Optimizing Emergency Department Operations: Analyzing Patient Flow, Capacity, and Resource Allocation

A Proposal report for the BDM capstone Project

Submitted by

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Contents

Declaration Statement

I am working on a Project titled “Optimizing Emergency Department Operations: Analyzing Patient Flow, Capacity, and Resource Allocation”. I extend my appreciation to California Department of Health Care Access and Information (HCAI) and the Office of the Patient Advocate (OPA), for providing the necessary resources that enabled me to conduct my project.

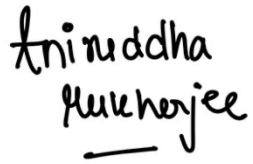
I hereby assert that the data presented and assessed in this project report is genuine and precise to the utmost extent of my knowledge and capabilities. The data has been gathered from secondary sources and carefully analyzed to assure its reliability.

Additionally, I affirm that all procedures employed for the purpose of data collection and analysis have been duly explained in this report. The outcomes and inferences derived from the data are an accurate depiction of the findings acquired through thorough analytical procedures.

I am dedicated to adhering to the principles of academic honesty and integrity, and I am receptive to any additional examination or validation of the data contained in this project report.

I understand that the execution of this project is intended for individual completion and is not to be undertaken collectively. I thus affirm that I am not engaged in any form of collaboration with other individuals, and that all the work undertaken has been solely conducted by me. In the event that plagiarism is detected in the report at any stage of the project's completion, I am fully aware and prepared to accept disciplinary measures imposed by the relevant authority.

I understand that all recommendations made in this project report are within the context of the academic project taken up towards course fulfillment in the BS Degree Program offered by IIT Madras. The institution does not endorse any of the claims or comments.



Signature of Candidate:

Name: Aniruddha Mukherjee

Date: 13th October 2025 (13/10/2025)

1 Executive Summary and Title

The healthcare system in California serves millions of patients annually through emergency departments (EDs), which function as critical access points for urgent medical care. Hospital emergency departments face mounting operational challenges including patient overcrowding, extended wait times, capacity constraints, and uneven resource distribution across facilities. These inefficiencies directly impact patient outcomes, staff burnout, and overall healthcare costs. This project focuses on analyzing emergency department operations across California hospitals using official data from the California Department of Health Care Access and Information (HCAI).

Through comprehensive analysis of ED encounter patterns, patient demographics, facility capacity metrics, and service utilization across multiple years, this study aims to identify operational bottlenecks and propose data-driven strategies for improvement. By examining year-over-year demand trends, capacity-to-encounter ratios, and demographic patterns, I will uncover actionable insights for identifying capacity gaps, understanding utilization patterns, and improving resource allocation. The expected outcomes include evidence-based recommendations for ED capacity expansion, targeted infrastructure investment, and enhanced operational efficiency that can benefit patients, healthcare providers, and hospital administrators throughout California's healthcare system.

2 Organization Background

The California Department of Health Care Access and Information (HCAI), formerly known as the Office of Statewide Health Planning and Development (OSHPD), is a US state government agency committed to expanding equitable access to healthcare for all Californians. HCAI collects, analyzes, and publishes healthcare data to inform policy decisions and improve healthcare delivery across the state. Since 2005, HCAI has maintained comprehensive patient-level administrative data from California's licensed hospitals, including emergency department encounters, inpatient admissions, and ambulatory surgery records.

The Emergency Department datasets used in this project represent real operational data from over 300 hospital facilities across California, capturing millions of patient encounters annually. These datasets include detailed information on patient demographics, diagnoses, discharge dispositions, facility characteristics, and ED capacity metrics. The data undergoes rigorous quality control, with facilities required to maintain error rates below two percent to ensure reliability. This publicly available data serves researchers, policymakers, and healthcare administrators in understanding ED utilization patterns and supporting evidence-based decision-making for healthcare system improvements throughout California.

3 Problem Statement

3.1 **Analyzing Year-Over-Year Emergency Department Utilization Trends**: This study examines temporal trends in ED visit volumes across multiple years (2012-2024) to identify growth patterns, seasonal variations, and long-term capacity planning needs across California facilities.

3.2 **Assessing ED Capacity Gaps and Operational Bottlenecks:** This analysis examines the relationship between ED encounter volumes and available treatment capacity across facilities to identify supply-demand mismatches and operational inefficiencies affecting patient care quality.

3.3 **Analyzing Patient Demographics and Resource Allocation Patterns:** This investigation explores how patient characteristics, diagnoses, and payer distributions vary across facilities and time periods to inform targeted resource planning and equitable healthcare delivery strategies.

