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OPTIMIZATION OF PATIENT AND NURSE MANAGEMENT IN HEALTH CARE: A CASE STUDY

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ABSTRACT

Effective patient selection and nurse allocation are crucial for optimizing hospital care, especially in resource-constrained environments. This study introduces a two-stage mixed integer linear programming (MILP) model designed to prioritize patients based on care urgency and match them with appropriately skilled nurses. Following consultations with healthcare professionals, patients were categorized into three priority levels: high (critical care), normal (basic care), and low (expert consultations). Applying the model to the surgery department of Pabna Medical College Hospital, Bangladesh, 196 out of 950 patients were selected for care: 117 requiring critical care, 59 needing basic care, and 20 for consultative care, necessitating the allocation of 41 nurses. The model demonstrated significant improvements in patient selection and nurse workload management, ensuring maximum patient service within capacity constraints and achieving a balanced distribution of nurse workloads. This approach enhances hospital efficiency and patient care quality, allowing non-chosen patients to seek alternative care options. The model's adaptability across different departments underscores its potential for widespread application in healthcare management.

Keywords: *Patient selection, Nurse allocation, Optimization, Healthcare, Surgery*.

1. INTRODUCTION

The current coronavirus disease pandemic (COVID-19) has rapidly altered our healthcare organization structure. Nobody would deny that the staff's working circumstances in the healthcare system significantly impact the patient's health. Therefore, addressing these issues could boost the effectiveness of the therapeutic process. Additionally, it is well recognized that adequate personnel and workload utilization have always been a top priority in any organization and one of the most crucial approaches to increase production. Because of this, work evaluation and patient scheduling have taken on more significance in certain hospital services that are in high demand yet have a staffing shortage (Van Huele & Vanhoucke, 2014). During COVID-19, nurse management faces challenges in meeting an increased demand with a limited supply, which includes nurse availability, shift, and other factors. Several studies have been written regarding overcoming queue problems and nurses' mental health in the pandemic (Sato et al., 2021). However, there is no research on how to design nurses' capacity for patient-centred treatment in the event of a pandemic and post-pandemic.

A mixed linear integer algorithm is offered to overcome these issues in the post-pandemic period. The fundamental limitations are considered along with the nurse's abilities, skills, and environmental parameters, as the patient's wants, conditions, and priorities. The patient selection and workload assessment must be resolved to build a framework for planning client-centred care without exceeding capacity (Aydas et al., 2021; De Grano, 2017; Sun & Li, 2011).

The working conditions of healthcare workers have a significant impact on the health of patients. As a result, enhancing these conditions may boost the success of the therapy procedure. In health care centres, care service demand fluctuates per day. Due to the pressure of workload, caregivers cannot provide efficient service throughout the day. Many patients visit the therapist but are not required to be admitted to the healthcare centre.

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Unpredictable workload throughout the day in a pandemic situation creates mass conflicts among tasks and schedules (Cardoen et al., 2009a, b). The following are some distinctive qualities that led to the selection of this service for the case study:

- Patients with disorders including hemiplegia, traumatic injury, peripheral nerve in jury, multiple sclerosis, broken body parts, physical injuries sustained during sporting activities, neck and waist pain, systemic rheumatism, cancer rehabilitation, etc. are cared for by nurses. The demand for this service is remarkably high due to the wide range of patients who can use it.
- Because the people who need nursing care may already have reduced mobility and cannot care for themselves, nurses frequently deal with situations that call for psychological and physical attributes, including patience, thoughtfulness, and strength. As is well known, they must use their physical strength to transfer patients, move instruments, equipment, and medicines, and operate very carefully and with extreme focus to maintain the patients' comfort while preventing any harm.

As previously said, due to the high demand for this service, careful patient selection and categorization are necessary to ensure that the greatest number of patients can take advantage of it while utilizing the most labour. Due to the challenging working conditions of nurses indicated above, it is crucial to balance the workload of nurses and create a fair schedule for them in addition to maximizing the number of patients who benefit from this service (Baesler et al., 2015).

