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Applying advanced analytics to guide emergency department operational decisions: A proof-of-concept study examining the effects of boarding

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ABSTRACT

Background: Emergency Department (ED) leaders are increasingly confronted with large amounts of data with the potential to inform and guide operational decisions. Routine use of advanced analytic methods may provide additional insights.
Objectives: To examine the practical application of available advanced analytic methods to guide operational decision making around patient boarding.
Methods: Retrospective analysis of the effect of boarding on ED operational metrics from a single site between 1/2015 and 1/2017. Times series were visualized through decompositional techniques accounting for seasonal trends, to determine the effect of boarding on ED performance metrics and to determine the impact of boarding "shocks" to the system on operational metrics over several days.
Results: There were 226,461 visits with the mean (IQR) number of visits per day was 273 (258–291). Decomposition of the boarding count time series illustrated an upward trend in the last 2–3 quarters as well as clear seasonal components. All performance metrics were significantly impacted ($p < 0.05$) by boarding count, except for overall Press Ganey scores ($p < 0.65$). For every additional increase in boarder count, overall length-of-stay (LOS) increased by 1.55 min (0.68, 1.50). Smaller effects were seen for waiting room LOS and treat and release LOS. The impulse responses indicate that the boarding shocks are characterized by changes in the performance metrics within the first day that fade out after 4–5 days.
Conclusion: In this study regarding the use of advanced analytics in daily ED operations, time series analysis provided multiple useful insights into boarding and its impact on performance metrics.

1. Introduction

With greater adoption of Electronic Health Records (EHR), Emergency Department (ED) leaders are increasingly confronted with large amounts of data with the potential to inform and guide operational decisions [1,2]. In the past decade numerous operational measures of emergency care have been developed [3], tied to physician and hospital payment incentives [4], and required by national public quality reporting programs such as the Centers for Medicare and Medicaid Services [5]. Specifically, measures of ED throughput including the timeliness of provider evaluation, discharge, admission, and ED boarding have become common parlance among ED leaders and frequent outcomes of focused interventions [4,6,7]. These measures, however have historically been examined and targeted for improvement in a silo without acknowledging the complexity and apparent inter-related nature of ED throughput, ED crowding, and outcomes such as patient satisfaction [8,9].

While traditional summary statistics (e.g. measures of central tendency, variation) and data visualization techniques (e.g. bar graphs, scatter plots) continue to have a key role in guiding decisions around improving operational metrics, routine use of more advanced analytic techniques, such as time series and regression analysis, have the potential to provide new insights for operational leaders into the complex inter-relationships of the metrics, uncover trends, weight the relative importance of key metrics, and test interventions [10-12]. Additionally these analytic techniques are becoming increasingly user-friendly with drag-and-click graphical user interface implementations in several common statistical and visualization software packages (e.g. R, STATA, Matlab, python).

Assessment of the impact of boarding, a situation that occurs when insufficient hospital capacity is available for admitted patients to be transferred to inpatient beds, is an area where the use of advanced analytics is potentially beneficial for operations leaders. Boarding is known

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to be, at the aggregate level, associated with numerous operational throughput metrics (e.g., length-of-stay, LWBS, door-to-doc), patient satisfaction, and patient outcomes [13]. Quantifying the effect of boarding on daily ED performance metrics through time series analysis would allow for meaningful interpretation (e.g. for every X boarders the length-of-stay increases by X minutes) and adjustment for other factors that may effect performance metrics such as daily visit volume.

We therefore sought to examine the potential application of readily available time series analysis methods to common ED operational metrics to guide decision making and administrative discussion around patient boarding.

2. Methods

2.1. Study design

Retrospective analysis of the effect of boarding on ED operational metrics. The study adhered to the STROBE guidelines and checklist for observational research [14]. This study resulted from a quality improvement project and was waived by the institutional IRB.

2.2. Study setting

Single site urban, academic, Level I trauma center with an annual census of approximately 90,000 patients with a single vendor EHR. Data pertaining to visits was obtained from a centralized data warehouse between January 2015 and January 2017.

2.3. Definitions and outcomes

For the purposes of analysis, a boarded patient was defined as a patient who remained in the emergency department after the patient had been admitted (determined by time of admission order) to the facility for 4 h, but had not been transferred to an inpatient unit [15]. We examined the impact of boarding on several operational metrics defined below. Throughput operational metrics adhered to the definitions outlined by Welch et al. [3] and included: Waiting Room Length of Stay (LOS), Treat and Release LOS, Overall LOS, Percentage of Patients Left-Without-Being-Seen (LWBS), and the percentage of patients who walked out. Overall patient satisfaction scores were collected from Press Ganey only on discharged patients.

