healthcare team and contribute to patient care in various ways (Lee *et al.*, 2023; Suman and Pravalika, 2023). Here are some key points highlighting the importance of the role of pharmacists: Medication Management (Ashkanani *et al.*, 2023; Kim *et al.*, 2023), Patient Education (Alabadallah *et al.,* 2023; Wilby et al., 2023), Medication Safety (Sikora, 2023), Collaborative Care (Mohamed Ibrahim *et al.,* 2022), Disease Management (de Oliveira Duarte *et al.*, 2023; Fujii *et al*., 2023; Meilianti *et al*., 2023; Undeberg *et al*., 2023; Urslak *et al*., 2023), Public Health and Preventive Care (Geiger *et al*., 2022; Amin *et al.*, 2023; Hedima and Okoro, 2023).

Pharmacists face several challenges in their profession (Febrinasari *et al*., 2023; Halimi *et al.*, 2023), which can impact their ability to deliver optimal patient care. Here are some common challenges faced by pharmacists. Workload and Time Constraints (Rudis *et al*., 2017; Terry *et al*., 2023), where pharmacists often experience heavy workloads and time constraints, with increasing demands for their services. This can limit the time available for patient counseling, medication management, and other clinical activities. In addition, burnout and stress (Fadare *et al*., 2022; Ljungberg Persson *et al*., 2023) are among the challenges faced by pharmacists. Indeed, the demanding nature of the profession, coupled with high patient expectations, can contribute to pharmacist burnout and stress. Long hours, workplace pressures, and a lack of work-life balance can impact job satisfaction and overall well-being.

To overcome these challenges, providing optimized scheduling and combating burnout and stress among pharmacists, implementing effective scheduling algorithms and strategies is crucial. Here are some approaches that can help. Balanced Workload Distribution, which consists of designing scheduling algorithms that distribute workloads evenly among pharmacists, taking into account factors such as experience, skill level, and workload preferences. Avoid overloading individuals with excessive shifts or extended working hours, as this can contribute to burnout. Furthermore, ensure adequate Rest Periods, which consist of ensuring that scheduling algorithms incorporate sufficient rest periods between shifts. Allowing pharmacists to have adequate time for rest and recovery can prevent fatigue and promote well-being. Furthermore, providing flexible Schedules that aim to offer flexible scheduling options whenever possible, such as part-time or flexible hours, to accommodate individual needs and promote work-life balance. This allows pharmacists to have more control over their schedules and reduces the likelihood of burnout.

Today, optimization in the healthcare sector has received significant attention as a means to deliver better and more cost-effective services, thereby reducing healthcare costs (Fei *et al*., 2010; Rais and Viana, 2011). In addition to this, hospitals are facing the problem of high costs and limited resources (e.g., medical supplies, equipment, doctors, and staff), and therefore, this issue is urgent and attracts the attention of many researchers, as it is imperative. Actually, healthcare scheduling can be quite challenging due to the number of constraints and preferences involved. These constraints include the demands on personnel and the limited resources available. Healthcare institutions operate around the clock, unlike most other organizations.

As a result, a lack of staffing and irregular work shifts may cause staff to feel dissatisfied with their jobs, as well as affect the satisfaction of patients. A rise in the number of elderly people will inevitably lead to an increase in the number of people in need of medical services (Rais and Viana, 2011; Batun and Begen, 2013). However, there seems to be an ever-increasing need for medical care, which may lead to an increase in fatalities, overworked manpower, increasing rates of infection among patients, and overcrowding among patients as a result of it (Oueida, 2020).

To create a schedule that is both legally compliant and fair to the staff, we must rigorously define the rules that govern the process. Hard Constraints are the non-negotiable rules, like safety limits and legal rest periods, that must always be satisfied. In contrast, Soft Constraints represent desirable goals, such as meeting a pharmacist's preference or balancing workload, which can be traded off, but at a measurable cost. This human-centered cost is tracked via Shift Deviation, which quantifies exactly how far the final schedule misses a target, ensuring that every compromise made in staff well-being is transparently calculated and minimized.

In addition to reducing the waiting time for patients, a scheduling system can better facilitate access to medical services. It also improves the quality of operations associated with health care (Fei *et al*., 2010; Hall, 2012). It is essential to determine the hard and soft constraints of a healthcare system before coming up with an appropriate schedule for the system. A hard constraint is a restriction that cannot be violated. On the other hand, a soft constraint is a restriction that is included as part of the cost function and should be minimized as much as possible.

Therefore, in order to improve the hospital's service quality and to contribute to its benefit to patients, it is crucial for hospitals to enhance, plan and schedule procedures related to the utilization of their resources. It is very important to improve the scheduling system in order to reduce costs and revenues as well as to facilitate greater access to healthcare services for hospital patients (Gupta and Denton, 2008).

1.1. Nurse rostering problem

It has been found that nurse rostering problems are a type of staff scheduling problem (Ernst *et al*., 2004). An effective scheduling system consists of the organization of a timetable that satisfies the demands of every individual without causing any conflicts or conflicts (Ernst *et al*., 2004). The optimization of nurse rosters has been found to be a particularly complex and difficult problem due to its complexity (Zhou *et al*., 2012). It has been attempted by many researchers to find a solution to this problem by utilizing different optimization models. There are two steps involved in the process of nurse rostering, and it is an NP-hard problem. To schedule staff, first determine their number, and then allocate them according to the schedule's time horizon.

There are so many entrenched problems in nurse scheduling that it requires a balanced approach to balance workload and preferences in the health care system (Burke *et al*., 2004). The nurse scheduling problem consists of the assignment of a group of skilled nurses over a predefined period to various kinds of shifts in an NP-hard optimization problem (Awadallah *et al*., 2013). A schedule that is feasible will require a hard constraint to be met while allowing a soft constraint to be met, but penalizing it for failing to meet it. It is important to maximize nurse scheduling preferences while minimizing the overall cost of the process (Gokalp, 2021).

Among the many personnel scheduling problems, the problem of optimizing Nurse Rostering (NRP) has developed into a major focus for researchers in the field. In recent years, many optimization researchers have become interested in this problem. In the field of healthcare systems, nursing shortages are an important and complex issue that needs to be addressed on a multifaceted basis. In order to solve the problems, a wide variety of techniques have been used by researchers, such as exact approaches, heuristic procedures, and metaheuristics. Among the open research challenges at the operational level, nurse rostering is a problem that is being addressed through the use of various metaheuristics. Due to the ability to balance exploration and exploitation, hybridizing metaheuristics with local search has been shown to solve NRP (Awadallah *et al*., 2015).

Different types of constraints, features, and a variety of real hospital data sets have been used to study the nurse rostering problem in a variety of countries (Pillay and Qu, 2018) with different types of constraints, features, and evaluations. There has been considerable focus on the INRC-I data set, as well as the INRC2010 data set, in most of the studies. There is a limitation in creating real data sets from hospitals in different countries. It is the responsibility of the hospitals to maintain their privacy in this regard. Due to the complexity of the dynamic version of the INRC-II and the multi-stage scenario, the number of studies has been limited. INRC-II has been studied mainly on small scales (4-8 weeks) in order to evaluate its effectiveness. A potential solution to nurse scheduling would be to take into consideration the conditions of each country in order to develop a more effective solution. In order to improve the performance of medical institutions, it might be necessary to integrate nurse scheduling with other healthcare problems, such as patient scheduling and physician scheduling.

1.2. Physician scheduling problems

The research community pays less attention to many scheduling problems in healthcare than they should. These problems include physician scheduling problems (Gendreau *et al*., 2006; Gunawan and Lau, 2013; Bruni and Detti, 2014), home health care scheduling problems (Demirbilek *et al*., 2019; Restrepo *et al*., 2020; Demirbilek *et al*., 2021), and telemedicine scheduling problems (Erdogan *et al*., 2018). A physician's schedule is one of the real-world problems that arise in hospitals. It corresponds to a type of staff schedule that is governed by a complex set of regulations. Scheduling physicians is the process of assigning a physician to certain activities or tasks during specific time slots/shifts, such as performing surgeries, clinics, scopes, phone calls, and administrative tasks. A planning horizon is selected, and a variety of preferences and constraints are taken into account (Gunawan and Lau, 2013) based on the planning horizon. In terms of physician scheduling problems, two types of rosters need to be planned for cyclic or ad-hoc use. A cyclic plan must be reconstructed because a physician may have different work rosters from week to week.

When it comes to cyclic planning, doctors typically follow a set model for their posts, including or not rotating on a weekly basis. Considering the physician problem, it has been shown that planning and scheduling appointments can be divided into three levels of decision-making (strategic, tactical, and operational planning) (Vijayan *et al*., 2022). The day-to-day scheduling of physicians is largely related to the day-to-day tasks that they are assigned on a daily basis (Van Huele and Vanhoucke, 2014). A mathematical programming model for solving a master physician scheduling problem has been proposed by researchers such as Gunawan and Lau (2013), whose motive was to develop a mathematical programming model to solve the master physician scheduling problem. An MIP approach is also proposed in (Bruni and Detti, 2014) and (Gross *et al*., 2018) to solve this problem by means of integer linear programming. Moreover, Smalley *et al*. (2015) found that doctors in the pediatric intensive care unit (PICU) were also assigned based on their availability to provide medical care. Alternatively, in the context of operating room scheduling, Van Huele and Vanhoucke (2014) used the MIP technique in order to solve the problem of scheduling operating rooms for physicians and surgeons.

In addition to this, Dos Santos and Eriksson (2014) have detailed physician problems in Swedish public hospitals in a case study. Additionally, Damcı-Kurt *et al*. (2019) presented the issue from a US hospital's perspective with a view on how the problem could be addressed. Several types of physician scheduling have been studied by the authors using a variety of priorities as a guide.

