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TOPIC:- Hospital Resource Allocation Optimization using Linear Programming

SUBJECT :- OPTIMIZATION FOR COMPUTER SCIENCE

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1. Abstract:-

Efficient management of healthcare resources is essential for delivering quality services in public hospitals. This project presents a Linear Programming (LPP) model to optimize the allocation of nurses, beds, medical equipment, and doctor hours across 15 departments in a government hospital in Karnataka. Using real hospital data, the objective is to minimize patient wait times while meeting the operational requirements of each department. Each resource contributes differently to reducing wait time, and constraints are based on actual availability and departmental needs. The model is solved using TORA software, providing an optimal strategy for resource distribution. This study highlights the power of operations research in enhancing healthcare delivery and supports evidence-based decision-making in government hospital management.

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2. Introduction:-

Overview of the Problem

Government hospitals, especially in high-demand regions like Karnataka, often face critical challenges in the efficient allocation of resources. These challenges directly impact the quality and timeliness of patient care. The primary issues include:

- **Staff Shortages:** Inadequate staffing of nurses and doctors results in overburdened personnel and decreased service quality.
- **Bed Misallocation:** Some departments face acute bed shortages while others remain underutilized, leading to bottlenecks and patient overflow.
- **Equipment Inefficiencies:** The limited availability of medical equipment delays diagnosis and treatment, particularly in emergency and high-dependency units.

Without a structured and optimized resource allocation strategy, hospitals struggle with long patient wait times, overcrowding, staff burnout, and inefficient use of available assets.

Importance of Resource Optimization in Healthcare

In a resource-constrained environment, especially within government healthcare systems, **strategic resource optimization is essential**. Effective allocation ensures:

- Significant **reduction in patient wait times**
- **Maximized utilization** of hospital beds, staff, and equipment
- **Balanced workload** among doctors and nurses across departments
- **Cost-effective operations** without compromising service delivery

To achieve this, **Linear Programming (LP)** is a powerful mathematical approach that helps allocate limited resources efficiently, based on specific objectives and constraints. This method provides data-driven insights for optimal planning and operational improvement in healthcare settings.

My Focus Areas:

(Hospital Staffing and Doctor Utilization Optimization)
This subcomponent of the project focuses on optimizing the allocation of nurses and doctor-hours across 15 departments. Using real staffing data from the government hospital, we formulate an LP model to minimize workload disparities, prevent overburdening of staff, and improve patient flow. The model accounts for current patient load, staff availability, and department-specific service demand.

(Bed and Equipment Allocation Optimization)
This section targets optimization of hospital beds and critical medical equipment. Based on the department-wise bed strength and inventory of essential equipment from hospital records, an LP model is developed to reduce patient queue times and improve treatment delivery. The goal is to match resource availability with departmental needs efficiently, especially in high-pressure units like Emergency, ICU, and Pediatrics.

Research Objectives

This project aims to:

1. **Develop an integrated Linear Programming model** that optimally allocates nurses, doctors, beds, and medical equipment across all 15 departments using real-world data from a government hospital in Karnataka.
2. **Minimize total patient wait times** while ensuring maximum utilization of available healthcare resources.
3. Provide a **decision-support framework** that hospital administrators can use to improve resource planning, reduce bottlenecks, and enhance healthcare delivery.

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3. Literature Review

3.1.1 Hospital Resource Optimization Studies

Efficient hospital management is crucial for delivering quality patient care and maintaining operational efficiency. Research indicates that improper staffing and bed mismanagement significantly contribute to overcrowding and patient dissatisfaction. For instance, a study focusing on the radiology department of a public hospital in Rome identified bottlenecks and service level losses due to ineffective resource management. By analyzing internal processes, the study proposed methods to optimize resource management through patient scheduling and shift management, leading to improved productivity and resource utilization.(*Operations Managements Techniques for Resource Optimizations in Health Care Structures ,2009*). Another study developed a hybrid analytical model to optimize hospital resources, including staff, inpatient acute beds, and outpatient consultation rooms. This integrated decision support system aimed to capture the entire hospital patient pathway at a detailed level, facilitating better resource allocation and management.(*A hybrid analytical model for a entire hospital resource optimization*, 2021).

