Methods for R-SAARs Hospital-specific Report, Part 2

Overall Aim: Evaluate your hospital's antimicrobial use (AU) data using robust, encounter level risk-adjusted models to compare with other study sites. This report aims to answer the question: How is my hospital's AU different than others, controlling for differences in patient-encounter characteristics?

Inclusion/Exclusion Criteria

Criteria are the same as in Part 1, with some exceptions:

> **Time**: Encounters with discharge date occurring within calendar year 2022 were included. Statistics and counts were completed across the whole encounter. Thus, for encounters admitted in 2021 but discharged after January 1, 2022, some data from 2021 were included.
>
> **Unit-level** reporting has additional exclusions: units <6 months of reported data, <20 days present, or <50 encounters with exposure to "All Antibacterials" in 2022 were excluded.

Statistical Methods

Development of the encounter-level, "robust" risk adjustment (R-SAAR) models (Aim 1 of R-SAARs Project)

Aim 1 of the R-SAARs study evaluated 4 strategies for risk-adjustment variable inputs: 1) diagnosis-related group (DRG) categories by Yu et al., 2) adjudicated Elixhauser comorbidity categories by Goodman et al., 3) all AHRQ Clinical Classification Software Refined (CCSR) diagnosis and procedure categories, and 4) adjudicated CCSR categories where codes not appropriate for AU risk-adjustment were excluded by expert consensus. The process for determining the inputs for strategy 4 required review of 867 codes over 4 months to attain expert consensus.

Encounters from 2020-2021 from 50 study hospitals were split randomly, stratified by bed size as follows: 1) training dataset including two-thirds of encounters among two-thirds of hospitals; 2) internal testing set including the remaining one-third of encounters within training hospitals, and 3) external testing set including the remaining one-third of hospitals. We used a gradient-boosted machine (GBM) tree-based model and two-staged modelling approach. We first predicted encounters likely to have any DOT, then predicted total DOT among encounters receiving antibiotics. To generate predictions in the test data, we first applied model 1 (to determine whether any DOT were likely) and then, among encounters with a predicted probability of DOT > 0.5 applied model 2 to generate an actual DOT. Accuracy was assessed using mean absolute error (MAE) in testing datasets. Correlation plots compared model estimates and observed DOT among testing datasets. The top 20 most influential variables were defined using modeled variable importance.

The R-SAARs expert panel reviewed the Aim 1 analysis results and selected the final variable input strategy to be used for calculation of expected DOTs and R-SAARs comparisons for data feedback in hospital reports. The panel evaluated the following factors in determining the variable input strategy: model accuracy, transparency/interpretability, feasibility. Model accuracy based on markers of inequity (e.g. race, ethnicity, and insurance status) were also assessed, but ultimately not used in final decision-making because the panel was unable to define or anticipate potential biases. Patterns of accuracy among strata of equity factors were similar among the 4 variable selection strategies. Ultimately, the panel selected the Agnostic CCSR strategy (#3 above which included all CCSR categories) for the R-SAARs risk-adjustment models in this report. After the final variable input strategy was selected, the same analytic process using CCSR inputs was performed for the remaining antimicrobial group outcomes to create R-SAARs risk adjustment models for each age group and antibiotic group (listed in Table 1 in Part 1 Methods).

Producing 2022 Expected DOT for each 2022 Encounter

To produce **Expected DOT**, we used model parameters from the R-SAARs models which were trained on 2020-2021 data, and applied them to the encounter-level data from 2022. Using the parameters from the models and 2022 data, we calculated the Predicted or Expected DOT for each 2022 encounter in study hospitals. Importantly, data from the whole encounter were included in these estimates of Expected DOT. This is a key difference between R-SAARs and NHSN SAAR risk-adjustment methods, which only counts AU from the time when an encounter was housed in a specified unit type.

Producing Facility-Wide R-SAARs and Percentile Scores

The method of indirect standardization was used to produce ***observed to expected (O:E) Ratios or R-SAARs***, and percentile estimates on the facility-wide level. Indirect standardization produces O:E ratios by comparing encounters at similar Expected DOT level and using the risk distribution for the whole All Hospitals population of encounters from 2022. This accounts for different risk distributions between hospitals in 2022 (e.g., comparing a hospital with many high Expected DOT risk patients to one with primarily low Expected DOT risk patients).