Furthermore, Gharbi *et al*. (2017) studied the problem using a case hospital from King Khalid University in Saudi Arabia. It has been proven that home healthcare scheduling is an optimization problem that has grown at various decision levels in healthcare, such as staffing or scheduling shifts, as it has grown over time (Fikar and Hirsch, 2017). There may be a need for different sets of nurses to be allocated to different groups of clients located in different parts of the country, for example. As a result, it is important to consider a variety of constraints, requirements, and preferences. These include the expertise of the nurse, the requirements of the client, and the length of time the nurse needs to be available. Home healthcare scheduling optimization maintains a balance between nurse and customer expertise, but the selection of skills varies depending on the regulatory environment and the client's needs. It has been found that metaheuristic algorithms are the most effective solution method when it comes to the scheduling of home healthcare services (Bennett and Erera, 2011; Allaoua *et al.,* 2013).

Authors in Hidri et al. 2020) studied a real-world situation that consists of scheduling a set of physicians in an ICU unit. The main objective is to reduce overtime and the unbalanced workload. A mixed integer linear program was proposed to solve the problem, and the obtained results are satisfactory.

1.3. Pharmacists' scheduling problems

Pharmacists are increasingly taking on functions other than those that are usually related to dispensing medicines and distributing health supplies based on the traditional product-oriented view of the profession. Among the many functions played by pharmacists, access to care is an essential aspect of the prevention of many diseases. In light of the fact that there is a shortage of health professionals, pharmacists are potentially the first point of contact and can provide clinical advice, which may help to decrease unnecessary medical visits to emergency rooms for common conditions (Martin and Manasse Jr, 2006).

As part of Pharmacy and Therapeutics Advisory Committees (P&T), protocols are often developed and vetted for their effectiveness. The pharmacist's role is often involved in the diagnosis and treatment of minor diseases, as well as the management of chronic diseases. Furthermore, pharmacists are also excellent human capital resources for the community due to the fact that they conduct primary prevention, such as health education, to help prevent diseases in the future. Therefore, it is necessary to recognize that pharmacists play an integral role in the healthcare infrastructure, which is why they need to be given more attention.

To maximize resources and address the workforce needs within the fields of pharmacy and hospitals, it is essential to examine current practices in using the existing human resources. Surprisingly, the pharmacists' scheduling problems are less treated in the literature, and very few studies are presented. In this context, authors in (Wright *et al.,* 2021) present the results of a survey study conducted within a hospital where the participants are pharmacists and technicians. This study is intended to explore the methods to be adopted to improve scheduling satisfaction.

Authors (Rudis *et al.,* 2017) developed a data-driven model to predict emergency department pharmacists (EDP) scheduling to ensure that their capacities are utilized effectively and that clinical activities are covered to the maximum extent possible. In (Gregório *et al.,* 2017) authors examine the workload and work patterns of community pharmacists in Portugal and establish a relationship with the demand for pharmaceutical services.

1.4. Multi-objective personnel scheduling and goal programming

As this study utilizes a multi-objective optimization framework centered on Goal Programming (GP), a brief literature review is presented. Recent research has increasingly focused on improving healthcare workforce scheduling through multi-objective optimization, particularly GP and related methods. Although few studies have directly addressed pharmacist scheduling, several works in nurse and general hospital staff rostering provide transferable methodological insights. Rerkjirattikal *et al.* (2020) developed a 0-1 GP model to balance workload fairness and individual preferences, achieving improved satisfaction and equitable task distribution.

Similarly, Fitriani *et al.* (2020) proposed a fuzzy GP (MINMAX) model to handle uncertainty in preference satisfaction, effectively balancing multiple goals under ambiguous constraints. Fourati et al. 2023) introduced a lexicographic GP combined with dynamic satisfaction functions to prioritize hierarchical objectives, ensuring that high-priority goals are consistently met. Hu *et al.* (2024) extended this concept using a robust multi-objective optimization model that considers demand and resource uncertainty, yielding resilient staff schedules.

Yasmine *et al.* (2024) later demonstrated that workload balancing via MIP formulations can significantly reduce consecutive working days and workload variance among healthcare workers. Koruca *et al.* (2023) developed an integrated, personalized scheduling system that merges optimization algorithms with staff preference interfaces, validating the model’s practicality in hospital environments.

In contrast, pharmacist scheduling research remains largely descriptive. Wright *et al. (2021) emphasized staff engagement and identified scheduling improvement priorities, while the American Association of Colleges of Pharmacy (AACP) National Pharmacist Workforce Study (AACP 2022) and Martello et al.* (2024) provided evidence-based benchmarks for workload and pharmacist-to-patient ratios. These findings support the need for algorithmic approaches capable of integrating human-centered preferences and quantitative optimization. Therefore, this study builds upon recent multi-objective scheduling advances and adopts a hybrid framework combining MIP feasibility with GP-based preference optimization, an approach that aligns with emerging best practices in healthcare workforce modeling (Fitriani *et al.*, 2020; Rerkjirattikal *et al*., 2020; Fourati *et al.*, 2023; Koruca *et al.,* 2023; Hu *et al.,* 2024; Yasmine *et al.*, 2024).

The key findings and methodologies of the literature reviewed above are summarized in Table 1, highlighting the varying approaches to multi-objective optimization and Goal Programming in healthcare scheduling.

Table 1. Comparative Review of Multi-Objective Optimization and GP Models in Healthcare Workforce Scheduling.

Paper (Year)	Domain	Method / Model	Objectives (Main)	Data / Case	Key Outcomes
Rerkjirattikal *et al*. (2020)	Nurse Rostering	0-1 Goal Programming	Workload fairness; individual preference satisfaction	Hospital case / empirical example	Improved preference satisfaction and more balanced workloads vs. baseline.
Fitriani *et al.* (2020)	Nurse Rostering	Fuzzy Goal Programming (MINMAX)	Days off distribution, minimize evening/isolation shifts under uncertainty	Case study (hospital)	Better handling of uncertain preferences; multiple goals satisfied within tolerances.
Fourati *et al.,* (2023)	Nurse Rostering	Lexicographic Goal Programming + Dynamic Satisfaction Functions	Enforce hierarchical priorities; satisfy high-priority goals first	Case study	Stronger adherence to high-priority goals; improved manager-level objectives.
Hu *et al.,* (2024)	Emergency / Staff Scheduling	Multi-objective robust MIP	Robustness to supply/demand uncertainty; cost/service trade-off	Rescue point staffing scenarios	Improved robustness; schedules perform better under uncertain supply/demand.
Yasmine *et al.,* (2024)	Nurse Rostering	MIP with workload balance objective	Reduce consecutive days and workload variance	French hospital department	Reduced consecutive working days; lower variance in workload.
Koruca *et al.,* (2023)	Hospital Personnel Scheduling	Software + Embedded Optimization (Practical System)	Preference-based personalized schedules; usability	Software validated with hospital users	Feasible personalized schedules; improved staff satisfaction and acceptance.
Wright *et al.,* (2021)	Pharmacist Staffing (Survey)	Qualitative / Engagement Study	Identify scheduling improvements valued by staff	Survey and internal workshop	Identified priority improvements (consistency, fewer evenings); no formal optimization.
AACP NPWS (2022)	Workforce Survey	National Survey Report	Document workload/time use; inform staffing policy	National pharmacist survey	Provides empirical basis for required staffing levels and priorities.
Martello *et al.* (2024)	Pharmacist Staffing	Empirical Analysis / Recommendations	Identify ideal pharmacist: patient ratios	Acute care hospital data	Recommended target ratios to guide staffing / rostering decisions.

1.5. Research gap

While scheduling practices among nurses and physicians have been extensively studied in the existing literature, research focusing on scheduling practices among pharmacists in the community is relatively limited. This scarcity of studies can be attributed to the traditional role of pharmacists, primarily involved in medication administration within hospital settings. However, the role of pharmacists has evolved significantly, expanding their responsibilities within the healthcare community. As a result, there is a growing need to explore and understand the scheduling practices specific to community pharmacists. This is the research gap for the current study.

Therefore, in this work, a real-world case study for pharmacists' scheduling in a local hospital is addressed. In order to solve the obtained problem, a mathematical model, in particular, an MIP model, is proposed. In addition, we develop a DSS to systematically generate balanced shift schedules that take into account as much as possible the pharmacists' preferences while satisfying the constraints.

The contributions of this study are:

Addressing a challenging case study in pharmacist scheduling that involves unique constraints.

Proposing an MIP tailored for this case.

Developing a DSS automated system to provide optimal schedules within a short time for pharmacists that eliminates overtime and takes into account the pharmacists' preferences.
The provided schedule takes into account simultaneously the cost-effective and the pharmacists' preferences.

The rest of the paper is organized as follows: Section 2 outlines the problem statement, the data collected, and its analysis. Section 3 details the methodology, which involves modeling the problem as a mixed integer linear program. Section 4 provides a comprehensive description of the developed DSS. In Section 5, the problem is solved, and the results are analyzed. Finally, Section 6 concludes the study and discusses potential future research directions.

2. PROBLEM DEFINITION AND COLLECTED DATA

This study was carried out in a local hospital (LH). LH is one of the largest private and advanced medical cities in the Middle East. It has a capacity of 1911 beds. It is expected to treat more than 20,000 inpatients and over 240,000 outpatients annually. The Main Hospital currently maintains 180 dedicated beds specialized in providing Medical, Surgical, Dental and Intensive Care Services. It also contributes to health education at the local level, as well as promoting disease treatment through medical research and specialized medical training programs. In addition, the LH contains the Children's specialized section, the Rehabilitation section, and the Women's specialized section.
The Pharmacy Services Administration at LH provides combined medical care in collaboration with the rest of the health crew, including providing the proper medication and the needed info of which to achieve the exact and safe curative results at the minimum costs. The administration also follows up on the medication usage and implements relevant educational and research programs. Pharmacy Departments are:1) In-Patient Pharmacy Department, 2) Ambulatory (Out-Patient) Pharmacy Department, and 3) Clinical Pharmacy Department.

