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Official Study Title: Cost of Emergency Department Boarding for Hospitalized Patients in a Statewide Medical System

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1. General Analysis Principles

All analyses will be conducted using retrospective data extracted from the ED Universe data warehouse. Analyses will follow this prespecified statistical analysis plan aligned with the study aims. Statistical significance will be assessed using a two-sided alpha level of 0.05. Effect estimates will be reported with 95% confidence intervals. Analyses will be performed using standard statistical software such as SAS, R, or Stata.

Analysis Population

The primary analysis population will include adult emergency department encounters (age ≥ 18 years) resulting in inpatient or observation admission to services that assume clinical responsibility for boarded patients (for example, for the academic medical center, these are floor patients admitted to medicine, family medicine, and neurology services). Encounters meeting prespecified exclusion criteria will be omitted.

Handling of Missing Data

Patterns and extent of missing data will be assessed for all variables. For variables with minimal missingness, complete-case analysis will be used. For variables with higher levels of missingness, missing indicator categories or appropriate imputation strategies will be considered based on the analytic context and assumed missingness mechanism.

Sample Size and Power Considerations

This study is a retrospective observational analysis using existing clinical, operational, and cost data from a large, multi-hospital academic health system. As such, a formal a priori

sample size calculation was not performed. Instead, the available sample size is determined by the total number of eligible emergency department encounters during the study period.

Based on historical ED volume and admission rates across participating University of Maryland Medical System hospitals, the expected sample size is anticipated to include many tens of thousands of admitted ED encounters. This large sample size will provide substantial statistical power to detect clinically meaningful associations between boarding duration and outcomes, including modest effect sizes, while allowing for multivariable adjustment and stratified analyses by hospital site and clinical condition.

Emphasis will be placed on the magnitude and precision of effect estimates rather than solely on statistical significance.

The following variables will be extracted from the existing ED universe database:

Variable	Variable Definition
Patient Demographics	
Age	Patient age at time of encounter
Sex	Patient sex
Race/Ethnicity	Self-identified race/ethnicity at registration
Medical Record Number	Identifies unique patient
Encounter Number	Identifies unique patient encounter (CSN)
Zip Code	Patient zip code on registration
Insurance Class	Medicaid/Medicare/Private Payor/Self Pay
Operational Time Stamps	
ED arrival time/date	Timestamp of patient arrival at the ED
Admission time/date	Timestamp when the admission order is placed
ED departure time/date	Timestamp when the patient leaves the ED
Hospital discharge time/date	Timestamp when the patient is discharged from the hospital

Clinical Information	
ED disposition	Final disposition of ED visit
Admission Service	Service/care team patient is first admitted to
Initial Level of Care	Level of care patient is first admitted to (med/surg, tele, IMC, ICU)
Admission type	Observation vs Inpatient
ED diagnoses	ICD-10 codes entered in ED clinical impression
Diagnosis-related group	Classification of the patient's diagnosis for billing purposes
ESI Level	Emergency Severity Index determined at ED triage
Means of Arrival	Arrived by walk, bus, EMS, police, etc.
Sitter Order	Sitter order placed during ED stay
ED restraint Order	Restraint order placed during ED stay
Code Status	Code Status at time of admission
Measures of Cost	
Direct Variable Cost	Includes direct nursing salary / fringe costs, medical supplies, drugs, ancillaries, etc. that are directly related to and highly variable with clinical volume
Direct Variable Cost breakdown	Various subcomponents of direct variable cost
Fixed Direct Cost	Includes nursing management, clinical equipment, physician costs, etc. that are directly related to but do not vary 100 % in relation to clinical volume
Fixed Indirect Cost	All expense departments that do not line up with revenue producing area such as information systems, finance, medical records, human resources and maintenance costs, etc.

The following variables will be extracted by an Epic Clarity query to augment the ED Universe data: Preferred language, married status, housing status, social deprivation index, isolation status at admission, behavioral flags. Hospital characteristics (academic, geography, capacity) will also be included. Charlson comorbidity index will be calculated from historical diagnoses.

