Measure Calculation

To calculate an overall hospital-wide mortality rate, we needed to combine the results of the 15 risk models (divisions) into one overall score. We envisioned a HWM measure that will provide a broad indication of a hospital's performance and capture cross-cutting hospital-wide characteristics that contribute to quality of care. As with CMS's other claims-based performance measures, the measure result will be a point estimate (the RSMR). While there are multiple approaches to calculate this overall RSMR through combining the results of the 15 models, after consultation with multiple statisticians and review with our Technical Work Group, our patient and family caregiver working groups, and our TEP during initial development, we are using a weighted mean with a hierarchical general logistic model (HGLM) approach. In the future when a national sample is available, an empirical correlation approach such as Markov Chain Monte Carlo (MCMC), which produces a statistically precise and conservative estimate of better and worse outliers, may be applied.

Weighted Mean with Volume

This approach requires first calculating a Standardized Mortality Ratio (SMR) for each hospital for each service-line division and then combines the SMRs for each hospital's divisions by taking the weighted average of the performance in each of the divisions, taking into account how precisely we were able to predict the outcome for that division. In technical terms, to calculate the point estimate for each hospital, we used the point estimates of all 15 SMRs (one from each division) and took the volume-weighted mean to create an overall hospital-wide combined SMR, similar to the HWR measure methodology. To calculate the RSMR for each hospital, we multiplied the overall hospital-wide SMR by the national observed mortality rate. The statistical approach is described in greater detail below.

Statistical Approach to Calculating Division-Level and Overall Standardized Mortality Ratios

This section provides further detail on the specific technical information for the statistical modeling for creating the final measure results. This includes information on the statistical models for each of the 15 divisions, how the results are calculated for each of the divisions, and then how those results are combined to form the overall mortality rate.

Models for Each Service-Line Division

We created 15 service-line division patient-level risk-adjustment models using logistic regression, with outcome Y_{idj} for the i-th patient in d division at the j-th hospital equal to 1 if the patient died within 30 days of admission and 0 otherwise. The patient-level risk-adjustment models allowed us to assess risk factors and model performance without reference to the variation in performance across hospitals.

For the hospital-level results among each of the 15 service-line divisions, we used hierarchical logistic regression models where death within 30 days is modeled as a function of patient-level demographic and clinical characteristics and a random hospital-level intercept. This accounted both for the natural clustering of observations within hospitals and captured a hospital-specific signal. We used the results of each hierarchical logistic regression model to calculate a standardized mortality ratio (SMR) for each hospital. The SMR was computed as the predicted mortality rate divided by the expected mortality rate at each hospital for each division. These contributing SMRs were then pooled for each hospital to create an overall hospital-wide SMR using the volume-weighted mean approach. To aid interpretation, this ratio was then multiplied by the overall national observed mortality rate for all index admissions in all cohorts, to produce the risk-standardized mortality rate or RSMR.

Specifically, for a given service-line division, we estimated a hierarchical logistic regression model as follows. Let Y_{idj} denote the outcome (equal to 1 if patient *i* in *d* division at hospital *j* dies within 30 days, 0 otherwise) for a patient in a specified division d $\subseteq$ {1,...,15}, at hospital *j*; $\mathbf{Z_{idj}}$ denotes a set of risk factors. Let *M* denote the total number of hospitals and V_{dj} the number of index patient stays among *d* division in hospital *j*. We assume the outcome is related linearly to the covariates via a logit function:

$$\text{logit}(\Pr(Y_{idj} = 1)) = \alpha_{dj} + \boldsymbol{\beta}^*\mathbf{Z_{idj}} \qquad (1)$$

$$\alpha_{dj} = \mu_d + \omega_{dl}$$

$$\omega_{dj} \sim N(0,\tau_d^{\,2})$$

where $\mathbf{Z_{idj}} = (Z_{idj1}, Z_{idj2}, \ldots Z_{idjk})$ is a set of *k* patient-level covariates. α_{dj} represents the hospital-specific intercept in d division; μ_d is the adjusted average outcome over all hospitals in *d* division; and $\tau_d^{\,2}$ is the between hospital variance component. The hierarchical logistic regression model for each cohort was estimated using the SAS software system (GLIMMIX procedure).