2.1. Manual schedule preparation

The head pharmacist at LH manually prepared the monthly schedule for pharmacists using an Excel template. The generation of the schedule is assigned to the head pharmacist, even though she does not have specialized training in this field. This is evident from the long time required to generate the schedule, as it was prepared manually. This often takes seven to ten working days. Furthermore, satisfying pharmacists' preferences is particularly challenging. Also, the schedule is generated at the end of the month, which gives no time for staff to adapt to the new schedule assigned to them.

At the beginning of each month, the assigned pharmacists are scheduled to check for the approved vacations and requested days off from each pharmacist. After gathering all the input data, the head pharmacist then tries to comply with the preferences of each member and law constraints.

The schedule is generated according to the following considerations:

The schedule covers a total of 28 consecutive days (4 weeks).
The pharmacists have different duties that they can cover depending on their seniority, work experience and preference.
There are three shifts: morning, evening, and night.
Each shift's duration is 9 hours.
The number of current duties is (23) as indicated in Table 2.
They also have priority and importance in terms of coverage. In-charge duties (duties with #) are duties that take the highest priority and need to be covered by limited-skilled pharmacists.
Also, a pharmacist covering an evening duty cannot cover a morning duty the next day without an off day between them, and vice versa.
There also needs to be two days off for each pharmacist every week; otherwise, it will be counted as overtime.
The night shift is an exception to this rule because it needs to be covered for 7 consecutive days, and the covering pharmacist takes 7 consecutive days off after.
Not all duties have to be covered each day; they are assigned depending on the requirement for that day, and some duties covered in the weekdays differ from those being covered on the weekends.
Furthermore, the head pharmacist also tries to look at the previous schedule to balance the workload in the current one.
Each pharmacist is required to cover 20 days a month, 5 days each week.

The pharmacists' schedules are then manually created using an Excel template. However, even specialized scheduling personnel struggle to achieve an optimal, balanced schedule that satisfies most preferences when relying on a manual approach. It is even less realistic to expect this from a non-specialized staff member who has other important responsibilities to manage.

Once the manual schedule is completed, it is sent to a reviewer to check for any contradictions or infeasibilities. After the review, the schedule is forwarded to the head pharmacist for final approval. If any issues or errors are identified during the review process, the schedule must be revised, which extends the time required to finalize and publish it.

2.2. Collected data

As shown in Table 2, there were 23 different kinds of duties, which are classified according to daily need and period (morning, evening, and night). Cells with (1) indicate duties that are needed on that day and that are covered by one pharmacist. When a cell contains (0), this means that the duty is not needed that day. For example, evening duty (E3) is required on all days of the weekdays except for the weekend (Friday and Saturday). In addition, duty (PP) is required to be covered only on the weekend (Friday and Saturday).

Table 2. Shift Assignment Results for Week 1.

Day	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Duty	***Morning shift duties***						
che	1	1	1	1	1	0	0
che	1	1	1	1	1	0	0
IV #	1	1	1	1	1	1	1
IV 2	1	1	1	1	1	0	0
DS #	1	1	1	1	1	1	1
DS2	1	1	1	1	1	0	0
DS3	1	1	1	1	1	0	0
DS4	0	0	0	0	1	0	0
UD#	1	1	1	1	1	1	1
UD2	1	1	1	1	1	1	1
UD3	1	1	1	1	1	1	1
UD4	1	1	1	1	1	1	1
UD5	1	1	1	1	1	0	0
UD6	0	0	0	1	0	1	0
IP#	1	1	1	1	1	0	0
IP3	1	1	1	1	1	1	1
IP5	1	1	1	1	1	0	0
PP	0	0	0	0	0	1	1
Evening shift duties							
E#	1	1	1	1	1	1	1
E2	1	1	1	1	1	1	1
E3	1	1	1	1	1	0	0
Night shift duties							
N#	1	1	1	1	1	1	1
N1	1	1	1	1	1	1	1

It is important to note that Table 2 implicitly reflects three different shifts based on the type of assigned duty. For instance, duty type E# corresponds to an evening shift, while duty type N1 is designated for a night shift. Furthermore, in this study, the provided manually performed schedules are those of months: February 26 to April 1; April 2 to April 29; and September 17 to October 14. These particular months were identified as some of the busiest periods by the head of pharmacists. For example, Figure 1 shows a manually generated schedule that covers the period from September 17 to October 14.

Sept 17 - Oct 14																														
			Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
			26	27	28	29	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sept 17 - Oct 14			17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NAME	OFF	WKD																												
AREEJ S	4	2	E#	E#	E#	O	O	E#	E#	E#	E#	E#	E#	E#	O	E#	E#	E#	E#	E#	E#	O	O	E#	E#	E#	O	O	E2	E2
WAAD	8	2	E2	E2	E2	E2	E2	O	O	E2	E2	E2	E2	E2	O	O	E2	E2	O	O	O	E#	E2	E2	E2	E2	E2	E2	O	O
KHLOOD R	4	2	AL																							E#	E#	E#	E#	E#
THABET	8	2	O	O	E3	E#	E#	E2	O	E3	E3	E3	O	O	E#	O	E3	E3	E3	E3	E3	O	E#	E3	E3	E3	E3	E3	O	O+
DUAA	4	2	IV#	IV#	IV#	IV#	IV#	O	O	IV#	IV#	IV#	IV#	IV#	O	O	O	IV#	IV#	IV#	IV#	O	O	IV#	IV#	IV#	IV#	IV#	IV#	IV#
RAYED	4	2	UD6	O	DS#	DS#	DS#	IV#	IV#	O	O	O	O	IV2	IV#	IV#	IV#	IV2	IV2	IV2	IV2	O	O	O	IV2	IV2	IV2	IV2	UD2	O
DEEMA	8	2	IV2	IV2	IV2	IV2	IV2	O	O	IV2	IV2	IV2	IV2	O	O	O	DS#	DS#	DS#	DS#	DS#	E2	O	O	IP5	IP5	IP5	IP5	O	O
IBRAHIM	8	3	NL	O	O	CH2	CH2	O	O	CH#	CH#	CH#	CH#	CH#	O	O	CH#	CH#	CH#	CH#	CH#	O	O	CH#	CH#	CH#	CH#	CH#	O	O
HIBAH AZIZ	4	3	CH#	CH#	CH#	CH#	CH#	O	O	CH2	CH2	CH2	CH2	CH2	O	O	CH2	CH2	CH2	CH2	CH2	IV#	IV#	CH2	CH2	CH2	O	O	O	O
ABDULRAHMAN	4	3	CH2	CH2	CH2	DS4	UD3	O	O	DS#	DS2	DS2	E3	E3	UD3	UD3	O	O	E2	E2	E2	O	O	IV2	UD2	O	CH2	CH2	UD3	UD3
Mukhtar	8	0	AL							UD#	UD#	UD#	UD#	UD#	O	O	UD#	UD#	UD#	UD#	UD#	O	O	UD#	UD#	UD#	UD#	UD#	O	O
RANA	8	4	AL							UD3	UD3	UD3	UD3	UD3	O	O	UD3	UD3	UD3	UD3	UD3	O	O	UD3	UD3	UD3	UD3	UD3	O	O
SAUD	8	8	UD3	UD3	UD3	UD3	O	UD1	UD1	O	O	O	UD6	O	UD1	UD1	UD6	UD6	UD6	UD6	UD6	O	UD#	UD5	UD5	UD5	UD5	UD5	O	O
MOHSEN*	8	3	DS#	DS#	O	O	O	O	O	O	DS#	DS#	O	DS#	DS#	DS#	UD5	DS2	DS2	DS2	O	UD#	O	DS#	DS#	DS#	DS#	DS#	UD1	UD1
ZAHRA	8	2	DS2	DS2	DS2	DS2	DS2	O	O	DS2	DS4	DS4	DS2	DS2	UD2	O	DS2	O	O	O	DS2	DS#	DS#	UD2	O	DS4	DS4	DS4	O	O
ALAA	4	2	UD5	UD5	UD5	UD5	UD5	UD3	O	UD2	UD2	UD2	UD2	UD2	O	O	UD2	UD2	UD2	UD2	O	UD2	UD2	O	O	UD2	UD2	UD2	O	O
SHAIKHA	4	2	UD2	UD2	UD2	UD2	UD2	O	UD3	UD5	UD5	UD5	UD5	UD5	O	O	O	O	UD5	UD5	UD5	UD3	UD3	O	DS4	O	UD4	O	PP	PP
ASEEL *	8	2	O	O	UD6	UD6	UD6	PP	PP	IP1	O	O	O	O	O	E2	IP5	IP5	IP5	IP5	IP5	O	O	IP3	IP3	IP3	IP3	IP3	O	O
NADA M	8	2	IP3	IP3	IP3	IP3	IP3	O	O	IP3	IP3	IP3	O	IP3	O	PP	IP3	O	IP3	IP3	IP3	O	O	AL						
NORAH	8	2	O	IP1	IP1	IP1	IP1	UD2	UD2	O	IP1	IP1	IP1	IP1	O	O	IP1	IP1	IP1	IP1	IP1	O	O	IP1	IP1	IP1	O	O	IP3	IP3
HAYAT	8	4	IP5	IP5	IP5	IP5	IP5	O	O	IP5	IP5	IP5	IP5	IP5	O	UD2	UD4	IP3	UD4	O	O	IP3	IP3	IP5	O	O	IP1	IP1	O	UD2
MAHA R			IP	IP	IP	IP	IP	O	O	IP	IP	IP	IP	IP	O	O	IP	IP	IP	IP	IP	O	O	IP	IP	IP	IP	IP	O	O
AFNAN	4	3	AL																			O	O	DS2	DS2	DS2	DS2	DS2	O	O
SARA BINMOHANA	6	2	E3	E3	E3	O	DS4	DS#	DS#	IP3	IP3	O	DS#	DS4	O	O	IV2	UD5	IP3	O	O	O	O	UD6	UD6	UD6	UD6	UD6	O	O
GHAZI	4	2	IP1	UD6	UD4	E3	E3	O	O	UD6	UD6	UD6	IP3	UD6	O	O	O	O	O	O	UD2	PP	PP	N1	N1	N1	N1	N1	N1	N1
MAHMOUD	SCH		OFF	OFF	OFF	OFF	OFF	OFF	OFF	N1	N1	N1	N1	N1	N1	N1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	N#	N#	N#	N#	N#	N#	N#
WALEED	SCH		N1	N1	N1	N1	N1	N1	N1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	N#	N#	N#	N#	N#	N#	N#	OFF	OFF	OFF	OFF	OFF	O	O
JAMAL	SCH		N#	N#	N#	N#	N#	N#	N#	N#	N#	N#	N#	N#	N#	N#	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	O	OFF
PEDIATRIC DISCHARGE			DS3	DS3	DS3	DS3	DS3	O	O	DS3	DS3	DS3	DS3	DS3	O	O	DS3	DS3	DS3	DS3	DS3	O	O	DS3	DS3	DS3	DS3	DS3	DS#	DS#
ABDULLAH	4	2	AL																											
BANDAR	4	2	AL																											