First, the full 2022, 50-hospital dataset was used to create strata (or categories) of risk for Expected DOT. We created these ***common risk strata*** by dividing all encounters with Expected DOT greater than zero into deciles, for a total of 11 strata. Next, we calculated the ***mean observed DOT*** among encounters across all hospitals in 2022, within each stratum. We repeated this process to create common risk strata for each age and antimicrobial group.

Once we had our common risk strata and Mean Observed DOT, we needed to calculate hospital-specific estimates of a ***Standardized Expected DOT***. For each hospital, we identified the number of 2022 encounters that fell within each common risk stratum. We multiplied this number of encounters by the stratum-specific Mean Observed DOT. Then, we summed across strata to produce a total Standardized Expected DOT. We also summed the facility-wide Observed DOT across strata, then divided this value by the total Standardized Expected DOT to produce the O:E ratio or R-SAAR on the facility-wide level. An example of these calculations for an individual hospital is provided in **Table 2**.

Table 2. Example of Facility-Wide Indirect Standardization Calculations for Adult, All Antibacterials, 2022				
Common Risk Strata, in Expected Encounter DOT	**Mean Observed DOT, among All Hospitals' 2022 Encounters**	**Number of Encounters in Example Hospital**	**Hospital-Specific, Standardized Expected DOT**	**Hospital-specific Observed DOT**
0	0.64	18,404	11,811.84	10,119
(0,1.6)	1.17	4,084	4,759.35	4,174
[1.6,2.04)	1.39	2,256	3,138.15	2,221
[2.04,2.76)	1.67	2,165	3,625.52	3,123
[2.76,3.57)	2.34	1,810	4,243.58	4,560
[3.57,4.42)	3.12	1,683	5,255.16	5,541
[4.42,5.41)	4.13	1,454	6,000.21	6,523
[5.41,6.78)	5.46	1,419	7,744.58	8,381
[6.78,8.82)	7.26	1,551	11,254.40	12,138
[8.82,12.8)	10.47	1,539	16,118.39	16,514
[12.8,928]	23.75	1,515	35,978.79	31,164
Total		37,880	109,930	104,458

For the Example Hospital in Table 2, we have Observed Total DOT of 104,458 days and Standardized Expected Total DOT of 109,930 days, which produces an O:E ratio or R-SAAR of 0.95. A ratio greater than 1 indicates that a hospital is using more DOT than average where less than 1 means they are using fewer. Since we have standardized our O:E ratios to the All Hospitals Mean Observed DOTs, we can also compare these O:E ratios among hospitals with less risk of bias due to differing risks of Expected DOT. Thus, we provided the percentile rank for each hospital as compared with the standardized O:Es from other study hospitals.

Producing Unit-level R-SAARs

While indirect standardization was used to produce Facility-Wide R-SAARs, this process was **not** repeated for unit-level estimates – largely due to timeline limitations in the study. Instead, we followed a process similar to what was used to produce unit-level SAARs and percentiles in Part 1.

To calculate unit-level Observed to Expected (O:E) ratios, or ***Unit-Level R-SAARs***, we summed the R-SAARs model calculated expected DOT and observed DOT across encounters with at least 1 day of exposure to that hospital or unit, and then divided these two estimates to produce an R-SAAR for that unit. Again, data from the whole encounter were included in these estimates, and thus the observed DOT estimate in Part 2 Unit-level plots will be higher than observed DOT in figures for Part 1. For example, if an encounter had time in both the medical ICU and the medical ward, AU data from that whole encounter would be included in R-SAAR estimates for both the medical ICU and also for R-SAAR estimates in the medical ward. Percentile scores for individual units' O:E were calculated only for unit-types with at least 10 units in the study.