4 Background of the Problem

Emergency departments serve as the safety net of the healthcare system, providing 24/7 access to critical medical care. However, California's EDs face significant operational challenges driven by both internal and external factors. Internally, hospitals struggle with staffing shortages, limited treatment station capacity, inefficient patient flow processes, and inadequate resource distribution across shifts and departments. Many facilities operate near or beyond capacity during peak hours, leading to extended wait times, delayed treatment, and increased risk of adverse patient outcomes.

Externally, EDs contend with unpredictable demand surges, seasonal variations in patient volumes, regional disparities in healthcare access, and the growing burden of patients using EDs for non-emergent care due to limited primary care availability. The COVID-19 pandemic further exposed vulnerabilities in ED capacity and resilience. High-acuity conditions like cardiac events, strokes, and respiratory emergencies require immediate attention, yet these critical cases often compete with less urgent visits for limited resources.

These systemic inefficiencies result in prolonged patient boarding times, ambulance diversions, staff burnout, and suboptimal patient satisfaction scores. Without data-driven operational insights, hospitals cannot effectively allocate staff, expand capacity strategically, or optimize patient throughput. This project addresses these challenges by leveraging comprehensive ED data to identify patterns, quantify bottlenecks, and propose evidence-based solutions for improving emergency department operations and patient care delivery across California's healthcare system.

5 Problem Solving Approach

Data Collection: This research utilizes publicly available datasets from the California Department of Health Care Access and Information (HCAI), specifically the Emergency Department Characteristics by Facility dataset (2023-2024), Emergency Department Volume and Capacity dataset (2021-2023), and ED Encounters by Facility dataset. These official government sources provide comprehensive, validated data covering hundreds of California hospitals with millions of patient encounters. The datasets include facility-level information, patient demographics, diagnoses (ICD-10-CM codes), procedures (CPT-4 codes), encounter counts, treatment station capacity, discharge dispositions, and payer information.

Data Cleaning and Preprocessing: The collected data will undergo thorough cleaning to handle missing values, standardize categorical variables, and ensure data consistency across multiple years. Facility identifiers will be validated against HCAI's facility listings. Diagnostic and procedure codes will be grouped into clinically meaningful categories. Treatment capacity metrics will be calculated as encounter-to-capacity ratios. Categorical variables including patient demographics, discharge dispositions, and payer types will be standardized for analysis. The cleaned datasets will be integrated to enable comprehensive multi-dimensional analysis.

Data Analysis: The study applies multiple analytical techniques to address the three problem statements. Exploratory Data Analysis (EDA) will examine ED encounter distributions, facility characteristics, and patient demographics through statistical summaries and visualizations. Year-over-

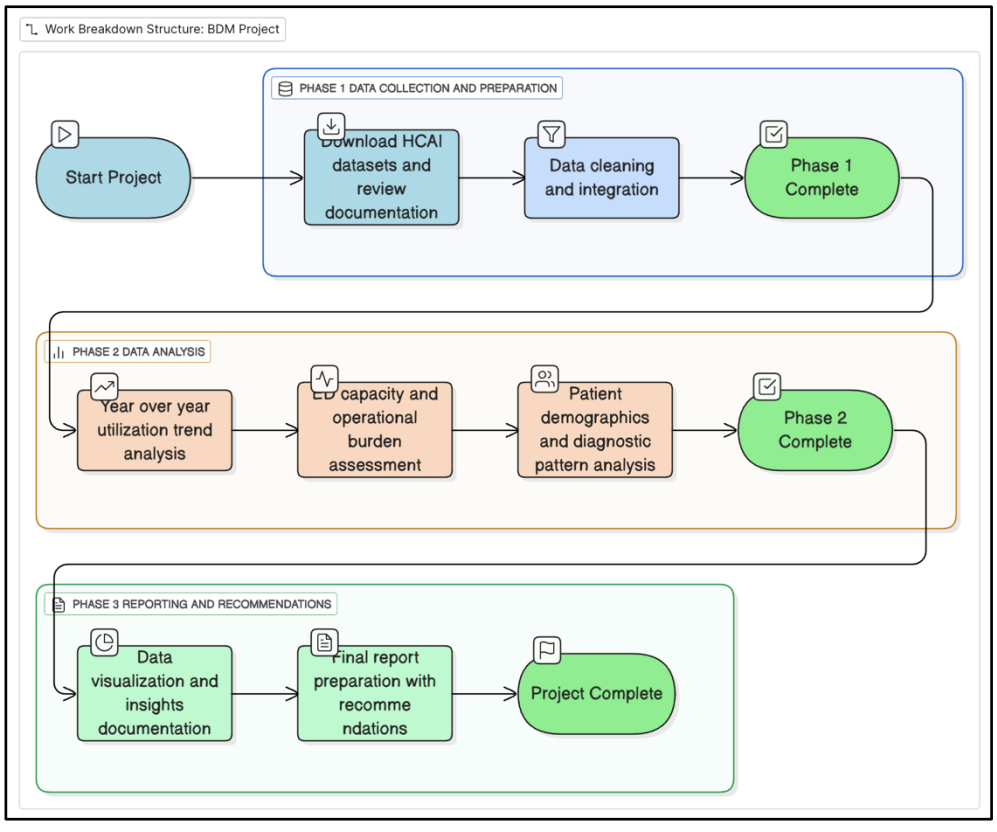
year trend analysis will identify long-term growth patterns, seasonal variations across years, and facilities experiencing significant increases or decreases in demand. Capacity analysis will calculate encounter-to-treatment-station ratios across facilities to quantify operational burden and identify capacity-constrained EDs. Demographic analysis will examine patient age distributions, payer mix, diagnosis patterns, and discharge dispositions to understand service utilization across different facilities. Geographic analysis will compare regional variations in ED utilization and capacity across California counties. Statistical analysis will assess relationships between facility characteristics, patient volumes, capacity metrics, and demographic patterns.