Figure 1. Pharmacists' manual schedule for the period between September 17 and October 14.

2.3. Analysis of the collected data and the manually prepared schedule

Manually created schedules were evaluated using two critical metrics. The first metric assesses the economic impact, with a particular focus on overtime. The second metric examines pharmacists' well-being by measuring how many consecutive shifts they work without a day off, as this can negatively impact job satisfaction and lead to increased fatigue. These two factors are reported by those responsible for scheduling as the most problematic. The first metric highlights imbalances in duty distribution among pharmacists, while the second points to the lack of sufficient rest periods, which can lead to burnout and dissatisfaction. These two metrics are denoted and defined as follows:

POU (Percentage of pharmacists having Over/Under workload): This metric represents the percentage of pharmacists who either have an excessive number of duties or are underutilized, leading to an imbalance in the distribution of work.

PCD (Percentage of pharmacists having Consecutive Days worked more than 5): This metric calculates the percentage of pharmacists who have been scheduled to work consecutive days without days off, highlighting potential concerns related to overwork and insufficient rest periods.

Tables 3-4 provide detailed results for these two metrics for the three previously selected months.

Table 3 provides a detailed comparison of over/under workload duties for pharmacists across three distinct periods, offering insights into the effectiveness of the scheduling system. A notable observation is the steady improvement in the percentage of pharmacists with perfectly balanced workloads (0 over/under duties). Beginning at 36% in the first period, this figure climbs to 37.04% in the second and 46.15% in the third.

When it comes to mild overwork, where pharmacists handle 1 or 2 extra duties, the results are relatively stable. The percentage of pharmacists with one extra duty hovers around 11-12% throughout all periods, suggesting that the system manages to control mild overwork effectively. However, the introduction of pharmacists with two extra duties in the second and third periods, at around 7%, suggests that indicating that further refinements could help eliminate these occurrences.

The data on mild underwork (-1 or -2 duties) shows more fluctuation. The percentage of pharmacists with one fewer duty remains consistently high, around 27-30%, across all three periods, indicating that mild underwork is a recurring issue. The more significant underwork (-2 duties) increases sharply in the second period to 11.11%, before dropping to 3.85% in the third period. This fluctuation shows that the persistence of mild underwork suggests that workload distribution still requires fine-tuning.

Severe underwork, where pharmacists are significantly underutilized with between 3 and 7 fewer duties, shows the most dramatic change across the periods. In the first period, 20% of pharmacists experience severe underwork, signaling a major imbalance at the outset. However, this figure drops sharply to around 3-4% in the second and third periods, reflecting a significant improvement. Despite this progress, the continued presence of severe underwork, though much smaller, suggests there is still some room for improvement in ensuring more consistent and fairer workload distribution.

This breakdown reveals considerable variation in how pharmacists adhere to their scheduled workdays. While some pharmacists meet or exceed expectations, ensuring full or even additional coverage, others fall behind, sometimes significantly. These discrepancies could impact overall operational efficiency and point to the need for improved scheduling strategies, more flexibility in shift assignments, or an investigation into factors like absenteeism, personal leave, or unexpected workload adjustments. Addressing these disparities is crucial to maintaining balance in workload distribution and ensuring the well-being of the workforce, as well as the continuous and effective operation of the pharmacy.

Table 3. Over/Under Workload Distribution Among Pharmacists Across Three Scheduling Periods.

Number of Over/Under workload duties	**POU Sep 17 – Oct 14 (25 pharmacists)**	**POU Feb 26 - Apr 1 (27 pharmacists)**	**POU Apr 2 - Apr 29 (26 pharmacists)**
[-7; -3]	20%	3.70%	3.85%
-2	4%	11.11%	3.85%
-1	28%	29.63%	26.92%
0	36%	37.04%	46.15%
1	12%	11.11%	11.54%
2	0%	7.41%	7.69%

Table 4. Occurrences of Pharmacists' Consecutive Working Days Across Three Scheduling Periods.

Total consecutive working days	**PCD Sep 17 – Oct 14 (25 pharmacists)**	**PCD Feb 26 - Apr 1 (27 pharmacists)**	**PCD Apr 2 - Apr 29 (26 pharmacists)**
6 days	36% (9 of 25)	29.63% (8 of 27)	26.92% (7 of 26)
7 days	24% (6 of 25)	7.41% (2 of 27)	23.08% (6 of 26)
8 days	4% (1 of 25)	3.70% (1 of 27)	3.85% (1 of 26)
9 days	0% (0 of 25)	0% (0 of 27)	0% (0 of 26)
10 days	8% (2 of 25)	3.70% (1 of 27)	0% (0 of 26)

Table 4 provides a detailed overview of the total consecutive working days for pharmacists across three different time periods. It highlights key trends in the scheduling system's ability to manage extended shifts and offers insights into areas of improvement.

The percentage of pharmacists working six consecutive days is relatively high across all periods. In the first period, 36% of pharmacists worked six consecutive days, which dropped to 29.63% in the second period and further to 26.92% in the third period. Reducing six-day shifts helps lower the risk of burnout and ensures pharmacists get more adequate rest between shifts, which is crucial for maintaining their productivity and well-being.

The results for seven consecutive working days show a more fluctuating trend. In the first period, 24% of pharmacists were assigned seven consecutive days, but this number significantly drops to 7.41% in the second period, only to rise again to 23.08% in the third period. This inconsistency suggests that the manual scheduling process struggled to avoid this kind of prolonged consecutive workload without rest. The increase in the third period might indicate specific challenges in that timeframe or a need for more refined scheduling processes to ensure consistency in avoiding long consecutive work periods.

The occurrence of eight consecutive working days remains consistently low throughout all three periods, with only one pharmacist being assigned such shifts. This represents a small percentage (3.85%to 4%) in each period. The low frequency of these extended shifts suggests that the scheduling system is relatively successful in preventing pharmacists from working excessively long stretches, though the presence of even a few eight-day shifts shows there is still some room for further optimization to eliminate such occurrences. In addition, there are no instances of pharmacists working nine consecutive days across any of the three periods.

In the first period, 8% of pharmacists worked 10 consecutive days, a concerning figure given the potential for fatigue and decreased performance during such long stretches. However, this percentage drops to 3.70% in the second period and is eliminated by the third period, where no pharmacists were assigned to work 10 consecutive days.

The results presented in Table 4 highlight that manual scheduling tends to generate unbalanced and extended consecutive work periods, which can contribute to pharmacist fatigue and decreased performance. The manual process lacks the adaptive precision required to fairly distribute shifts, underscoring the need for a systematic and data-driven approach to ensure equitable workloads. This inefficiency also increases the risk of errors and non-compliance with labor regulations, negatively impacting both employee well-being and organizational performance.

Based on the analysis of the collected data, several key challenges emerge that the scheduler is likely to encounter:

Unfair workload distribution: One of the most prominent issues with the manually generated schedules is the uneven allocation of work among pharmacists. This imbalance can lead to overburdening certain staff members while others may have significantly fewer responsibilities, creating dissatisfaction and potential burnout for those carrying a heavier load.

Disregard for staff preferences: Another critical problem is the failure to accommodate employee preferences, particularly regarding time off. Many pharmacists may find that their requests for days off are not considered, which can severely affect morale and job satisfaction. Ensuring that individual needs and preferences are met is essential for maintaining a positive and motivated workforce.

These challenges highlight the limitations of manual scheduling processes and point to the need for more automated, data-driven solutions that can better manage workload equity, respect employee preferences, and minimize errors. By addressing these issues, the overall scheduling system can be improved, leading to a more satisfied staff and smoother pharmacy operations.

The analysis of the local hospital's scheduling data in Section 2 clearly identified the core human challenges: unacceptable levels of overtime, work imbalance, and fatigue from excessive consecutive shifts. Addressing these problems requires a rigorous, systematic solution. This section introduces the core of our research, the mathematical model, which translates these complex, often competing human and operational goals into a structured, solvable MIP framework. We move from problem diagnosis to the precise engineering of an optimal solution.

3. SOLUTION METHODOLOGY

In this section, the problem under study is formulated as an MIP model. The parameters, decision variables, and constraints of this MIP model are presented below.

3.1. Parameters and Decision Variables

The complete set of indices, parameters, and decision variables defining the mathematical model is presented in Table 5.

Table 5. Parameters and decision variables.