2.4. Analysis

Data analysis included descriptive statistics on ED performance metrics and boarding. Continuous data are presented as means and 95% confidence intervals (CIs). All analyses were conducted based on daily time intervals, except those involving patient satisfaction scores which were analyzed on a weekly basis secondary to lack of daily data. Boarding data was aggregated to a count of the total number of boarders per day, LOS metrics were aggregated to median values, LWBS and Walkouts were calculated as percentages. Patient satisfaction scores were averaged over the week time frame.

Time series are often viewed as having various components that reflect seasonal patterns, general trends in the data, and noise. A trend exists when there is an increasing or decreasing direction in the data, while seasonal patterns are cyclical patterns over a fixed, known period (daily, weekly, etc.). Separating and visualizing these components, a process called time series decomposition, can be extremely helpful to the decision maker [16]. For the study, we demonstrate the decomposition of the boarding count daily data with using the seasonal trend decomposition Loess algorithm. [17].

To determine the effect of boarding on ED performance metrics and to develop meaningful adjustment factors (e.g. for every X boarders the length-of-stay increases by X minutes), time series analysis was performed using univariate autoregression integrated moving averages (ARIMA) models with external regressors [18]. For each operational metric a separate ARIMA model was constructed that included boarding count and number of visits per day as external regressors. The adequacy of each model was analyzed using autocorrelation functions and periodograms. Stationarity of the models was examined by using the Dickey-Fuller and Phillips-Perron unit root tests, while Portmanteau statistics were used to determine if any autocorrelation remained in the residuals of the model [18]. Final model selection was determined by a search over model parameters for the best performing model according to the Akaike information criteria (AIC).

We constructed multivariable vector auto-regression moving average models (VARMA) to determine the impact of boarding "shocks" to the system on operational metrics over several days. Time series variables included the operational metric, boarding count, and visits per day. Unlike a simple structural regression model, where the relationship between dependent and independent variables is assumed static, the VARMA modelling offers a more dynamic approach to the nature of interaction between variables via a system of autoregressive equations [19]. The advantage of this system is that it is able to estimate the impact of changes in one variable on the other variable not only at a point of time, but also over period of time. Impulse response functions, a function that describes the cascade of changes in a variable due to an unexpected shock in another variable, were calculated for each performance metric to demonstrate the potential multiday effect of boarding spikes [20].

All data were analyzed using R (R Foundation for Statistical Computing, Vienna, Austria.).

3. Results

There were 226,461 visits with a mean number of visits per day of 273 (IQR 258–291). The mean boarding count per day was 19.5 (IQR 9–26) with a maximum of 79. The daily mean (IQR) for Overall LOS, Treat and Release LOS, and Waiting Room LOS was 266 (IQR 240–288), 228 (IQR 204–250), and 8.2 [5-9], respectively. The mean LWBS percentage was 3.4 (IQR 1.2–5.1) and walkout percentage was 4.9 (IQR 2.8–6.8). with 4437 (2.0%) returned Press Ganey surveys during the study period The mean weekly Press Ganey score was (82.8 IQR 78–88). Times series graphs of key operational metrics are presented in Fig. 1.

Decomposition of the boarding count time series is demonstrated in Fig. 2 and illustrates an upward trend in the last 2–3 quarters as well as clear seasonal components.

The results of the ARIMA models with the effect of boarding counts on performance metrics are presented in Table 1. ARIMA model types and the number of Fourier terms as determined by AIC varied for each performance metric. All performance metrics were significantly impacted ($p < 0.05$) by boarding count, except for overall Press Ganey scores ($p = 0.65$). For every additional increase in boarder count, overall LOS increased by 1.55 min (0.68, 1.50). Smaller effects were seen for Waiting Room LOS and Treat and Release LOS. The percentage LWBS and Walkouts changed by 0.07% for every additional increase in boarder count.

The impulse responses for a boarding count shock for each of the performance metrics are demonstrated in Fig. 3. The impulse responses indicate that the boarding shock of 1 patient is characterized by an increase in the performance metrics within the first day that fades out after approximately 4–5 days.

4. Discussion

In this proof of concept study examining the use of advanced analytics in daily ED operations, time series analysis provided multiple insights into boarding and its impact on performance metrics. Greater clarity and understanding of the effect of boarding on emergency department operations and performance is critical, as our specialty

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