The issue raised in this study is connected to a model presented in (Ogulata et al., 2008), where a hierarchical mathematical programming problem is suggested to produce weekly staff scheduling. The concept is broken down into three hierarchical phases: patient selection, staffing assignment, and patient scheduling throughout the day. The scheduling procedure for two different types of nursing teams, regular teams from care units and the float team that covers shortages in the hospital, is examined. Heuristics and the corresponding multi-objective model are described (Legrain et al., 2020). In Valouxis & Housos (2000), a post-optimization phase utilizing tabu search is carried out after a nonoptimal solution is produced by solving the mathematical model. Bard et al. (2014) provided an algorithm to support therapists' weekly planning. This research addresses the following two research questions (RQ) associated with the real case:

RQ-1: Based on hospital capacity and patient priority, how many patients were selected for service care (basic, critical, suggestion)?

RQ-2: How many nurses should be allocated to serve the selected patients?

In this study, the patients who are admitted to the healthcare centre are separated and categorized by weight level. According to patients' needs and priority levels, the expected nurse allocation can be calculated to provide insight into care service demand during the pandemic or post-pandemic.

The major contribution of this research is the real case-related mathematical model formulation to enhance the performance of hospital service care management. Although this model is only applied to the surgery department, it can be applied to any department by changing the parameters. However, this model is generic for selecting patients and nurse allocation for any hospital service care management department.

The remaining part of the paper is organized as: section 2 describes the background and literature review. Section 3 describes the methodology in terms of problem description, patient selection, and nurse allocation. Section 4 formulated the mathematical model focusing on the problem description. Section 5 uses a real-world case study to implement the model. Section 6 describes the results and discussion. Finally, section 7 describes the limitations, future directions, and conclusions of the study.

2. LITERATURE REVIEW

The COVID-19 pandemic has posed additional challenges to many countries already strained healthcare systems. From a practical perspective, it turns out that it is difficult for a nursing home to give a customer preference for a more prominent place (Barbini et al., 2014). This requires registration of client settings, which is not yet common during a post-pandemic situation. The pandemic and post-pandemic situations result in patient utilization and nurse workloads affecting timely, comprehensive, and safe care (Halcomb et al., 2020; Joo & Liu, 2021; Turale et al., 2020).

The selection of patient procedure is related to the mathematical model based on patient selection presented in (Ogulata et al., 2008), where a hierarchical mathematical programming problem is proposed to produce weekly staff scheduling. Using a multi-stage integer linear programming problem, Fargetta & Scrimali (2022) established a model to guarantee the maximum number of selected patients. Considering the nurses' capacity and the patients' priority, this stage's goal is to choose from the candidate list the patients scheduled for the following days.

Additionally, patients might be given varying degrees of priority. A proper schedule must take this discrepancy into account. According to specialized doctors, the three categories of patient priority are very high, high, medium, low, and very low (Fargetta & Scrimali, 2022).

2.1 Patient Selection

The patient selection dilemma is identifying the most significant number of patients who can benefit from care, given the personnel numbers in place. Due to the incredibly high demand for care services, the selection of patients and identification of patient priority levels must be finished before booking. In a qualitative study by (Joo & Liu, 2021), nurses expressed their inability to provide patient and family-centered care because of changes in patient management methods (e.g., group care and use of protective equipment) and limitations (e.g., limited patient contact). This would prevent the spread of diseases. Given the nature of the infection, caregivers are forced to prioritize caregiving tasks dealing with the patient's oxygenation status, positioning to maximize lung expansion and administration of antibiotics and antivirals over other caregiving tasks. For instance, monitoring and other patient communication and interaction (Danielis et al., 2020).

The authors (Bard et al., 2014) offer an algorithm to aid in the weekly planning of therapists. It specifically enables one to balance the needs of patients and therapists while lowering treatment, travel, administrative, and mileage reimbursement costs. A parallel greedy randomized adaptive search procedure (GRASP) that uses a novel decomposition technique and a set of benefit measures that specifically address the trade-off between feasibility and solution quality is used to find solutions. The patient demand and nurse's expertise can be studied daily with the aid of this investigation. The integration of artificial intelligence (AI) and machine learning (ML) into spine surgery can also offers promising advancements in optimizing preoperative patient selection and predicting and managing postoperative outcomes (Lopez et al., 2022).

2.2 Nurse Allocation and Workload Evaluation

The demand for services varies throughout the day in most service systems. The anticipated workload must be projected and converted into the necessary number of personnel throughout the day to satisfy the intended service level before creating an acceptable shift plan. The patient’s priority level, demand, and condition must be matched with the quality of the nurses. The intensity of the nurse's activity, experience, and skills must be considered to assess the workload throughout the day. For example, common manual handling tasks can be categorized as being at the same quality level. These tasks include moving patients between trolleys, beds, and chairs, repositioning patients in bed, pushing beds, trolleys, wheelchairs, and commode chairs, and carrying five heavy pieces of equipment (Yip, 2001).