Category	Notation	Description
Parameters	n	Total number of pharmacists
	d	Total number of duties (23 duties in the case study)
Indices	i	Index for pharmacists, $i = 1, \dots, n$
	j	Index for duties, $j = 1, \dots, d$
	k	Index for days, $k = 1, \dots, 28$

Category	Notation	Description
	z	Index for weeks in a month, $k = 1, \dots, 4$
Indexed Parameters	$r_{j,k}$	The required number of pharmacists to cover duty j in day k
	$al_{i,k}$	The annual leave status of pharmacist i on day k. $al_{ik} = 0$ if pharmacist i is on leave on day k, and $al_{ik} = 1$ otherwise.
	$f_{i,j}$	Ability of pharmacist i to cover duty j, $f_{ij} = 1$ if pharmacist i is able to cover duty j, and $f_{ij} = 0$ otherwise.
	$pref_{i,j}$	The weight of preference of pharmacist i to cover duty j
Decision Variables	$X_{i,j,k}$	Binary: 1 if pharmacist i is assigned to duty j on day k, 0 otherwise
	$O_{i,k}$	Binary: 1 if pharmacist i is assigned overtime on day k (work day > 5 days/week), 0 otherwise
	h_z^+	Total overtime in week z
	h_z^-	Total underload in week z

An example of the preferences $(pref_{i,j}, i = 1, \dots, n;\ j = 1, \dots, d)$ is shown in Figure 2, while the preferences, their meanings, and associated weights are provided in Table 6.

Preferences		1	2	3	4	5	6	7	8	9	10	11
		CH#	CH2	IV#	IV2	DS #	DS2	DS3	DS4	UD#	UD2	UD3
1	Abduelah	Normal	Normal	Normal	Low	Low	Low	Low	Low	Low	Low	Normal
2	hibah	Normal	Normal	Normal	Low	Low	Low	Low	Low	Normal	Low	Normal
3	Ibrahim	High	Normal	Normal	Low	Low	Low	Low	Low	Low	Low	Low
4	abdulrahamn	Low	Normal	Normal	Low	Low	Low	Low	Low	Low	Low	Low
5	Duaa	Low	Low	High	Low	Low	Low	Low	Low	Normal	Normal	Normal
6	Deem	Low	Low	Low	Low	Normal	Low	Low	Low	Low	Low	Low
7	Mohsen	Low	Low	Low	Low	Normal	Low	Low	Low	Normal	Normal	Low
8	sarah	Low	Low	Low	Low	Normal	Low	Low	Low	Low	Low	Low
9	bander	Low	Low	Low	Low	Normal	Low	Low	Low	Low	Normal	Low
10	RANA	Low	Low	Low	Low	Low	Low	Low	Low	Normal	Low	Normal
11	SAUD	Low	Low	Low	Low	Low	Low	Low	Low	Normal	Normal	Normal
12	ALAA	Low	Low	Low	Low	Low	Low	Low	Low	Low	Normal	Low
13	SHIEKHAH	Low	Low	Low	Low	Low	Low	Low	Low	Low	Normal	Normal
14	RAED	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

Figure 2. Sample of pharmacists' preferences.

Table 6. Preference Levels and Corresponding Weights Used in the Scheduling Model.

Preference	Meanings	Weight
Low	Not preferred	1
Normal	Preferred	2
High	Highly preferred	3
O	Not capable of covering	0

3.2. Constraints

Pharmacy duties are scheduled under the following constraints.

1. Skill and seniority-based assignment.

$$X_{i,j,k} \le f_{i,j} \quad \forall i = 1 \dots . n;\ \forall j = 1 \dots . d;\ \forall k = 1 \dots .28. \tag{C1}$$

This constraint ensures that each pharmacist is only assigned to duties that match their skill level and qualifications. Senior pharmacists handle more complex or supervisory duties, while junior staff perform less demanding tasks, promoting both safety and professional development.

2. One duty per pharmacist per day.

$$\sum_{j=1}^{d} X_{i,j,k} \leq 1,\ \forall i = 1 \dots . n;\ \forall k = 1 \dots .28\ . \tag{C2}$$

Each pharmacist can be assigned to at most one duty per day. This restriction prevents overlapping shifts and ensures a fair and balanced daily workload across staff.

3. Only one pharmacist per duty per day.

$$\sum_{i=1}^{n} X_{i,j,k} \leq 1,\ \forall j = 1 \dots . d;\ \forall k = 1 \dots .28\ . \tag{C3}$$

Every duty that must be covered on a given day is assigned to at most one pharmacist. This maintains clarity in task allocation and prevents duplicate assignments for the same duty.

4. No consecutive morning–evening or evening–morning shifts.

$$\sum_{j=1}^{18} X_{i,j,k} + \sum_{j=19}^{21} X_{i,j,k+1} \leq 1,\ \forall i = 1 \dots . n;\ \forall k = 1 \dots .27\ . \tag{C4}$$

$$\sum_{j=1}^{18} X_{i,j,k+1} + \sum_{j=19}^{21} X_{i,j,k} \leq 1,\ \forall i = 1 \dots . n;\ \forall k = 1 \dots .27\ . \tag{C5}$$

These constraints prevent pharmacists from working a morning shift followed by an evening shift the next day (and vice versa). This rule minimizes fatigue and scheduling conflicts, ensuring pharmacists are well-rested for optimal performance and patient safety.

5. Duty coverage requirement.

$$\sum_{i=1}^{n} X_{i,j,k} = r_{j,k},\ \forall j = 1 \dots . d;\ \forall k = 1 \dots .28\ . \tag{C6}$$

This constraint guarantees that all required duties are covered each day. It enforces that the total number of assigned pharmacists matches the required staffing level for each duty and day, ensuring continuity of service.

6. Annual leave restriction.

$$\sum_{j=1}^{23} X_{i,j,k} \leq al_{i,k},\ \forall i = 1 \dots . n;\ \forall k = 1 \dots .28\ . \tag{C7}$$

A pharmacist on annual leave cannot be scheduled for any duty during that period. This ensures compliance with approved leave schedules and avoids scheduling conflicts.

7. Weekly overtime accounting.

$$\sum_{k=1}^{7} O_{i,k} = h_1^+,\ \forall i = 1 \dots . n\ . \tag{C8}$$

$$\sum_{k=8}^{14} O_{i,k} = h_2^+,\ \forall i = 1 \dots . n\ . \tag{C9}$$

$$\sum_{k=15}^{21} O_{i,k} = h_3^+,\ \forall i = 1 \dots . n\ . \tag{C10}$$

$$\sum_{k=21}^{28} O_{i,k} = h_4^+,\ \forall i = 1 \dots . n\ . \tag{C11}$$

These four constraints record the total overtime hours worked by each pharmacist in each of the four weeks of the scheduling period. They form the basis for calculating fair overtime distribution and workload balance.

8. Weekly workload threshold (maximum five duties).

$$\sum_{k=1}^{7} \sum_{j=1}^{21} (X_{i,j,k} - O_{i,k}) \leq 5,\ \forall i = 1 \dots . n\ (first\ week)\ . \tag{C12}$$

$$\sum_{k=8}^{14} \sum_{j=1}^{21} (X_{i,j,k} - O_{i,k}) \leq 5,\ \forall i = 1 \dots . n\ (second\ week)\ . \tag{C13}$$

$$\sum_{k=15}^{21} \sum_{j=1}^{21} (X_{i,j,k} - O_{i,k}) \leq 5,\ \forall i = 1 \dots . n\ (third\ week)\ . \tag{C14}$$

$$\sum_{k=22}^{28} \sum_{j=1}^{21} (X_{i,j,k} - O_{i,k}) \leq 5,\ \forall i = 1 \dots . n\ (fourth\ week)\ . \tag{C15}$$

These constraints ensure that overtime is only counted after a pharmacist exceeds five regular duties in a week. They help enforce fair workload limits and avoid excessive weekly assignments.

9. Relationship between regular, overtime, and underload duties.

$$\sum_{k=1}^{7} \sum_{j=1}^{21} X_{i,j,k} - 5 = \sum_{k=1}^{7} O_{i,k} - h_1^-,\ \forall i = 1 \dots . n. \tag{C16}$$

$$\sum_{k=8}^{14} \sum_{j=1}^{21} X_{i,j,k} - 5 = \sum_{k=8}^{14} O_{i,k} - h_2^-,\ \forall i = 1 \dots . n. \tag{C17}$$

$$\sum_{k=15}^{21} \sum_{j=1}^{21} X_{i,j,k} - 5 = \sum_{k=15}^{21} O_{i,k} - h_3^-,\ \forall i = 1 \dots . n. \tag{C18}$$

$$\sum_{k=22}^{28} \sum_{j=1}^{21} X_{i,j,k} - 5 = \sum_{k=22}^{28} O_{i,k} - h_4^-,\ \forall i = 1 \dots . n. \tag{C19}$$

These equations maintain the relationship between assigned duties, overtime hours, and underload (unassigned capacity). They ensure that workload deviations are balanced across all pharmacists, supporting equity in scheduling.

10. Consistent night duties across a week.

$$X_{i,j,1} \leq X_{i,j,1+k}\ \ \forall i = 1 \dots . n;\ \forall j = 22, 23;\ \forall k = 1 \dots .6. \tag{C20}$$

$$X_{i,j,8} \leq X_{i,j,8+k}\ \ \forall i = 1 \dots . n;\ \forall j = 22, 23;\ \forall k = 1 \dots .6. \tag{C21}$$

$$X_{i,j,15} \leq X_{i,j,15+k}\ \ \forall i = 1 \dots . n;\ \forall j = 22, 23;\ \forall k = 1 \dots .6. \tag{C22}$$

$$X_{i,j,22} \leq X_{i,j,22+k}\ \ \forall i = 1 \dots . n;\ \forall j = 22, 23;\ \forall k = 1 \dots .6\ . \tag{C23}$$

If a pharmacist is assigned to a night duty (duty 22 or 23), they continue that same duty type throughout the week. This provides consistency, allowing the pharmacist to maintain a stable sleep schedule and avoid health risks associated with frequent shift changes.