Standardized Mortality Ratio for Each Service-Line Division

We used the results of each hierarchical logistic regression model to calculate standardized mortality ratio as the predicted number of deaths over the expected number of deaths for each service-line division at each hospital. The predicted mortality rate in each division was calculated, using the corresponding hierarchical logistic regression model, as the sum of the predicted probability of death for each patient, including the hospital-specific (random) effect. The expected number of deaths in each division for each hospital were similarly calculated as the sum of the predicted probability of death for each patient, setting the hospital-specific (random) effect to be zero. Using the notation of the previous section, the model specific risk-standardized mortality ratio was calculated as follows. To calculate the predicted mortality rate $pred_{dj}$ for index admissions in each division d=1,...,15 at hospital *j*, we use:

$$pred_{dj} = \sum \text{logit}^{-1}(\alpha_{dj} + \boldsymbol{\beta}^*\mathbf{Z_{idj}}) \qquad (2)$$

where the sum is over all m_{Dj} index admissions in division d with index admissions at hospital *j*. To calculate the expected number exp_{dj} we use:

$$exp_{dj} = \sum \text{logit}^{-1}(\mu_d + \boldsymbol{\beta}^*\mathbf{Z_{idj}}) \qquad (3)$$

Then, as a measure of excess or reduced mortality rate among index admissions in cohort D at hospital *j*, we calculate the standardized mortality ratio SMR_{dj} as:

$$SMR_{dj} = pred_{dj}/exp_{dj} \qquad (4)$$

Hospital-Wide Risk-Standardized Mortality Rate

To report a single mortality score, the separate service-line division SMRs are combined into a single value.

For a given hospital, *j*, which has patients in some subset of divisions d $\subseteq$ {1,...,15}, we calculate the SMR as described above for each division for which the hospital discharged patients. If the hospital does not have index admissions in a given division *d*, then the weight $w_{dj} = 0$. Then, calculate the variance-weighted logarithmic mean:

$$SMR_j = \exp((\sum w_{dj} \log(SMR_{dj})) / \sum w_{dj}) \quad (5)$$

where the sums are over all service-line divisions and w_{dj} is the hospital volume V_{dj}; note that if a hospital does not have index admissions in a given division (w_{dj} = 0) then that cohort contributes nothing to the overall score SMR_j. This value, SMR_j, is the hospital-wide standardized mortality ratio for hospital *j*. To aid interpretation, this ratio is then multiplied by the overall national observed mortality rate for all index admissions in all cohorts, $\bar{Y}$, to produce the risk-standardized hospital-wide mortality rate ($RSMR_j$).

$$RSMR_j = SMR_j * \bar{Y} \quad (6)$$

Creating Interval Estimates

For Hybrid HWM Measure development, confidence interval estimates were not calculated due to the smaller sample size in the development and re-specification datasets. In the future, the below approach can be used to create confidence interval estimates.

We will first estimate the mean and variance for each $\log(SMR)_{dj}$ based on the MCMC posterior distribution of the $\log(SMR_{dj})$. We let $\log(SMR_d)$ denote the vector of $\log(SMR_{dj})$, where j=1,2,…,J. We will then utilize all posterior means of $\log(SMR_{dj})$ from each division and each hospital, if it exists, to construct the covariance matrix of $\log(SMR_d)$, where d=1,2,…,15. This covariance matrix estimates the dependency of SMRs between divisions and will be same for all the hospitals. We then will construct our confidence interval for SMR_j by considering all possible variances and covariances. Let f(.) denotes the equation (5). According to the delta method, we have:[42]

Because the $\log(SMR_{dj})$ are estimates rather than observations we will account for the measure errors using $\sum_{d=1}^{D}(Var(\log(SMR_{dj}))$, which will be estimated from the posterior distribution. Because we will not assume the $\log(SMR_{dj})$ from different divisions are independent we cannot set the covariances to zero; instead as an approximation we will sum over all the empirical variances and covariances of $\log(SMR_{dj})$ using $\sum_{d=1}^{D}\sum_{d'=1}^{D} Cov(\log(SMR_d), \log(SMR_{d'}))$, which will be from the covariance matrix. Assuming a normal distribution for each SMR_j, the confidence interval estimates will be calculated as $SMR_j \pm Z_{0.975} \times SD(SMR_j)$ where $Z_{0.975}$ is the 97.5% quantile for a standard normal distribution.

Given $RSMR_{j=}$ SMR_j* ¯, we will calculate the lower and upper bound of the confidence interval for $RSMR_j$ by multiply ¯ to the corresponding estimates of the lower and upper bound of the SMR_j.

**Please see the Comprehensive Methodology Report for reference and acronyms, as this is an excerpt from that report.*