The integration of qualification levels is a characteristic feature of nursing homework scheduling (Bellenguez-Morineau & Néron, 2007; Huang et al., 2012; Schimmelpfeng et al., 2012). However, (Bellenguez-Morineau & Néron, 2007) studies the minimum workforce for a viable timetable in case of stringent start time limits. Schimmel Feng et al. (2012) offer a task-scheduling technique for rehab centers with different prerequisites and precedence limitations across activities. Still, they do not account for personal preferences for work duration (Schimmelpfeng et al., 2012). Galiano et al. (2023) conducted an integrative review to analyze the impact of technology on nursing workload allocation, highlighting the benefits, challenges, and barriers associated with these innovations.

3. METHODOLOGY

The research methodology is divided mainly into three parts: i) problem description ii) mathematical model development iii) application of the model. The mathematical model is further split into two stages. First of all, the number of patients is selected for care services based on the hospital capacity (doctor, nurse, staff, equipment etc.) and patient priority (high, normal, and low). In this process, patients are chosen from the total number of patients applied for admission/appointment into healthcare services based on the existing facilities. In the second stage, this research aims to optimize the nurse workload by minimizing the number of nurses. The output of the first stage will act as a demand constraint of the second stage. The methodology adopted for this research is shown as a block diagram in the following Fig. 1.

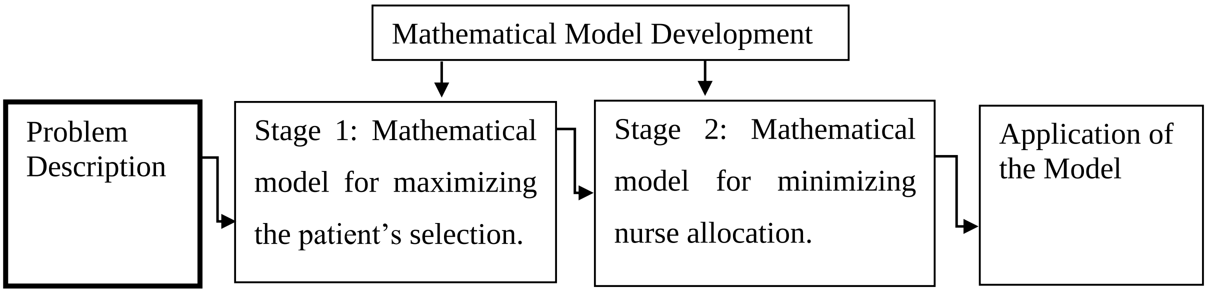

Fig. 1: Overview of Methodology

3.1 Problem Description

Hospital service care is urgently needed for the patients, and it's their right too. Different types of inpatients and outpatients come to the hospital to have their desired services. Nowadays, the hospital admission/ appointment system has been online so that the patient is notified in advance whether he is selected for care. However, hospital service management is having difficulty selecting the optimal number of patients to be cared for based on their service care needed (basic, critical, suggestion care) and hospital capacity (doctor, nurse, staff, equipment, etc.). Therefore, this problem also impacts subsequently on the optimal nurse allocation. The allocation of nurses largely depends on the number of patients selected for the care service. These problems associated with (i) optimum (maximum) patient selection and (ii) optimum (minimum) nurse allocation must be resolved in order to develop a framework for scheduling client-centered care without exceeding capacity.

3.1.1 Optimal Patient Selection

The first sub-problem is finding the maximum number of patients who can benefit from care, given the staffing levels in place. The selection of patients must be completed prior to booking due to the exceptionally high demand for care services. When a patient applies for the appointment, they have to select the category under which he is willing to have the service (basic or critical or suggestion). The categories under which they are treated can be assured by previous appointments of doctors based on the prior test reports. A patient is categorized based on the other conditions or factors that are considered by a specialist and sets priority weights accordingly. So, that hospital management can easily select the optimal number of patients considering the hospital's service capacity. Additionally, patients might be given varying degrees of priority. A proper schedule must take this discrepancy into account. According to specialized doctors, the three categories of patient priority are high, normal, and low.

