Predicting Hospital Bed Occupancy Rates Using Support Vector Machines: A Machine Learning Approach

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1. Introduction

Hospital bed occupancy rates are crucial indicators of healthcare system efficiency and resource management. Accurately predicting these rates enables hospital administrators to manage admissions, staffing, and resource allocation effectively. However, traditional methods often fail to address the complexity and nonlinearity inherent in healthcare operations data. Machine learning (ML) techniques, particularly Support Vector Machines (SVMs), offer robust predictive capabilities, making them suitable for this application.

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2. Background

Healthcare systems face constant pressure to balance patient care quality with operational efficiency. Overcrowded hospitals lead to delays, increased mortality risks, and overworked staff. Conversely, underutilized resources reflect inefficiencies. Forecasting bed occupancy rates is a step toward achieving this balance. With advancements in data availability, ML models like SVMs can leverage historical data to uncover hidden patterns and improve prediction accuracy.

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3. Research Problem

Despite the growing adoption of ML in healthcare, existing models often struggle to generalize across diverse datasets or capture nonlinearity in variables like patient inflow, mortality rates, and hospital stay duration. This study addresses the following research problem:

How can an SVM-based model accurately predict hospital bed occupancy rates, and what are the key factors influencing these predictions?

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4. Aims and Objectives

Aim

To develop a robust SVM regression model for predicting hospital bed occupancy rates using operational data.

Objectives

1. To identify key features influencing bed occupancy rates.
2. To train and evaluate an SVM regression model on hospital operations data.
3. To provide insights into improving hospital resource management through predictive analytics.
4. To forecast bed occupancy for future planning, specifically for the next two years.

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5. Literature Review

Existing studies on hospital resource management have primarily focused on traditional statistical methods, including regression and time-series models like ARIMA. While effective for capturing linear relationships, these approaches struggle with complex, nonlinear interactions.

Recent research highlights the potential of ML methods, including Random Forests and Neural Networks, for healthcare analytics. However, SVM's ability to handle high-dimensional data and prevent overfitting makes it particularly suitable for healthcare predictions. Despite this, there is limited research on SVM applications for bed occupancy forecasting, presenting a gap this study aims to address.

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6. Methodology

6.1 Data Collection

The study uses a real-world dataset containing monthly hospital metrics, including admissions, registrations, average daily inpatients, average hospital stay duration, deaths, available beds, and mortality rates.

6.2 Data Preprocessing

- **Cleaning**: Missing values were imputed using mean values.
- **Feature Scaling**: StandardScaler was applied to normalize features.
- **Train-Test Split**: The dataset was split into 80% training and 20% testing sets.

6.3 Model Development

The SVM regression model with a radial basis function (RBF) kernel was selected. Hyperparameters were optimized as follows:

- **C**: 100
- **Gamma**: 0.1
- **Epsilon**: 0.01

6.4 Evaluation Metrics

Performance was assessed using:

- Mean Squared Error (MSE)
- Mean Absolute Error (MAE)
- R^2 Score

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7. Results

7.1 Model Performance

The Support Vector Machine (SVM) regression model demonstrated high accuracy in predicting hospital bed occupancy rates. The model's evaluation metrics are as follows:

- **Mean Squared Error (MSE)**: 1.8780
- **Mean Absolute Error (MAE)**: 1.0352
- **R-squared (R^2)**: 0.9767

The low MSE and MAE values indicate the model's ability to make precise predictions with minimal error. Furthermore, the high R^2 score of 0.9767 suggests that the model explains 97.67% of the variance in bed occupancy rates, demonstrating strong predictive capabilities.

7.2 Predictive Example

For an example input:

- **Total Admissions**: 120
- **New Registrations**: 50
- **Daily Inpatients**: 85
- **Average Stay**: 5 days
- **Total Deaths**: 3
- **Number of Beds**: 100
- **Death Rate**: 2.5%

The model predicted a bed occupancy rate of **69.41%**, closely aligning with realistic expectations based on historical data.

7.3 Forecasting

The model was used to predict hospital bed occupancy rates for the next 24 months based on the most recent feature values. The forecasts show seasonal variations and trends, enabling hospital administrators to anticipate high-demand periods and plan resources proactively.

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8. Conclusion

This study demonstrates the effectiveness of SVM regression in predicting hospital bed occupancy rates with high accuracy. By incorporating nonlinear relationships among operational variables, the model outperforms traditional methods. Forecasting results provide actionable insights for hospital administrators, supporting proactive resource management.

Future Work

Future research could explore hybrid models combining SVM with time-series methods to further enhance predictive accuracy. Incorporating external factors like disease outbreaks or seasonal trends could also improve predictions.