11. Mandatory rest week after night duty.

$$\sum_{j=1}^{d} X_{i,j,7+k} \leq 1 - X_{i,22,1}\ \ \forall i = 1 \dots . n;\ \forall k = 1 \dots .7. \tag{C24}$$

$$\sum_{j=1}^{d} X_{i,j,14+k} \leq 1 - X_{i,22,8}\ \ \forall i = 1 \dots . n;\ \forall k = 1 \dots .7. \tag{C25}$$

$$\sum_{j=1}^{d} X_{i,j,21+k} \leq 1 - X_{i,22,15}\ \ \forall i = 1 \dots . n;\ \forall k = 1 \dots .7. \tag{C26}$$

$$\sum_{j=1}^{d} X_{i,j,7+k} \leq 1 - X_{i,23,1}\ \ \forall i = 1 \dots . n;\ \forall k = 1 \dots .7. \tag{C27}$$

$$\sum_{j=1}^{d} X_{i,j,14+k} \leq 1 - X_{i,23,8}\ \ \forall i = 1 \dots . n;\ \forall k = 1 \dots .7. \tag{C28}$$

$$\sum_{j=1}^{d} X_{i,j,21+k} \leq 1 - X_{i,23,15}\ \ \forall i = 1 \dots . n;\ \forall k = 1 \dots .7. \tag{C29}$$

Following a week of night shifts, the pharmacist is given a full week off. This recovery period reduces fatigue, restores circadian rhythm, and prevents burnout, ensuring sustained performance and safety.

12. Limit on weekend duties.

$$\sum_{j=1}^{d} (X_{i,j,6} + X_{i,j,7} + X_{i,j,13} + X_{i,j,14} + X_{i,j,20} + X_{i,j,21} + X_{i,j,27} + X_{i,j,28}) \leq 4, \forall i = 1 \dots . n. \tag{C30}$$

Each pharmacist may work at most four weekend duties per month. This constraint protects work-life balance and morale, providing sufficient rest time and preventing overburdening staff with undesirable weekend shifts.

These constraints collectively ensure fairness, compliance with hospital policies, and balanced workload distribution. By formalizing these operational rules, the model transforms daily scheduling intuition into a systematic optimization process accessible to non-technical users.

3.3. Objective function

The objective function consists of two main components. The first focuses on minimizing overtime costs, addressing the economic aspect, while the second prioritizes accommodating pharmacist preferences. These sub-objectives are weighted based on their importance, with minimizing overtime receiving the highest priority and thus the greatest weight, while maximizing preference satisfaction is given secondary consideration. The objective function to be minimized is expressed as follows.

$$Min\ Z = 100 \times \sum_{z=1}^{4} h_z^{+} - \sum_{i=1}^{n} \sum_{j=1}^{d} \sum_{k=1}^{28} pref_{i,j} \times X_{i,j,k}$$

The expression accurately reflects the balance between cost efficiency and employee satisfaction. By prioritizing overtime reduction, the model ensures financial sustainability, while also valuing pharmacists' preferences to enhance job satisfaction and morale. This dual focus helps in creating an optimal work environment that aligns with both organizational goals and employee needs.

With the MIP model defined and all constraints formalized in Section 3, the next critical step is the implementation of a functional system capable of solving this complex optimization problem. This section details the development of the DSS, which serves as the interface and execution environment for the model, transforming the mathematical formulation into a practical scheduling tool for hospital managers.

4. DECISION SUPPORT SYSTEM IMPLEMENTATION

LINGO software was used to implement the mixed-integer linear program, which is connected to EXCEL to import input data and export results. In addition, a graphical user interface (GUI) is implemented via VBA embedded macros in EXCEL. By providing a user-friendly platform for data entry and automated schedule generation within defined constraints, this system functions as a DSS. Using this DSS greatly reduced the time required to prepare pharmacists’ schedules. In addition, the DSS offers flexibility for integrating individual preferences, making the scheduling process more efficient and tailored to user needs. The DSS allows users to input their specific scheduling preferences directly into the system, which then optimizes the schedule based on these inputs. This means that pharmacists can have their individual needs and constraints considered, resulting in a more personalized and satisfactory schedule. As a result, the scheduling process becomes more adaptive and responsive to the varying demands of pharmacy staff.

Detailed information about the DSS system is provided in this section. The main interface is illustrated in Figure 3, which serves as a welcoming graphical user interface (GUI). The purpose of this interface is to simplify the process of entering all scheduling data. Annual leave requests, pharmacist availability, specific staffing requirements, and individual preferences can all be entered by users. Furthermore, the system provides the option of defining the number of pharmacists needed for a given schedule.

By clicking the "Schedule" button after entering all relevant data, the user can create an automated schedule. This feature significantly streamlines the scheduling process, automatically producing a timetable that meets the specified constraints. Furthermore, the interface incorporates a quick utilization analyzer, which provides real-time insights into resource allocation and efficiency. The system includes a toggle function that enhances user experience and navigation. By using this toggle, users can seamlessly switch between different features and sections of the system. With these features, the interface provides an efficient and intuitive way to manage complex scheduling processes.

Figure 4 shows the real-time interface for entering pharmacists' annual leave preferences. The process is simplified by allowing users to click directly on the pharmacist and their leave date. Compared to the traditional method of data collection, this method simplifies and streamlines it considerably. This method eliminates the need for manual data entry, which could potentially lead to errors. It also eliminates the need for manual calculations, as the system does the calculations on the fly. Additionally, it eliminates the need for manual tracking, as the system keeps track of all leave requests in real-time.

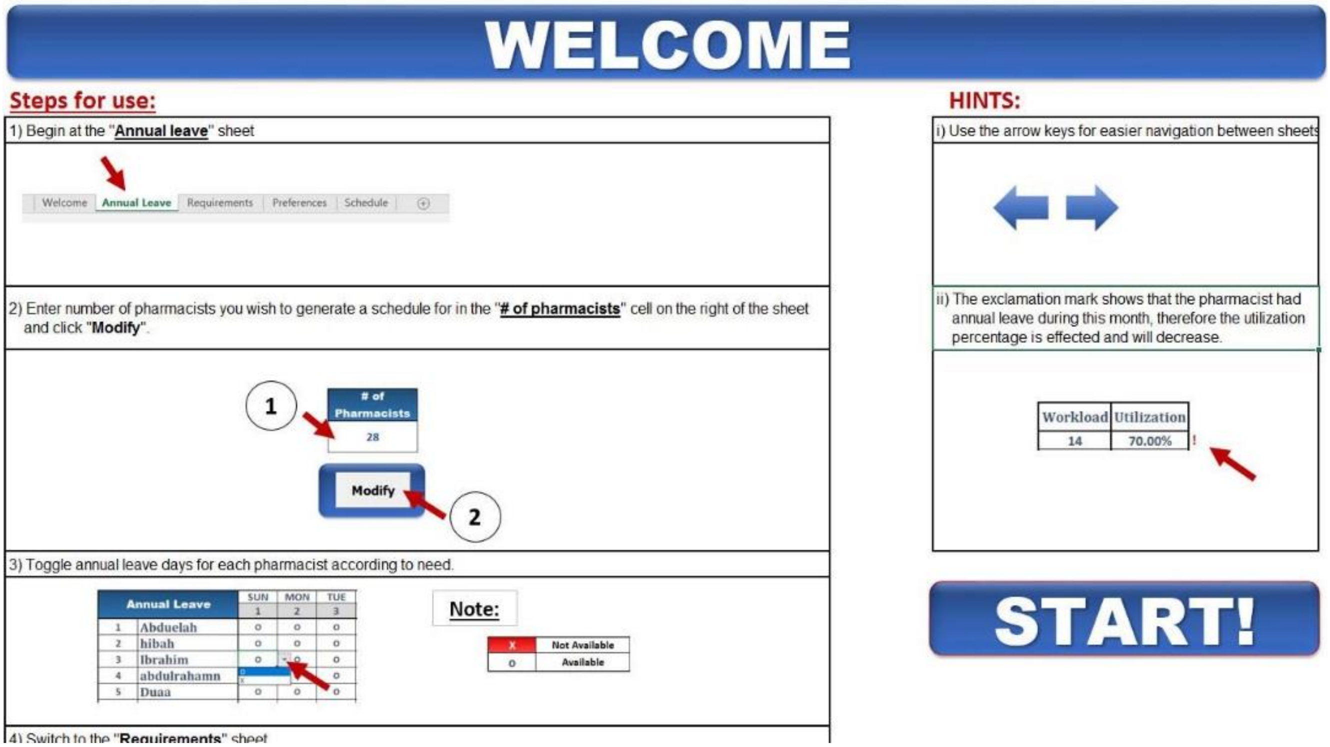
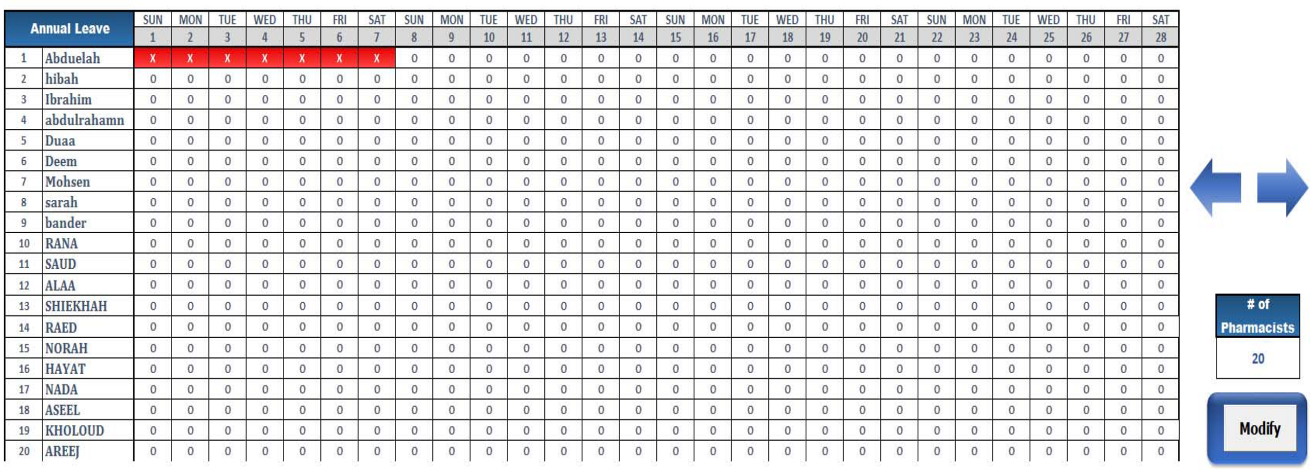