There are additional caveats to interpreting Unit-Level R-SAARs:

1. Lack of Indirect Standardization. Because the method of indirect standardization was not performed per unit- or unit-type, Unit-Level R-SAARs should be interpreted differently than Facility-Level R-SAARs.
    a. First, the comparisons are made to estimates from the 2020-2021 model training data and not to the All Hospitals 2022 data, thus there is some temporal difference in these O:E comparisons. This is partially addressed by providing percentile scores for 2022 O:E ratios among units of the same unit-type.
    b. Second, we were not able to use indirect standardization for the unit-level O:E estimates to account for differing risks of Expected DOTs. Thus, we suggest against making comparisons across units. Instead, we encourage ASPs to use Unit-Level RSAARs as a method to assess an individual unit for potential opportunities as compared to 2020-2021 model estimates, but not to compare the quantitative values relative to 2022 R-SAARs from other unit-types. Instead, we offer percentiles of R-SAARs to help understand where that unit might compared to other units of the same type.
2. Estimates of zero Expected DOT for some units with rare antimicrobial use.
    a. As described above, R-SAARs models first estimate whether an encounter would have any antibiotic exposure. If the model estimate was <0.5 probability of any antibiotic use, that encounter's Expected DOT estimate would be set to zero. In low use units, sometimes the whole unit's Expected DOT estimate is zero, thus an O:E ratio cannot be calculated. In this scenario, the modeled Expected DOT and the Observed DOT would be visible in the plot, but the O:E estimate would be left blank.
3. Small Population Effects. R-SAAR values on the unit-level may be susceptible to effects from small populations. For antibiotic groups used infrequently or units with small populations, R-SAARs values can get quite large (e.g. produce an O:E up to 11), but be based on few encounters.
    a. We have indicated in red text the units with smaller populations (<50) encounters exposed to that unit and agent group to assist with identifying units that might be affected.
    b. We have included the number of encounters exposed to that unit and antimicrobial group in figures in parenthesis next to the unit name.
    c. We did not report Unit-level R-SAARs estimates for units with <6 months of reported data, <20 days present, or <50 encounters with exposure to "All Antibacterials" in 2022.

Definitions

Definitions for Age Group, Antimicrobial Group, Route, Unit Type were the same as in Part 1.

Days of Therapy (DOT): the number of calendar days of antibacterial agent exposure, defined the same way as in the NHSN AU Option and in Part 1. DOT will be calculated on the encounter level in Part 2, which is different than AU Rates per 1,000 days present.

Facility-wide: Inpatient units were defined as those unit-types considered "Facility-wide" using NHSN methods. No specific unit types were excluded from facility-wide estimates given we had

the ability for robust risk adjustment. Facility-wide estimates in Part 2 are split for adult and pediatric age groups.

Expected DOT: Predicted number of DOT calculated using encounter-level, 2020-2021 R-SAAR model parameters and 2022 encounter variables.

Common Risk Strata: strata (or categories) of risk for Expected DOT among 2022 data from all study hospitals based on deciles. Each hospital encounter was grouped with other encounters within a similar range of expected DOT (see Table 2). A total of 11 risk categories were created based on deciles.

Mean Observed DOT per common risk stratum: average or mean observed DOT among 2022 encounters within a common Expected DOT risk stratum.

Standardized Expected DOT: number of 2022 encounters multiplied by the mean observed DOT by common risk stratum

Total Standardized Expected DOT: sum of stratum-specific standardized expected DOT values for an individual hospital, calculated during the indirect standardization method

Facility-wide Observed to Expected (O:E) Ratio or Facility-wide R-SAAR: total observed DOT divided by the total standardized expected DOT, calculated using indirect standardization method. Ratio greater than 1 indicates a facility is using more DOTs than average where less than 1 means they are using fewer.

Facility-wide R-SAAR Percentile: percentile rank among 50 hospitals in the study based on the facility-wide R-SAAR value

Unit-level Observed to Expected (O:E) Ratio or Unit-level R-SAAR: Sum of 2022 Expected DOTs divided by the sum of Observed DOT among encounters with at least 1-day present in that unit. Ratio greater than 1 indicates a unit is using more DOT as compared to the model estimates of training data (2020-2021), where less than 1 indicates the unit is using fewer.

Unit-level R-SAAR Percentile: percentile rank among other units of that same type in the study based on the unit-level R-SAAR value, included only for units that had at least 10 of that unit-type in the study.

Results in Part 2 Report

Section 1: Aims to provide descriptive information on study hospitals and Your Hospital to inform comparisons.