3.1.2 Optimal Nurse Allocation/Assignment

The second stage, workload minimization by minimizing the number of nurses, estimates the nurses required for the following week based on the previous demand data. It is acknowledged that attention must be paid to care by appointment. These care jobs can be reasonably thoroughly planned based on the client's needs and preferences. For example, giving medicine and helping get out of bed in the morning. The majority of demand is tied to daily life activities during the day. The output of the first stage will be input for the second stage and act as a demand constraint. The developed model will determine the optimal number of nurses required for the number of patients selected for service care. This assignment of the nurses will be based on the service care required and the nurse's skill in that care service.

4. MODEL FORMULATION

As per the problem description, this model is two-stage mixed integer linear programming (MILP). First of all, this model optimizes the number of patients selected for service care based on the hospital capacity and patient priorities. In the second stage, the developed model optimizes nurse allocation for service care as per the demand created in the first stage. The service care provided by the hospital is considered to be in a deterministic environment. We assume the expected number of facilities in the healthcare center and the service equipment is known and fixed.

4.1. Stage 1: Model

This model is for optimizing (maximize) the patient selection problem. The indices and parameters are as follows:

- P: Set of critical care patients indexed by p
- Q: Set of basic care patients indexed by q

- R: Set of suggestion care patients indexed by r
- w_b, w_c, w_s: priority level of patients (basic, critical, suggestion)
- t_p^b : basic care time of p[th] patient
- t_p^c : critical care time of p[th] patient
- t_p^s : Suggestion care time of p[th] patient
- H: total weekly minutes for care service (Total Hospital service hours)
- T^b: total weekly minutes of basic care
- T^c: total weekly minutes of critical care
- T^s: total weekly minutes of Suggestions
- D^b: Each patient's basic care should not exceed a predefined time.
- D^c: Each patient's critical care should not exceed a predefined time.
- D^s: Each patient's Suggestions for care should not exceed a predefined time.

Decision variables at stage 1 are defined as follows:

$$x_b = \begin{cases} 1 & ; if\ patient\ is\ selected\ for\ basic\ care \\ 0 & ; \quad otherwise \end{cases}$$
$$x_c = \begin{cases} 1 & ; if\ patient\ is\ selected\ for\ critical\ care \\ 0 & ; \quad otherwise \end{cases}$$
$$x_s = \begin{cases} 1 & ; if\ patient\ is\ selected\ for\ suggestion\ care \\ 0 & ; \quad otherwise \end{cases}$$

Now, the objective function is to maximize patient selection, and the following problem is the mixed integer problem.

Maximize
$$Zp = \sum_{p=1}^{P}(w_c * x_c) + \sum_{q=1}^{Q}(w_b * x_b) + \sum_{r=1}^{R}(w_s * x_s) \tag{1}$$

Subject to,
$$\left(\sum_{p=1}^{P} t_p^c\, x_c + \sum_{q=1}^{Q} t_p^b\, x_b + \sum_{r=1}^{R} t_p^s\, x_s\right) \leq H \tag{2}$$

$$\sum_{p=1}^{P} t_p^c\, x_c \leq T^c \tag{3}$$

$$t_p^c\, x_c \leq D^c ; \quad \forall \quad p \epsilon P \tag{4}$$

$$\sum_{q=1}^{Q} t_p^b\, x_b \leq T^b \tag{5}$$

$$t_p^b\, x_b \leq D^b ; \quad \forall \quad q \epsilon Q \tag{6}$$

$$\sum_{r=1}^{R} t_p^s\, x_s \leq T^s \tag{7}$$

$$t_p^s\, x_s \leq D^s ; \quad \forall \quad r \epsilon R \tag{8}$$

$$t_p^b, t_p^c, t_p^s \geq 0 \tag{9-11}$$

$$x_b, x_c, x_s \geq 0 \tag{12-14}$$

$$x_b, x_c, x_s \,\epsilon\, \{0,1\} ; \quad \forall \quad p\epsilon P, q\epsilon Q, r\epsilon R \tag{15}$$

In the objective function (1), the total number of chosen patients is increased while taking into account patient priority. Constraint (2) total time for service care should not exceed the daily working hours [generally, hospitals run 24/7]. Constraint (3) presents total daily critical care duration must not exceed the total allotted critical care time per day. Constraint (4) expresses that daily critical care of each patient should not cross the total allotted time for each patient in a day. (5) presents total daily basic care duration must not exceed the total allotted basic care time per day. Constraint (6) expresses that daily basic care of each patient should not cross the total allotted time for each patient in a day. Constraint (7) presents total daily suggestion care duration must not exceed total allotted suggestion care time per day. Constraint (8) expresses that daily suggestion care of each patient should not cross the total allotted time for each patient in a day. Inequality (9-11) is a nonnegativity constraint, which represents the service care duration of a patient (basic, critical, suggestion). Inequality (12-14) is a nonnegativity constraint, which represents total number for care service (basic, critical, suggestion) must be positive. Another thing is that sum of the priority weights is equal to 1 i.e, $(w_b + w_c + w_s) = 1$.