Tools and Software: Python serves as the primary analytical platform, utilizing Pandas and NumPy for data manipulation, Matplotlib and Seaborn for visualization, and statistical libraries for analysis. Excel will be used for initial data exploration of the HCAI pivot tables. Geographic visualization tools may be employed to map regional patterns across California counties. All analysis will be conducted using reproducible code to ensure transparency and validation.

Documentation and Validation: Every analytical step from data collection through final recommendations will be thoroughly documented to ensure reproducibility and academic integrity. Data quality checks will verify the integrity of HCAI source data. Statistical validation will confirm the reliability of findings. Results will be cross-referenced with published literature on ED operations and healthcare utilization patterns to ensure findings align with established healthcare research.

6 Expected Timeline

6.1 Work Breakdown Structure:



6.2 Gantt chart

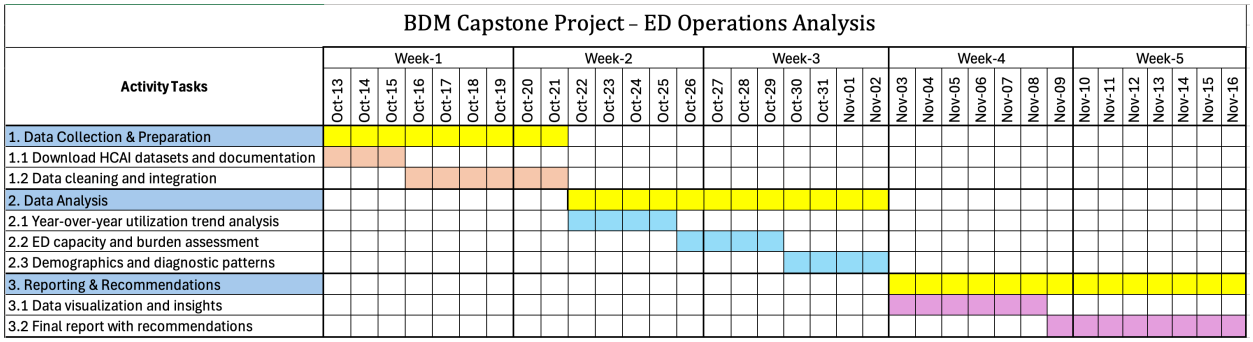


Fig1: Expected Timeline of Completion for the Project

7 Expected Outcome

The analysis of California HCAI emergency department data will yield actionable insights for healthcare administrators and policymakers.

- **Identification of Growth Trends and Capacity Needs**: By analyzing year-over-year ED visit volumes from 2012-2024 across facilities, the study will identify long-term growth patterns and facilities experiencing the highest increases in demand, informing strategic capacity expansion planning.
- **Quantification of Operational Burden**: Using encounter-to-treatment-station ratios, the analysis will identify which facilities operate under the highest burden, enabling targeted resource allocation and infrastructure investment decisions where capacity constraints are most severe.
- **Demographic and Diagnostic Insights**: Analysis of patient age distributions, payer mix, principal diagnoses, and discharge dispositions will reveal facility-specific utilization patterns, supporting tailored service design and resource planning for diverse patient populations.
- **Regional Disparity Assessment**: Geographic comparison of ED utilization rates and capacity metrics across California counties will highlight underserved areas and regional inequities, informing policy decisions to improve equitable access to emergency care.

These evidence-based findings will support California hospitals and health departments in making informed operational and strategic decisions to enhance emergency department efficiency and patient care quality.