Figure 3. Graphical user interface for the developed DSS



	Annual Leave	SUN 1	MON 2	TUE 3	WED 4	THU 5	FRI 6	SAT 7	SUN 8	MON 9	TUE 10	WED 11	THU 12	FRI 13	SAT 14	SUN 15	MON 16	TUE 17	WED 18	THU 19	FRI 20	SAT 21	SUN 22	MON 23	TUE 24	WED 25	THU 26	FRI 27	SAT 28
1	Abduelah	X	X	X	X	X	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	hibah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Ibrahim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	abdulrahamn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Duaa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Deem	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Mohsen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	sarah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	bander	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	RANA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	SAUD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	ALAA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	SHIEKHAH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	RAED	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	NORAH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	HAYAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	NADA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	ASEEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	KHOLOUD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	AREEJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4. Screenshot of the pharmacists' annual leave input sheet in the DSS

Figure 5 shows the input data sheet for duty requirements. In this sheet, users can easily specify staffing needs by selecting "Yes" or "No" for each duty. "Yes" indicates that the specific duty requires the services of a pharmacist, while "No" indicates that there is no need for a pharmacist. As a result of this straightforward input method, the scheduling process is both simple and time-saving, allowing for a quick and efficient way to define staffing requirements. By providing a clear and user-friendly interface, this feature enables users to rapidly introduce and modify requirements without unnecessary complexity, greatly improving data entry ease and speed.

In Figure 6, pharmacists' preferences regarding future duties are entered on the input sheet. For each pharmacist and each duty, four options are presented when the corresponding cell is clicked: "Normal," "High," "Low," and "O". These options allow pharmacists to indicate their preference for certain duties, with "High" representing a strong preference, "Low" indicating not preferred preference, "Normal" for standard preference, and "O" meaning not capable of covering. Therefore, this helps schedule pharmacists efficiently by taking their preferences into account. In this design, individual preferences can be captured quickly and easily, enabling quick and easy data entry. The system saves time by offering clear, selectable options instead of manually entering or processing data. Additionally, it ensures that pharmacist preferences are accurately reflected in the schedule, reducing errors. As a result, scheduling becomes more efficient and personalized.

Requirements	SUN	MON	TUE	WED	THU	FRI	SAT
	1	2	3	4	5	6	7
CH#	YES	YES	YES	YES	YES	NO	NO
CH2	YES	YES	YES	YES	YES	NO	NO
IV#	YES	YES	YES	YES	YES	YES	YES
IV2	YES	YES	NO	YES	YES	NO	NO
DS #	YES	YES	YES	YES	YES	YES	YES
DS2	YES	YES	YES	YES	YES	NO	NO
DS3	YES	YES	YES	YES	YES	NO	NO
DS4	NO	NO	NO	NO	YES	NO	NO
UD#	YES	YES	YES	YES	YES	YES	YES
UD2	YES	YES	YES	YES	YES	YES	YES
UD3	YES	YES	NO	YES	YES	YES	YES
UD4	YES	YES	YES	YES	YES	YES	YES
UD5	YES	YES	YES	YES	YES	NO	NO
UD6	NO	NO	NO	YES	NO	YES	NO
IP#	YES	YES	YES	YES	YES	NO	NO
IP3	YES	YES	YES	YES	YES	YES	YES
IP5	YES	YES	YES	YES	YES	NO	NO
PP	NO	NO	NO	NO	NO	YES	YES
E#	YES	YES	YES	YES	YES	YES	YES
E2	YES	YES	YES	YES	YES	YES	YES
E3	YES	YES	YES	YES	YES	NO	NO
N#	YES	YES	YES	YES	YES	YES	YES
N1	YES	YES	YES	YES	YES	YES	YES

Figure 5. Duty requirements input sheet in the DSS interface.

Preferences		1	2	3	4	5	6	7	8	9	10	11
		CH#	CH2	IV#	IV2	DS #	DS2	DS3	DS4	UD#	UD2	UD3
1	Abduelah	Normal	Normal	Normal	Low	Low	Low	Low	Low	Low	Low	Normal
2	hibah	Normal	Normal	Normal	Low	Low	Low	Low	Low	Normal	Low	Normal
3	Ibrahim	High	Normal	Normal	Low	Low	Low	Low	Low	Low	Low	Low
4	abdulrahamn	Low	Normal	Normal	Low	Low	Low	Low	Low	Low	Low	Low
5	Duaa	Low	Low	High	Low	Low	Low	Low	Low	Normal	Normal	Normal
6	Deem	Low	Low	Low	Low	Normal	Low	Low	Low	Low	Low	Low
7	Mohsen	Low	Low	Low	Low	Normal	Low	Low	Low	Normal	Normal	Low
8	sarah	Low	Low	Low	Low	Normal	Low	Low	Low	Low	Low	Low
9	bander	Low	Low	Low	Low	Normal	Low	Low	Low	Low	Normal	Low
10	RANA	Low	Low	Low	Low	Low	Low	Low	Low	Normal	Low	Normal
11	SAUD	Low	Low	Low	Low	Low	Low	Low	Low	Normal	Normal	Normal
12	ALAA	Low	Low	Low	Low	Low	Low	Low	Low	Low	Normal	Low
13	SHIEKHAH	Low	Low	Low	Low	Low	Low	Low	Low	Low	Normal	Normal
14	RAED	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

Figure 6. Pharmacists' preferences introduction in the DSS interface.

Figure 7 shows the pharmacist's schedule, which is automatically generated and presented in a clear format. In the schedule, pharmacists are given an overview of their assignments for the next four weeks. As a result of the automated scheduling system, the schedule is generated quickly, accurately, and without errors.

Besides its rapid performance and precision, the system offers a straightforward "Print" button for immediate schedule printing. This functionality significantly reduces time spent and minimizes typical problems like duplicate entries, scheduling mistakes, and uneven workload distribution. Automating the process provides a more efficient and dependable approach to schedule management.

Figure 8 presents the conceptual framework of the automated pharmacist scheduling system. The framework illustrates the flow of information from input parameters, including pharmacists' availability, preferences, and duty requirements, to the optimization engine that employs MIP and GP techniques. The optimization results are then processed within a DSS, which evaluates and visualizes the generated schedules. This integrated approach ensures the production of optimized schedules that balance workload distribution, minimize overtime, and align with pharmacists' preferences, thereby supporting effective and data-driven scheduling decisions.

Figure 7. Generated a schedule for the pharmacists.

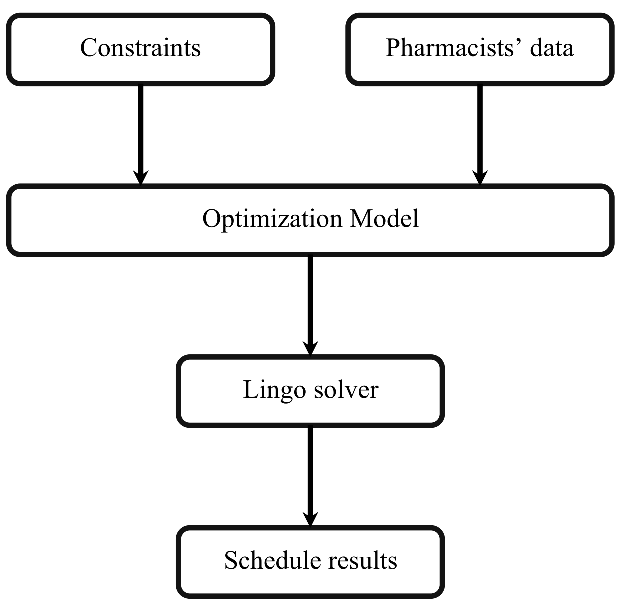


Figure 8. Decision Support System (DSS) Flow Diagram

The subsequent section presents the computational results and detailed analysis. Before proceeding, it is important to note that the mathematical model formulated in Section 3 represents the core optimization logic applied to the real-world case study described in Section 2. The following results validate the effectiveness of the automated DSS in addressing the specific scheduling challenges, namely, workload imbalance (POU) and excessive consecutive work periods (PCD), identified through the analysis of the local hospital's manual schedules.

5. DECISION SUPPORT SYSTEM VALIDATION

To comprehensively assess the performance and efficiency of the proposed scheduling method, data on various elements are collected. This includes anticipated annual leave, pharmacists' personal preferences, and the projected number of pharmacists required during May and June. These months are notably hectic, with a marked rise in workload and patient demand, and the collected data enables a thorough validation of the proposed automated method, confirming its effectiveness under the intense conditions usually experienced during these times.

5.1. Detailed results

Tables 7 and 8 provide an analysis of the automatically generated schedules for the two months of May and June. The evaluation of these schedules is based on two predefined metrics: POU and PCD.

Table 7. Over/Under Workload Distribution Among Pharmacists for May and June Scheduling Periods.