4.2 Stage 2: Model

This model is to optimize (minimize) the nurse allocation problem. Indices and Parameters are as follows:

- *N*: Set of nurses $i \in N$
- *QL:* Set of qualities $j \in QL$
- N_c: Nurse Capacity
- Z_p: Total number of patients selected for care services/demand [from stage 1]

Decision variables at this stage are defined as follows:

y_i= 1 if patient selected, 0 otherwise

a_{ij}= 1 if the patient i assigned to nurse j, 0 otherwise

The objective is to minimize the number of nurses, and the following problem is the mixed integer problem.

$$\text{Minimize,} \quad Z_N = \sum_{i=1}^{N} y_i \tag{16}$$

Subject to,

$$\sum_{i=1}^{N} \sum_{j=1}^{QL} a_{ij} * x_i \geq \text{Zp/D}$$

$$\text{i.e.,} \ \sum_{i=1}^{N} \sum_{j=1}^{QL} a_{ij} * x_i \geq \sum_{p}^{P} \{ (w_b * x_b) + (w_c * x_c) + (w_s * x_s) \} \tag{17}$$

$$\sum_{i=1}^{N} \sum_{j=1}^{QL} a_{ij} * x_i \leq \text{Nc} \tag{18}$$

$$\sum_{j=1}^{QL} a_{ij} * y_i \leq 5 \ ; \ \forall \ i \epsilon N \tag{19}$$

$$\sum_{j=1}^{QL} a_{ij} \geq 1 \ ; \ \forall \ j \epsilon QL \tag{20}$$

$$a_{ij}, x_i \ \epsilon \ \{0,1\} \tag{21-22}$$

In the objective function (17), minimize the total number of nurses while taking into account selected patients. Constraint (18) should not exceed the demand generated from stage 1. Constraint (19) should not exceed the total number of nurses (nurse capacity). Constraint (20) tasks handled by the nurse should not exceed five within the shifts. Constraint (21) ensures at least one care service is provided to each selected patient. Inequality Constraint (21-22) represents constraints that must be integer. Note that sum of the priority weights is equal to 1 i.e, $(w_b + w_c + w_s) = 1$.

5. CASE STUDY

The case study is conducted in the nursing service in a tertiary-level government hospital in Bangladesh. Data were collected from Pabna Medical College Hospital, Pabna, Bangladesh. The particulars of the Pabna Medical College hospitals, according to the local health bulletin, 2022, are: The hospital has 3 shifts: morning, evening and night. The morning, afternoon and night time schedules are 08.01 to 14.00, 14.01 to 20.00 and 20.01 to 08.00 in 24-hr clock format. Additionally, the total doctor = 60, total intern doctor = 80, total nurse =300, total ot room = 7, total section = 10, total staff =1000 and total MATs = 100. In each department, an average of 20 nurses are allotted in the morning shift and, an average of 15 nurses are allotted in the evening and an average of 15 nurses are allotted in the night shift. Daytime focus was given in this investigation (7.00-23.00). The facility can support patients who are admitted and provide care around the clock. There are over 100 care tasks every day that take place during the day. The tasks classified by various quality levels that are pertinent to this investigation are shown in Table 2. The capacity that is available is based on the priority and condition of the patients. The goals are to increase the number of patients as much as possible, ensure the care service availability for each chosen patient, and deliver the necessary care as close as possible to their time preferences. This will allow the clients to receive treatment in accordance with their needs and preferences. The developed model is applied to the surgery department.

5.1 Problem Identification

Some problems that patients and staff encounter and some inappropriate applications in this service can be explained as follows.

- Problem associated with patient selection: No priority level is assigned to the chosen patients. The nurses' quality level is not taken into account when assigning patients to them. As a result, the needed level of quality nursing service for each patient cannot be provided on time. This signifies that the patient will not receive the essential service on time.
- Problem associated with nurse allocation: Due to strong demand, nurse workload is extremely high during pandemics and post-pandemics. Patients are assigned to nurses at random, and fairness among them is not taken into account. Furthermore, as a result of this discriminatory assignment approach, certain nurses may occasionally have overcapacity workloads while others have lower-capacity workloads.

