

Predicting Seasonal Influenza Hospitalizations using Simple Statistical Models

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Purpose

To determine which of a set of simple candidate statistical models (CSM) most closely fits a series of hypothetical influenza hospitalization curves (HIHC), stratified by season severity ([Centers for Disease Control and Prevention, 2016](#)).

Which of these simple CSMs would provide the best severity forecast at the beginning of the flu season (i.e., epiweek 40) based purely on fit to the HIHCs described below?

Subquestion: Which model best predicts the proportion of flu-attributable hospitalizations?

General approach

1. Fit a quadratic trend filter model ([Brooks et al., 2015](#)) to FluSurv-NET hospitalization data for the seasons 2003–2004 through 2017–2018, based in part on the approach described by Brooks et al. ([Brooks et al., 2015](#)).
2. Simulate 3,000 HIHCs using the empirical Bayes model as a “generative model”.
3. Stratify these HIHCs into groups representing High/Moderate and Mild severity HIHCs, based on the CDC’s categorization ([Biggerstaff et al., 2018](#); [Centers for Disease Control and Prevention, 2018](#)).
4. Fit each CSM within each severity stratum and test for goodness of fit. Systematically alter the functional form of epiweek indicators as in Wang et al.’s study of influenza mortality ([Wang et al., 2012](#)).

Forecasting targets

All weeks will be specified using the *MMWR* Week convention ([Centers for Disease Control and Prevention, a](#)):

1. Peak week
2. Peak number of hospitalizations
3. Total hospitalizations

These targets follow in part from ([Brooks et al., 2015](#)).

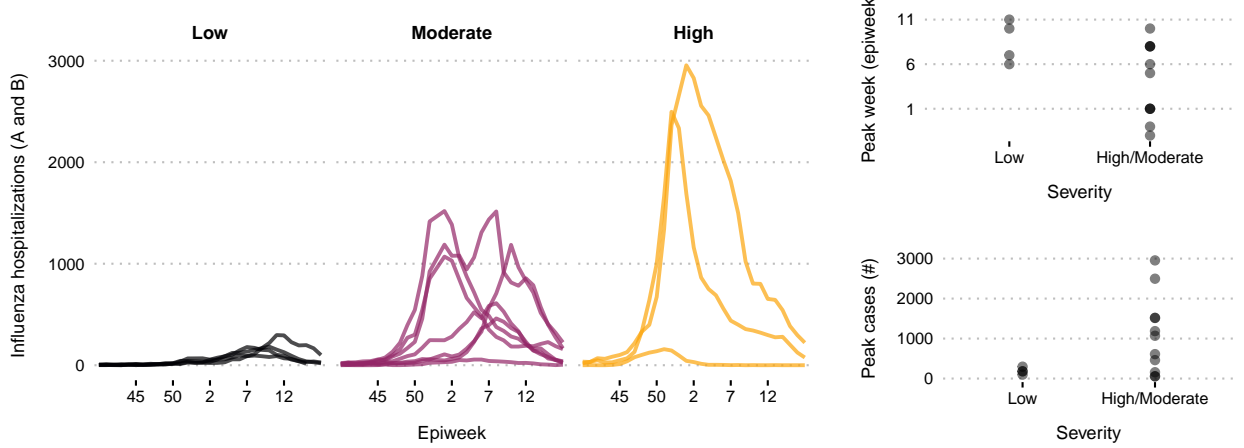


Figure 1: Empirical hospitalization curves, peak weeks, and peak number of cases – 2003–2017 (Source: FluSurv-NET, CDC). Data excludes 2009–2010 pandemic influenza season and 2017–2018 due to no official severity designation.

Curve fitting and simulation

We will simulate HHCs using a modified version of the curve-fitting approach described by Brooks et al. (Brooks et al., 2015).

First, we fit a quadratic trend filter to historical hospitalization curves released by the CDC (beginning with the 2003–2004 season), using the R package `glmgen` (Brooks et al., 2015; Centers for Disease Control and Prevention, 2016). This model is fit within flu severity group (Mild, High/Moderate).

For each season s and each week i , Brooks et al. conceptualize a seasonal influenza curve as some function plus noise¹:

$$y_i^s = f^s(i) + \epsilon_i^s, \epsilon \sim N(0, \tau^s),$$

where

$$f^s(i) = \frac{\theta}{\max_j f(j)} \left[f \left(\frac{i - \mu}{v} + \arg \max_j f(j) \right) \right]$$

Based on fitting the quadratic trend filtering model to empirical data (i.e., historical CDC flu hospitalization data), we estimate error τ^s :

$$(\hat{\tau}^s)^2 = \text{avg}_i \left[y_i^s - \hat{f}^s(i) \right]^2$$

and then sample from the model, introducing noise for each weekly observation based this estimate of τ^2 .