Number of Over/Under workload duties	**POU: May (28 pharmacists)**	**POU: Jun (28 pharmacists)**
-6	0%	0%
-5	0%	0%
-4	10.70%	0%
-3	14.30%	14.30%
-2	14.30%	14.30%
-1	3.60%	32.10%
0	57.10%	39.30%
1	0%	0%

Table 7 presents the POU for the months of May and June. Remarkably, no pharmacist exceeds the desired workload of 20 duties per month (five duties per week). However, several pharmacists have a workload below this target. This is because there is no additional need for duties to be assigned while still adhering to the preferences set by the pharmacists. In June, we observed increased strain on some pharmacists due to the addition of four weeks of annual leave. This has impacted the overall workload distribution. Specifically, 14.3% of the pharmacists have three fewer duties than their required monthly coverage of 20 duties. Additionally, 32.1% of pharmacists are short by one duty compared to the monthly target. Despite these shortfalls, 39.3% of the pharmacists are able to meet their full requirement of 20 duties.

Table 8. Percentage of Pharmacists with Extended Consecutive Working Days (Automated Schedule).

Consecutive working days	**PCD: May (4 pharmacists)**	**PCD: June (7 pharmacists)**
6 days	14.28% **(4 pharmacists)**	14.28% **(4 pharmacists)**
7 days	0%	10.71% **(3 pharmacists)**
8 days	0%	0%
9 days	0%	0%
10 days	0%	0%

According to Table 8, the total occurrences of a pharmacist working more than 5 consecutive days are 4 and 7, respectively, for May and June. Their distribution is 4 occurrences of 6 consecutive days for May. For June, there are 4 consecutive 6-day periods and 3 consecutive 7-day periods. Additionally, it may happen that a pharmacist works for 6 or 7 consecutive days in the same month. Table 8 shows that in May, pharmacists worked more than 5 consecutive days on 4 occasions, all of which were 6-day stretches. In June, there were 7 instances: 4 of them were 6-day stretches, and 3 were 7-day stretches. It's also possible for a pharmacist to work both 6 and 7 consecutive days within the same month. These findings confirm that the automated scheduling system effectively minimizes extended work periods, demonstrating its ability to maintain balanced workloads and reduce the risk of burnout. Such improvements not only enhance staff well-being but also contribute to sustained operational efficiency in pharmacy management. The distribution suggests that most extended work periods are kept to 6 days, with only a few instances of 7-day stretches, which helps maintain a healthier work-life balance. Additionally, the consistency between May and June reflects effective management of work schedules.

5.2. Pairwise comparison between manual and automated procedures

The following section provides a pairwise comparison between manually generated schedules and those produced through the automated DSS scheduling system. This comparison aims to highlight differences in efficiency, accuracy, and overall performance between the two methods. The results are presented as averages, offering a clear summary of the outcomes across multiple test cases, ensuring a comprehensive evaluation of both approaches**.** The numerical results of this comparison are provided in Tables 9-10.

Table 9. Comparison of Pharmacist Over/Under Workload (POU) Distribution: Manual vs. Automated Scheduling.

# Of Over/Under workload duties	Manual: POU	Automated: POU
[-4; -3]	8.97%	19.64%
-2	6.41%	14.29%
-1	28.21%	17.86%
0	39.74%	48.21%
1	11.54%	0%
2	5.13%	0%

Table 9 compares the distribution of over/under workload duties between manual and automated systems, highlighting the differences in how each system manages workload distribution. The significant outcome is the enhanced ability to balance workloads, with the automated system achieving this for 48.21% of duties, in contrast to the 39.74% achieved manually. This demonstrates that the automated system is more proficient in evenly distributing workloads, as nearly half of all duties are balanced using this method. In the automated system, there is a significant reduction in mild overwork for +1 and +2 duties. While the manual system sees 11.54% of duties in the +1 overwork category and 5.13% in the +2 category, the automated system eliminates these instances. This result indicates that the automated process was more effective at preventing minor overwork scenarios than the manual approach.

However, the automated system demonstrates a rise in significant underutilization, especially for workloads ranging from [-4; -3]. In comparison, the manual system has 8.97% of tasks in this range, while the automated system accounts for 19.64%, highlighting a substantial increase in severe underwork instances. This observation suggests that, while the automated system significantly enhances workload balance overall, occasional overcorrections may occur due to rigid constraint prioritization. Future model refinements could introduce adaptive weights or feedback mechanisms to further smooth workload distribution and address underutilization cases.

In the case of moderate imbalances, like -1 and -2 duties, the automated system produces varied outcomes. For -1 duties, the manual method shows a higher occurrence at 28.21%, but the automated approach decreases this to 17.86%. Conversely, for -2 duties, the manual system reports 6.41%, yet the automated system raises it to 14.29%, suggesting that while the automated process reduces mild underwork, it also heightens moderate underwork, reflecting certain trade-offs.

In conclusion, the automated system excels in balancing workloads and preventing overwork. Nonetheless, it leads to more instances of significant underwork and raises the occurrence of moderate underwork. While automation enhances the distribution of tasks, additional refinements might be needed to address the issue of severe disparities.

Table 10. Comparison of Pharmacist Excessive Consecutive Working Days (PCD): Manual vs. Automated Scheduling Methods.

# Consecutive working days	Manual: PCD	Automated: PCD
6	30.77%	14.29%
7	17.95%	5.36%
8	3.85%	0%
9	0%	0%
10	3.85%	0%

Table 10 highlights the comparison between manual and automated systems, emphasizing the percentage of pharmacists working shifts that span 6 to 10 consecutive working days. For six straight working days, the manual system reports a considerably higher rate of 30.77%, in contrast to the automated system's 14.29%. This indicates that the automated system more effectively minimizes the number of employees working six consecutive days, contributing to reduced fatigue and enhanced overall well-being.

In the context of 7 consecutive working days, there's a significant difference between the two systems. The manual system shows a rate of 17.95%, whereas the automated system decreases this figure to 5.36%. This demonstrates the automated system's effectiveness in reducing prolonged work durations, leading to improved workload management.

Despite being used for 8 consecutive working days, the manual system continues to register a 3.85% error rate, whereas the automated system achieves a 0% error rate. This demonstrates the effectiveness of automation in reducing excessive consecutive workdays, thereby helping to prevent burnout.

Neither system allows employees to work for 9 consecutive days, ensuring that such extreme work schedules are avoided and a fundamental level of protection against excessive work hours is maintained.

In a span of 10 consecutive working days, only 3.85% of employees in the manual system encounter this issue, compared to 0% in the automated system. This highlights that automation is more successful in avoiding prolonged work stretches, which can negatively impact employee well-being and efficiency.

Overall, the automated system substantially reduces the frequency of prolonged consecutive workdays, supporting healthier work patterns and improved job satisfaction. Compared with manual scheduling, it achieves a 50% reduction in extended-duty occurrences and completely eliminates 8-10 day continuous shifts, confirming the model's robustness and real-world applicability for hospital administrators. By cutting down on the number of times workers have to work 6, 7, 8, or even 10 days in a row, the system shows a distinct enhancement in how workloads are distributed. This indicates that automation can improve employee scheduling, lowering the chances of overworking and promoting a healthier, more balanced work-life.

The findings from this study demonstrate that adopting an optimization-based scheduling approach can significantly improve fairness, reduce fatigue, and enhance adaptability in pharmacy operations. Beyond the case study hospital, this methodology can be generalized to other healthcare institutions facing similar staffing and workload challenges. For practitioners, the DSS offers a ready-to-use tool that transforms complex scheduling tasks into manageable, data-driven decisions. Academically, the integration of MIP and GP contributes to the growing literature on intelligent healthcare workforce planning, highlighting how optimization models can directly impact organizational performance and employee well-being.

6. CONCLUSIONS

Creating a pharmacist schedule is a complex and time-consuming task, especially when multiple constraints, such as preferences, workload balancing, and leave days, must be satisfied. The development of a DSS, using LINGO software for modeling and an Excel-based user interface, significantly streamlined this process, reducing the time, effort, and potential errors involved in manual scheduling. The system allows users to easily input key data, such as the number of pharmacists required, individual preferences, availability, daily duty requirements, and annual leave days, thereby simplifying the entire scheduling process.

In this work, the benefits of implementing this DSS were immediately evident. Not only did it drastically reduce the time required to generate a schedule, cutting it from seven to ten days to just a few seconds, but it also eliminated the issue of pharmacists working overtime, which had been common in manually generated schedules. Furthermore, the proposed DSS ensures a fair and optimized workload distribution while integrating individual pharmacist preferences. This leads to enhanced transparency, improved equity in task assignments, and greater satisfaction among staff. For hospital managers, the DSS provides a practical, evidence-based framework that can be readily implemented to improve scheduling efficiency and workforce morale. Additionally, the automated system proved superior in managing consecutive working days, significantly reducing the occurrence of extended work periods (6 to 10 consecutive days), which can lead to employee fatigue and burnout. By minimizing such excessive shifts, the system fosters a healthier work environment and contributes to maintaining productivity and morale among pharmacists.

In addition to time and error reduction, the automated system brings scalability and flexibility, allowing it to handle larger teams or varying schedules with minimal additional effort. While the DSS showed substantial improvements in overall scheduling efficiency, there were instances of increased underwork in certain cases, indicating that further refinements may be needed to fully optimize the workload distribution. Future enhancements could expand its functionality, such as accommodating more complex constraints, integration with other hospital systems, or even predicting future scheduling needs based on past data. Overall, this system represents a significant advancement in efficiency and effectiveness for pharmacist scheduling, offering a sustainable solution that can adapt to ongoing challenges in workforce management. Future research will focus on extending the model to handle dynamic, real-time events, such as last-minute absences, which would require the implementation of a robust optimization or re-scheduling layer.

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