5.2 Decision Regarding Patient Selection & Nurse Allocation

According to the viewpoint of specialized doctors, the model at this stage reflects the priority of patients, which was divided into three tiers as high (critical), normal (basic), low (suggestion). This research also sets priority weights based on discussions with key personnel involved in hospital service care management. We engaged with five experts, each providing their own perspectives on priority setting. From these discussions, we derived an average set of priority weights: 0.60 for critical care (W_c), 0.30 for basic care (W_b), and 0.10 for suggestion care (W_s). It was expected that 950 patients (for critical care p = 200, for basic care q = 250, for suggestion care r = 500) would request hospital admission to get care from a care worker/nurse for a week. A specific care professional with the necessary experience and training for the job performs the critical care service. The following categorization of patients is based on the conditions or factors a specialist considers.

Case-1: A patient is selected for basic care under some condition when

- Patients need a care worker to complete his/her daily caring tasks such as taking oral medicine on time, taking saline or medicine with injection
- Patients are unable to take care himself/herself
- Patients need bed rest with proper nursing care
- Patients required daily checkups and any other condition
- Aged patients need to take special care

Case-2: A patient is selected for critical care under some condition if

- Patients have life-threatening injuries and illness
- Patients who undergo very intensive surgery or who have poor outcomes after surgery
- Patients severely injured or have serious infections.
- People who have trouble breathing on their own and require a ventilator to breathe for them
- Patients who are required for intensive care unit (ICU) or any other urgent conditions

Case-3: A patient is selected for suggested care under some conditions. When

- It requires guidelines for patients, psychological support, etc., at the pre-surgery stage.
- It requires providing the patient with rules and regulations, do's and don'ts, food charts, etc., at the post-surgery stage.

6. EXPERIMENTAL ANALYSIS

6.1 Numerical Analysis of Patient Selection

In this stage, the model used the case data from the designated hospital, Pabna Medical College & Hospital, Pabna, Bangladesh. This research work will function within the time constraints. These constraints are the constraints of the model. The facilities (doctors, nurses, staff, no. of equipment, tools, etc.) are embedded in the time constraints. For example, how many patients can the existing capacity and facilities serve per week, keeping in mind that this model considers the availability of facilities for a particular week? This model considers 24/7 service hours which are split into three shifts per day. The total time allotted for a care service is 70 hours/week for critical care, 56 hours/week for basic care, and 14 hours/week for suggestion care. Rest 4 hours/day for allowance, set up time, the interval between two consecutive surgeries, unavoidable delays, launch break, prayer break, etc. This model also assumed an average of 35 minutes for critical care, 20 minutes for basic care, and 5 minutes for suggestion care are required.

According to the equations (1-15) and respective values, the objective function and constraints are as follows:

Maximize $$Zp = \sum_{p=1}^{200} 0.60 * x_c + \sum_{q=1}^{250} 0.30 * x_b + \sum_{r=1}^{500} 0.10 * x_s \quad (1a)$$

The objective function (1a) represents the maximum patient selection under the average set of priority weights.

Constraint 1: If the selected patient is selected for critical, basic, and suggestion care, then decision variables are $\boldsymbol{x_b = 1}$, $\boldsymbol{x_c = 1}$, $\boldsymbol{x_s = 1}$, p =1,2,3…200, q =1,2,3…250 and r =1,2,3…500.

$$\left(\sum_{p=1}^{P} t_p^c x_c + \sum_{q=1}^{Q} t_p^b x_b + \sum_{r=1}^{R} t_p^s x_s\right) \le H$$

i.e., $$\left(\sum_{p=1}^{200} t_p^c x_c + \sum_{q=1}^{250} t_p^b x_b + \sum_{r=1}^{500} t_p^s x_s\right) \le 10080 \quad (2a)$$

The constraints (2a) express that total care time must not cross 10080 minutes per week.

Constraint 2: If the patient is selected for critical treatment, then decision variables are $\mathbf{x_c = 1}$ and p =1,2,3…200.

$$\sum_{p=1}^{P} t_p^c x_c \le T^c$$

i.e., $$\sum_{p=1}^{200} t_p^c \le 4200 \quad (3a)$$

Then, the constraint is for each patient, $\boldsymbol{t_p^c x_c \le D^c}$

i.e., $$t_p^c \le 35 \quad (4a)$$

The inequality (3a) & (4a) state that the total allotted time for critical care patients must be within 70 hours or 4200 minutes per week, and each critical care patient must be served within 35 minutes.