Importantly, encounters included in these analyses include all types of inpatient units in the hospital, including more specialized units, which differs from NHSN SAAR methods which target specific unit-types (e.g. medical and surgical wards). Use these data to understand how your hospital might be unique or different from other study hospitals.

Table 1 provides information about the demographic characteristics of your hospital's encounters using descriptive statistics. Table 2 includes the number and percent of encounters with the diagnosis and

procedure variables most influential in the Adult (Table 2A) and Pediatric (Table 2B) All Antibacterials R-SAARs risk-adjustment models.

Section 2: Aims to provides risk-adjusted comparisons of Facility-wide AU among All Study Hospitals, as compared with Your Hospital

Figure 1 includes histogram plots with a density overlay to show the shape of the study hospitals' distribution of Facility-side R-SAARs after indirect standardization. Plots are separated into Adult Encounters and Agent Groups (**Figure 1A**) and Pediatric Encounters and Agent Groups (**Figure 1B**), for hospitals with pediatric populations. Data are presented for all Adult and Pediatric Antimicrobial Groups on the facility-wide level. The X axis indicates the Facility-wide R-SAAR value. The Y axis indicates the number of hospitals. Indicators for 10th, 25th, 50th, 75th, and 90th percentiles of the distribution are provided as well as a large yellow bar showing Your Hospital's Facility-wide R-SAAR value. Text includes the values of the R-SAAR and percentile for your hospital, as well as the range observed among all hospitals.

Table 3 includes information on the most frequently used individual agents at your hospital, with the number of encounters exposed to that agent and DOT per encounter for that agent among exposed encounters. The same, unadjusted calculations are provided among all study hospitals' encounters for comparison. Table 3 is split for Adult Encounters (Table 3A) and Pediatric Encounters (Table 3B) for hospitals with pediatric populations.

Table 4 includes information on AU by Agent Group for Adult (**Table 4A**) and Pediatric (**Table 4B**) Encounters. Data is again presented with encounter level statistics, indicating the number of encounters exposed to that agent group and DOT per encounter for that agent group among exposed encounters.

Section 3: Aims to provide comparisons of Observed AU to R-SAAR risk-adjustment models' calculated expected AU for encounters exposed to a hospital unit, along with Unit-level O:E ratios or Unit-level R-SAARs.

Figure 2 includes plots of each hospital unit with both the observed AU and expected AU rate estimates, as well as the Unit-level O:E ratio or Unit-level R-SAAR. Units are sorted by unit-type. The light blue dot indicates the expected AU value calculated from the 2020-2021 R-SAAR models, and the dark blue dot indicates the observed AU value for that unit in 2022. Remember that this observed DOT estimate is the calculated DOT from the whole encounter for any patient with at least 1 day on the unit, and will likely be a higher number than reported in Part 1. Plots are provided by antimicrobial group and age group for all units mapped in your facility. Units that are most susceptible to small population effects are shown with red text for units with <50 exposed patients to that agent group. The number of encounters exposed to that unit and antimicrobial group are also reported in parentheses after the unit name to indicate population sizes. O:E Percentiles are included for units where there are at least 10 units of that type in the study.

Figure 2 is split for Adult Units and Agent Groups (**Figure 2A**) and Pediatric Units and Agent Groups (**Figure 2B**) for hospitals with pediatric populations.

Appendix: Aims to provides values for comparisons provided in Part 2 Report.