We impose a lower bound of 0 hospitalizations via the following transformation of \hat{y}_i^s , which we denoted below as \hat{z}_i^s :

$$\hat{z}_i^s = 0.5 \left(|\hat{y}_i^s| + \hat{y}_i^s \right)$$

¹ Brook et al. use their method to forecast a current flu season, where b represents the current season's epidemic threshold of weighted influenza-like illness percent. Because hospitalization curves have a lower bound of 0, we drop b from the original equation.

Parameters in quadratic trend filtering model

The HIHCs are simulated using the following sampling scheme for each parameter represented in the model for hospitalization count (y_i^s) at each week. Note that all equations are either adapted from or appear in (Brooks et al., 2015).

$$\langle f, o, \nu, \theta, \mu \rangle$$

Shape (f)

$$f \sim U\{\hat{f} : \text{historical season } s\}$$

Noise (σ)

$$\sigma \sim U\{\hat{\tau}^s : \text{historical season } s\}$$

Peak height (θ)

$$\theta \sim U[\theta_m, \theta_M]$$

Results in the following curve:

$$f_3(i) = f_2(i - \mu + \arg \max_j f_2(j))$$

Pacing (ν)

Curve-stretching around peak week:

$$\nu \sim U[0.75, 1.25]$$

Results in following curve:

$$f_4(i) = f_3\left(\frac{i - \arg \max_j f_3(j)}{\nu} + \arg \max_j f_3(j)\right)$$

Candidate models

Incidence-rate difference models

- Generate a set of predicted flu-related hospitalizations based on a standard incidence rate difference model typically used to model flu cases. Implement in flumodelr based on (Izurieta et al., 2000; Thompson et al., 2009).
- Thresholds: 0.1 and 0.15 as in (Thompson et al., 2009).

Serfling model (least squares)

Modified from ([McConeghy et al.](#)):

$$Y = \beta_0\alpha + \beta_1t + \beta_rX_r + \dots + \beta_p\cos\left(\frac{2\pi t}{52}\right) + \beta_q\sin\left(\frac{2\pi t}{52}\right)$$

Where t = time (epiweek), subscript r denotes a vector of β coefficients and variables, and subscripts p and q take on particular numbers based on the length of r .

Modified Serfling model

Modified ([McConeghy et al.](#)):

$$y = \alpha_0 + \beta_1t + \beta_2Flu_t + \beta_pX_p + \dots + \sin\left(\frac{2\pi t}{period}\right) + \cos\left(\frac{2\pi t}{period}\right) + u$$

Where t = time (epiweek) and subscript p denotes a vector of *beta* coefficients and variables.

Generalized additive model (Prophet)

This model will be implemented using Facebook's R package *prophet* ([Taylor and Letham, 2017](#)). Exact specifications TBD upon consultation with Kevin.

Model terms

The following model terms will be entered into the vector of covariates considered for each model (see Serfling and modified Serfling equations):

- a) Cyclical terms (Serfling, Fourier, etc.)
- b) Historical (empirical) flu hospitalizations
- c) Historical data on viral activity (NREVSS), outpatient surveillance (ILI-Net)
- d) Average weekly temperature
- e) Climate factors (e.g., prior summer temperatures)
- f) Lags and leads of c or d
- g) Indicators for weeks of Thanksgiving and/or Christmas ([Brooks et al., 2015](#); [Taylor and Letham, 2017](#))

Goodness of fit

- Root mean squared error (RMSE)
- Bayesian information criterion (BIC)
- Relative bias
- Cross-validation, sample-splitting?

Sensitivity analysis

Challenge

The composition of institutions reflected in the FluSurv-NET has changed over time ([Centers for Disease Control and Prevention, b](#); [Kandula et al., 2019](#)), meaning the FluSurv-NET estimates for influenza-related hospitalizations may not be comparable across time.

Response

Redo the analysis three times: one for each set of years in which the same participating institutions reported flu data to CDC. See ([Centers for Disease Control and Prevention, b](#)) for more information.

Limitations

Brooks et al. showed that their empirical Bayes model improved upon standard lagged CDC predictions for several forecasting targets of the overall influenza curves (season onset, peak week, peak rate/count, duration of season). In adapting their approach to hospitalizations, we should ensure we can achieve similar accuracy.

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