We will apply both unadjusted and adjusted methods within key clinical diagnosis strata, focusing on high-volume, floor-level admissions commonly targeted by quality initiatives: chest pain/ACS, sepsis, stroke/TIA, diabetes complications, COPD/asthma, heart failure, pneumonia, and UTIs, as well as sickle cell disease and psychiatric conditions.

Hospitalization Type	ICD-10s
Stroke/TIA	G45*, I60*, I61*, I62*, I63*
Diabetes	E018*, E10*, E11*, E13*
Asthma/COPD	J41*, J42*, J43*, J44*, J45*,
Sepsis	A40*, A41*, R65.2*
Hypertension	I10*, I15*, I16*, I1A.0
Heart Failure	I50*, I11.0, I13.0, I13.2
Pneumonia	J12*, J13*, J14*, J15*, J16.0, J16.8, J17*, J18*, J95.851
UTI	N39.0*, N30.0*, N30.1*, N30.2*, N30.8*, N30.9*, O23.4*
Sickle Cell Disease	D57*

Chest pain hospitalizations will be determined by DX_ID string identifiers for ED diagnoses associated with chest pain and ACS: 1050608, 125822, 1258317, 1253058, 1258315, 1253057, 1258314, 1242169, 10035, 1302003, 2042622, 2177271, 1242168, 1258316, 1258313, 1258312, 1281020, 2373933, 176258

Psychiatric hospitalizations will also be identified using DX_ID aligned with local quality metrics.

2. Aim 1: Scope and Predictors of ED Boarding

Outcomes

The primary outcome for Aim 1 is emergency department boarding duration categorized into ordered levels: <4 hours, 4–12 hours, 12–24 hours, and >24 hours. Secondary outcomes include continuous boarding time measured in hours and the proportion of total hospitalization time spent boarding.

Analysis

Ordered (ordinal) logistic regression will be used to evaluate associations between patient-level, clinical, and system-level covariates and categorical boarding duration. Candidate covariates will include demographics, markers of acuity, comorbidity burden, admission service, temporal factors, and hospital site. Will present unadjusted results stratified by ordinal outcome.

Adjusted models will be developed using backward variable selection beginning with a multivariable model containing all prespecified candidate covariates. These models will identify independent contribution of eligible variables to individual risk of experiencing higher category of boarding time. Variables will be retained based on statistical significance and clinical relevance. The proportional odds assumption will be assessed using standard diagnostic methods. We hypothesize patients with public insurance and markers for behavioral disturbance (restraints, one-to-one sitter orders) will have increased odds of boarding.

3. Aim 2: Effect of Boarding on Hospitalization Costs

Outcomes

Primary outcomes for Aim 2 include total direct variable hospitalization cost and daily direct variable cost, defined as total direct variable cost divided by hospital length of stay.

Analysis

Univariable analysis will be presented, including stratified by condition. Multivariable regression models will be used to estimate the association between emergency department boarding and hospitalization cost outcomes. Boarding will be modeled both categorically and as a continuous exposure. Cost outcomes will be analyzed using generalized linear models with appropriate distributional families and link functions to account for right-skewed cost data. Also will perform stratified analysis by conditions on hospitalization.

4. Aim 3: Impact of Boarding Environment on ED Patients

Analysis

We will examine relationships between boarding exposure metrics and outcomes. Multivariable regression models will be used to evaluate associations between boarding

environment measures, including the Boarding Density Ratio and Boarding-to-Census Proportion, and patient-level outcomes (such as ED direct variable cost, ED length of stay, care quality metrics for stroke and STEMI, and downstream healthcare utilization). Models will adjust for patient demographics, acuity, chief complaint, temporal factors, and hospital characteristics. Boarding environment measures will also be categorized into quartiles to evaluate potential non-linear and threshold effects and dose-response effects.