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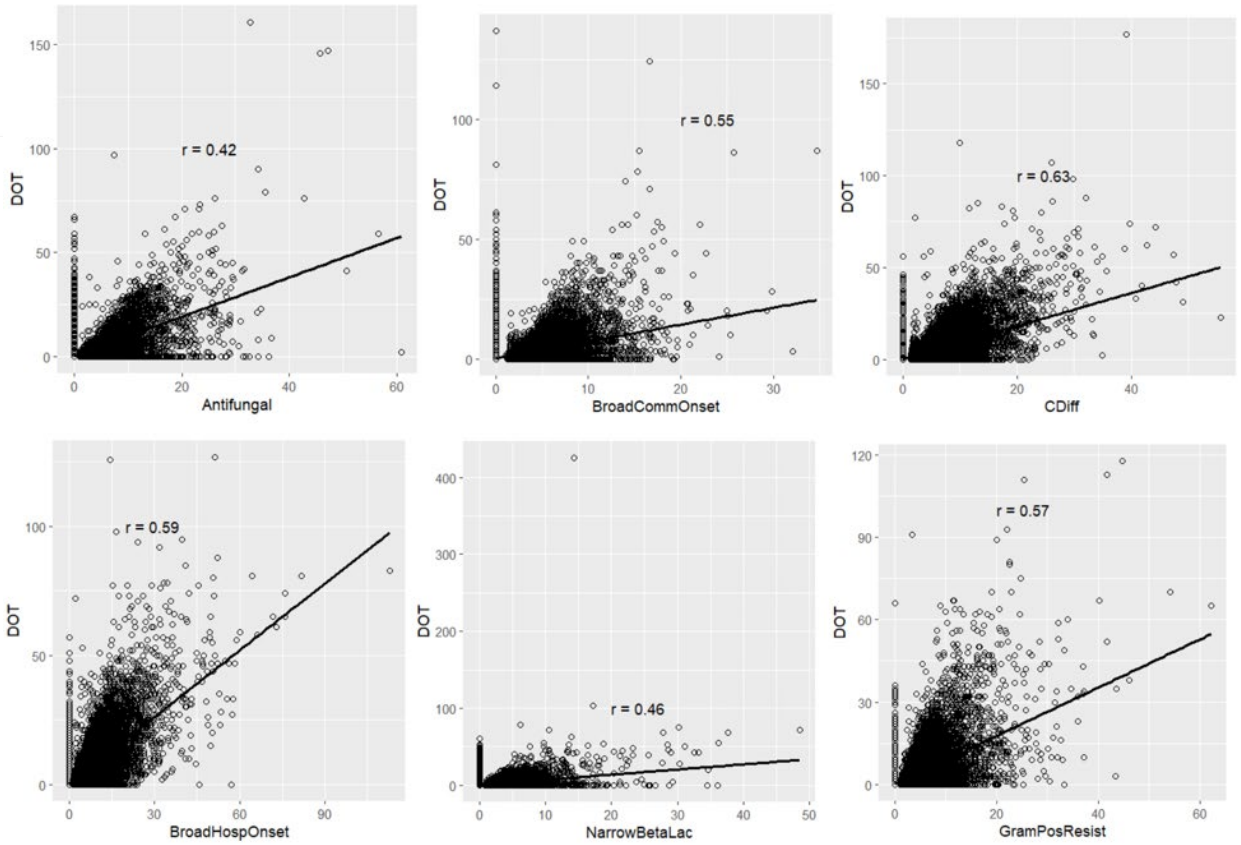
This CSV file includes Your Hospital's calculated R-SAARs on the facility- and unit-levels, and values for the comparisons presented in plots.

Appendix. R-SAARs model information

First, calibration plots show how well each R-SAARs model-predicted or Expected DOT fit to the external testing data set. The X axis is the Estimated DOT and the Y axis is the Observed DOT.

Figure 1. Calibration plots for the Adult Agent Groups



Correlation values ("r") can be interpreted as a number between -1 and 1, where 1 indicates perfect correlation, -1 would be perfect correlation in the opposite direction, and 0 indicates no correlation. Table 1 below gives the correlation values for all age and agent groups. Less frequently used agent groups (e.g. adult antifungal, pediatric azithromycin) had worse model performance in the testing data.

Table 3. Correlation of Expected DOT to Observed DOT in External Testing Dataset, All Locations

Age Group	Agent Group	Correlation value R-SAARs Model Expected DOT
Adult	All antibacterials	0.73
	Anti-fungal	0.42
	C. difficile agents	0.63
	Hospital-onset	0.59
	Community-onset	0.56
	Narrow Beta Lactam	0.46

	Resistant Gram-positive	0.57
Pediatric	All antibacterials	0.68
	Anti-fungal	0.55
	Azithromycin	0.28
	C. difficile agents	0.64
	Broad Community-onset	0.52
	Narrow Beta Lactam	0.49
	Broad Hospital-onset	0.61
	Resistant Gram-positive	0.50

Influential variables are based on model importance value in the R-SAARs models, and indicate which variables were most responsible for the model performance. This list of variables for the All Antibacterials groups in both pediatric and adults is provided in Section 1.