Constraint 3: If the patient selected for basic treatment, then decision variables are $\boldsymbol{x_b = 1}$ and q=1,2,3…250.

$$\sum_{q=1}^{Q} t_p^b x_b \le T^b$$

i.e., $$\sum_{q=1}^{250} t_p^b \le 3360 \quad (5a)$$

Then, the constraint is for each patient, $\boldsymbol{t_p^b x_b \le D^b}$

i.e., $$t_p^b \le 20 \quad (6a)$$

The inequality (5a) & (6a) state that the total allotted time for basic care patients must be within 56 hours or 3360 minutes per week, and each basic care patient must be served within 20 minutes.

Constraint 4: If the patient is selected for suggestion care, then decision variables are $\boldsymbol{x_s = 1}$ and r =1,2,3…500.

$$\sum_{r=1}^{R} t_p^s x_s \le T^s$$

i.e., $$\sum_{r=1}^{500} t_p^s \le 840 \quad (7a)$$

Then the constraint is for each patient, $\boldsymbol{t_p^s x_s \le D^s}$

i.e., $$t_p^s \le 5 \quad (8a)$$

The inequality (7a) & (8a) state that the total allotted time for suggestion care patients must be within 14 hours or 840 minutes per week and each suggestion care patient must be served within 5 minutes.

After solving the problem (solved by using OPL, CPLEX Software), we got a total of 196 patients out of the 950 patients who were prescribed care services were chosen from those who requested admission to the hospital in order to get care services.

6.2 Numerical Analysis of Nurse Allocation

The care employees that are available are categorically separated into several degrees of qualities (QLs) or expertise. This "differentiated practice" is founded on a differentiation in responsibility, education, and level of care complexity. The relevant expertise level for this investigation is listed in Table 1, along with the activities that go with them. The most popular shift lengths for care workers to complete tasks are 6, 6 and 12 hours. The goal is to give the required care as near as feasible to the clients' preferred times, i.e., with the least amount of delay, to enable them to live their lives as they see fit. A consistent, systematic process is used to inventory the necessary care (activities) and corresponding time preferences. There are over 100 care activities every day that take place during the day.

Overall, a skilled medical/surgical nurse must be adaptable when it comes to working conditions and sensitive to the incredibly diverse needs of various patients. Their main duty is to tend to the requirements of people who are recovering from medical procedures as well as those who have serious medical issues. On top of that, every medical/surgical nurse should do the following duties:

Table 1: Tasks to be carried out according to Expertise level

Expertise of Nurse	The task to be carried out
QL1	Giving preoperative instructions.
QL2	Preparing patients for surgery.
QL3	Assisting the anesthetist and Surgeons when needed.
QL4	Sterilizing and marking incision sites.
QL5	Intervening when there are complications.
QL6	Administering medication.
QL7	Preparing the operating room.
QL8	Maintain and update patient files, medical charts, and health records.
QL9	Adjust specialized medical equipment as needed and interpret and record measurements.

The following Table 2 represents the 5-nurse expertise on different tasks to be carried out by them. It is important to note that this model considers 100 nurses and their expertise. The selection of a nurse with a certain expertise/quality level indicates the no. of patients served by the nurse.

Table 2: Random 5 nurses and their qualities

Quality of nurse	• Each patient must be served at least by one nurse of a certain quality (QL1-QL9). • The selection of a nurse with a certain expertise/quality level indicates the number of patients served by the nurse.							
	QL1	QL2	QL3	QL4	QL5	QL6	QL7	QL8	QL9
N1	1	1	0	1	1	1	0	1	1
N2	0	1	1	1	0	1	1	1	0
N3	1	0	1	1	1	0	1	1	1
N4	1	1	1	0	0	1	1	0	0
N5	0	1	0	1	1	1	0	1	1

Considering the maximum number of patients from the first stage as the constraint of this stage. Equation 18 and 19 becomes the following:

$$\sum_i^N \sum_j^{QL} a_{ij} * x_i \geq \text{Zp/D}$$
$$\text{i.e., } \sum_i^N \sum_j^{QL} a_{ij} * x_i \geq 196 \quad (18a)$$

$$\sum_i^N \sum_j^{Q} a_{ij} * x_i \leq Nurse\ capacity\ (\text{Nc})$$
$$\text{i.e., } \sum_i^N \sum_j^{QL} a_{ij} * x_i \leq 100 \quad (19a)$$

After solving the problem (solved by using OPL, CPLEX Software), we got 41 nurses selected from 100 nurses to serve the selected patients (196) obtained from stage 1.