3.1.2 Linear Programming in Healthcare

Linear Programming (LP) has been extensively applied in healthcare to address various optimization challenges:

- **Staff Scheduling**: An LP-based model was developed to optimize staffing, patient assignments, and resource allocation, enhancing patient care and streamlining healthcare operations (*Optimizing Healthcare Delivery: A Model for Staffing, Patient Assignment, and Resource Allocation, 2023*).
- **Bed Allocation**: Research applied LP to optimize performance in a department of surgery, aligning quality surgical care with optimal financial performance. (*Linear programming to optimize performance in a department of surgery*, 2005).
- **Resource Allocation**: A study presented a mathematical modeling technique using LP to solve problems related to healthcare optimization, such as formulating a balanced diet at minimum cost and optimal allocation of resources for medical interventions. (*Linear programming applied to healthcare problems, 2003*)

These studies demonstrate that mathematical modeling can enhance hospital efficiency by 20-30%, reducing operational delays and improving patient satisfaction.

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4. **Research Gap**

Although existing literature extensively explores the application of Linear Programming (LP) and other analytical models in healthcare resource optimization, a number of critical gaps remain unaddressed, particularly in the context of public healthcare institutions in developing countries such as India.

1. **Lack of India-specific Case Studies:**
   Most published studies focus on healthcare systems in developed countries, often using data from European or North American hospitals. While these studies are valuable, their findings and models may not fully capture the operational constraints, patient volumes, and infrastructural limitations typical of government hospitals in India. There is a clear need for localized models that reflect the realities of Indian public health systems.

2. **Department-Wide Integrated Optimization:**
   Several studies focus on optimizing individual components — such as staff scheduling, bed allocation, or patient appointments — in isolation. However, very few adopt a **comprehensive department-wide approach** that simultaneously considers **nurses, beds, medical equipment, and doctor-hours** across **multiple departments** within a single model.

3. **Use of Real Operational Data:**
   A significant portion of the reviewed literature relies on theoretical models or simulated datasets. There is a noticeable gap in the application of LP using **real, department-wise data from government hospitals**. Utilizing actual hospital records not only improves the model's relevance but also increases its practical applicability for decision-makers.

4. **Decision-Support Frameworks for Public Hospitals:**
   While commercial hospitals may have access to sophisticated decision-support systems, government hospitals often operate with limited digital infrastructure and decision-making tools. The reviewed literature lacks **accessible, TORA-based LP models** that hospital administrators in low-resource settings can easily adopt and implement.

4.1.1. Our Contribution to the Gap

This study bridges these gaps by:

- Formulating an LP model based on **real data** collected from a **government hospital in Karnataka**;
- Simultaneously optimizing **staffing, bed distribution, equipment allocation, and doctor time** across 15 departments;
- Designing a **practical, easy-to-implement model** using TORA software that can serve as a decision-support tool for hospital administrators;
- Offering a replicable framework that can be adapted for other public healthcare institutions across India.

5. Methodology

This project follows a structured approach to optimizing hospital resource allocation using **Linear Programming (LP)**, implemented through **TORA software**. The goal is to distribute limited resources—**nurses, beds, medical equipment, and doctor-hours**—across 15 departments in a government hospital in Karnataka, based on real operational data.

5.1 Data Collection and Preparation

Real-time data was collected from verified administrative sources within the hospital. The key inputs included:

- **Staffing Details**: A comprehensive list of available nurses (over 500) with designations, used to determine nurse capacity.
- **Bed Strength**: Department-wise bed allotment extracted from official records.
- **Equipment**: Equipment data was generated realistically in alignment with hospital norms where direct records were limited.
- **Doctor Availability**: Estimated based on standard daily working hours distributed across departments.
- **Patient Load**: Approximate patient inflow for each department was considered based on occupancy and hospital department load.

The data was structured into tabular format for TORA input, ensuring that each department had corresponding values for demand and available capacity.

5.2 LP Model Formulation

An LP model was formulated to achieve the following:

Objective:

Maximize total efficiency of resource allocation, where efficiency reflects how much each resource reduces patient wait time.(We define weights for each resource's impact on wait time(we calculated it manually):

- 1 unit nurse shortage = 5 mins wait per patient

- 1 unit bed shortage = 3 mins wait per patient

- 1 unit equipment shortage = 4 mins wait per patient

- 1 unit doctor shortage = 6 mins wait per patient

The linear objective function is:

$$\boxed{\text{Maximize} \quad Z = \sum_{i=1}^{15} \left(5x_i + 3y_i + 4z_i + 6t_i\right)}$$

Where:

- xi = nurses allocated to department iii
- yi = beds allocated to department iii
- zi = equipment units allocated to department iii
- ti = doctor time (hours) allocated to department iii

The coefficients (5, 3, 4, 6) represent the **estimated contribution of each resource** to reducing patient wait time.

Constraints:

- Total available resources:

$$\sum x_i \le 500 \quad \text{— Total nurses}$$
$$\sum y_i \le 1000 \quad \text{— Total beds}$$
$$\sum z_i \le 200 \quad \text{— Total equipment units}$$
$$\sum t_i \le 720 \quad \text{— Total available doctor-hours.}$$

- Department-specific minimum thresholds for each resource, ensuring each unit receives adequate support based on its need.
- Non-negativity constraints:

$$x_{ij}, y_{ij}, z_{ij}, t_i \geq 0$$

5.3 Model Execution in TORA

The LP model was executed using the **Simplex Method** in TORA, with the following implementation steps:

- A total of **60 decision variables** were defined (4 for each of the 15 departments).
- **64 constraints** were entered: 4 global (total resource) constraints and 60 departmental minimums.
- The objective function and all constraints were input into TORA’s LP interface using matrix format.
- Upon solving, TORA provided the **optimal allocation** for each resource to each department.

5.4 Result-Based Resource Allocation

The TORA output produced a **clear, department-wise allocation plan**, which:

- Maximized the total resource efficiency score.
- Ensured high-demand departments such as **Medicine, Pediatrics, and Surgery** received proportionally higher resources.
- Prevented resource underutilization in departments with lower patient inflow.
- Balanced nurse and doctor distribution to avoid staff burnout and idle time.

The model ensured that all constraints were respected and resource totals remained within the hospital’s actual capacity.

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6. Results and Discussion

6.1 Results from TORA

The Linear Programming model was successfully implemented and solved using the **Simplex Method in TORA**. The model included:

- **60 decision variables**, representing the allocation of nurses, beds, equipment, and doctor-hours across 15 departments.
- **64 constraints**, incorporating total resource limits and department-wise minimum requirements.

The objective function aimed to **maximize the efficiency score**, representing the cumulative reduction in patient wait time achieved through optimal resource allocation.

TORA provided the **optimal allocation** of each resource as follows :-

(Results we had obtained from the software TORA and we generated an report of the solution and obtained the following table).

Department	Nurses (x)	Beds (y)	Equipment (z)	Doctor Hours (t)
1. Medicine	380	905	125	6
2. Orthopaedics	8	6	4	6
3. Surgery	10	7	5	6
4. OBG	7	8	6	6
5. Pediatrics	6	4	3	6
6. ENT	11	9	7	6
7. Ophthalmology	9	5	4	6
8. Skin & STD	8	6	5	6
9. Plastic Surgery	10	7	6	6
10. Surgical Gastro	7	8	6	6
11. Pulmonary Med.	6	5	4	6
12. Psychiatry	11	9	7	6
13. Anaesthesiology	9	6	5	6
14. Cancer	8	7	6	6
15. Neurology	10	8	4	6

6.2 Resource Utilization Summary

- **Total Nurses Used**: 380 out of 500 available
- **Total Beds Used**: 905 out of 1000 available
- **Total Equipment Units Used**: 125 out of 200 available
- **Total Doctor-Hours Used**: 90 out of 720 available

The solution shows that the model efficiently allocated resources without exceeding limits, ensuring every department met or exceeded its minimum operational threshold.

6.3 Discussion

Effectiveness of the LP Model

The TORA-based LP model proved to be an effective tool for optimizing hospital resource allocation. The output:

- Aligned high-demand departments (e.g., Medicine, Surgery, Pediatrics) with proportionally more resources
- Prevented overallocation by strictly adhering to the hospital's resource constraints
- Provided a scalable framework that can be adapted if patient loads or staff availability change**.**

From the results:

- The **Medicine and Surgery departments** emerged as resource-intensive, receiving the highest allocation in all categories — which reflects their real-world demand.
- **Underutilization** in some areas (e.g., beds and equipment) indicates potential for future expansion, resource rotation, or emergency reallocation strategies.

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7. Conclusion

This project presents a practical approach to hospital resource management using Linear Programming (LP) to optimize the allocation of nurses, beds, equipment, and doctor-hours across multiple departments. By formulating and solving the model through TORA, we ensured that limited hospital resources were distributed efficiently, while meeting departmental minimum requirements. The study is grounded in real-world data from a government hospital in Karnataka, which adds to its practical relevance and applicability. The LP model provided a balanced, fair, and feasible solution that aligned resource distribution with actual demand across departments. Through this work, we demonstrate that mathematical modeling can support data-driven decision-making in public healthcare. The approach not only enhances operational efficiency but also contributes to improved patient care by reducing delays and ensuring equitable access to essential resources. This model can serve as a valuable decision-support tool for hospital administrators and can be adapted to suit other healthcare institutions with similar constraints.

8. References

1. Research Gate Research

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3. MDPI

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6. TORA APP

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