7. RESULTS AND DISCUSSION

This study presents a two-stage MILP model to optimize patient selection and nurse allocation, focusing on maximizing patient care while balancing nurse workloads. Two main focuses can be obtained as a result:

- Maximizing the number of patients selected for service care while considering capacity restrictions and priority levels.
- Considering the expertise level when allocating nurses and evaluating the anticipated weekly average workload.

The data set from this service at Pabna Medical College Hospital is employed for the case study. There is a chance to compare the results of the real system with the suggested model using hospital information. First, 196 patients are accepted for this service, considering the priority level and their care service sequence for the available care workers. It is important to note that every patient is a priority, but hospital service facilities are limited in terms of doctors, nurses, staff, equipment, etc. In this method, the total number of patients who can be accepted simply depends on the required care duration with lower sequence numbers. The overall number of applicants accepted into each priority level in this system is therefore determined randomly. The Sensitivity Analysis is carried out for different sets of priority weights, as shown in Table 3.

Table 3: Patient selection and corresponding nurse requirements under set of priorities

Set of Weights	Critical Care (W_c)	Basic Care (W_b)	Suggestion Care (W_s)	No. of Selected Patients	Nurse Required
Set 1	0.75	0.20	0.05	185	38
Set 2	0.70	0.20	0.10	191	39
Set 3	0.60	0.30	0.10	196	41
Set 4	0.65	0.30	0.05	191	39
Set 5	0.55	0.25	0.20	205	43

From Table 3, it is observed that set 3 is the optimum set of priorities. The hospital can cover all the critical and emergency patients by increasing the facilities. However, it is not the ultimate solution because we have limited resources. Not only one hospital is responsible for covering all patients; there are other options. This model will assist in scheduling nurses and patients in a healthcare facility that prioritizes patients' needs, achieves an equitable distribution of nurses' workload to optimize work shifts, and reduces nurses' time wastage by matching their skill level to the necessary patients. It also enables a more evenly distributed workload for care workers because the proposed patient selection pattern and workload are better balanced.

8. CONCLUSIONS

The study presents a two-stage mixed integer linear programming (MILP) model that effectively optimizes patient selection and nurse allocation in a hospital setting. By prioritizing patients based on care urgency and matching them with appropriate nurses, the model maximizes the number of patients served while balancing nurse workloads. The implementation of this model at Pabna Medical College Hospital demonstrated its capability to handle 196 patients out of 950, identifying the critical ones requiring immediate attention and ensuring a fair distribution of workload among 41 nurses.

8.1 Implications

The proposed model has significant implications for healthcare management, particularly in resource-constrained environments. It offers a systematic approach to improve patient care efficiency and nurse workload management. By ensuring that critical patients receive timely care and optimizing nurse assignments based on skill levels, the model can enhance overall healthcare delivery and patient satisfaction. This approach can be extended to other departments within the hospital and adapted for various healthcare settings, making it a versatile tool for improving hospital operations.

8.2 Limitations

Despite its strengths, the model has several limitations. It does not account for patient preferences regarding service days, which can affect patient satisfaction and care continuity. The model is also based on a static weekly schedule and may not adapt well to dynamic changes in patient inflow and nurse availability. Additionally, the model assumes deterministic conditions, not considering potential uncertainties in patient conditions, nurse availability, or equipment failures. The reliance on accurate and comprehensive data, which may not always be available, further limits the model's practical application.

8.3 Future Directions

Future research should focus on addressing the limitations of the current model. Incorporating patient preferences and dynamic scheduling adjustments could enhance its applicability and effectiveness. Developing a stochastic version of the model to handle uncertainties in patient and nurse availability would provide a more robust solution. Additionally, integrating advanced technologies such as robotics, electronic health records, and ICT support could improve data accuracy and model performance. Exploring the model's application in different healthcare settings and departments will help validate its generalizability and adaptability. Further studies could also investigate the impact of nurse workload optimization on patient outcomes and staff well-being, providing a comprehensive understanding of the model's benefits.

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