The Hilltop Pre-AH Model™
In Brief
January 2020

1. Intended Use

The Hilltop Pre-AH Model™ is a risk prediction model that uses a variety of risk factors derived from Medicare claims data to estimate the probability that a given patient incurs an avoidable hospital event in the near future.[1] These risk scores are intended to assist Maryland Primary Care Program (MDPCP) practices with the identification of beneficiaries that have a high risk of incurring an avoidable hospitalization or emergency department event. The Pre-AH Model™ risk scores, used in conjunction with provider clinical guidance, can facilitate a more efficient and impactful allocation of practices' care management resources.

a. Differentiation from CMS HCC Risk Scores

The Hilltop Pre-AH Model™ risk scores are conceptually distinct from the CMS Hierarchical Condition Category (HCC) risk scores that are also presented in CRISP MDPCP dashboard. The Hilltop Pre-AH Model™ risk scores use risk factors based on diagnoses, procedures, medications, utilization, demographics, and geographic factors in order to produce a practice- specific ranking of patient **risk of avoidable hospital events in the near future**. The CMS HCC risk scores are based on a model that uses diagnosis codes and a limited set of demographic information from a base year in order to predict *expenditures* over the following year. There is likely to be some overlap

[1] These events are hospitalizations/ED visits are those incurred for medical conditions or diagnoses "for which timely and effective outpatient care can help to reduce the risks of hospitalization by either preventing the onset of an illness or condition, controlling an acute episodic illness or condition, or managing a chronic disease or condition" (Billings et al., 1993). Note that this event definition – hospital or ED visits for reasons that are impactable by primary care practices - may differ from that of other prediction tools that are built for hospitals. This measure is discussed in greater detail in Section 3.3.1 of *Maryland Primary Care Program (MDPCP) Pre-AH Risk Score Specifications and Codebook, Version 2*.

among individuals who incur an avoidable hospitalization and individuals who experience high medical spending, but the overlap is unlikely to be complete.[2] High medical expenditure can reflect a number of factors ranging from moderate utilization of high-cost procedures, high utilization of moderate-cost procedures, underlying morbidity, or geographic differences in treatment or referral practices.

Additionally, it is important to note that "risk" for the CMS HCC risk model refers to *actuarial* risk: this model seeks to predict average expenditures over large groups of individuals. In contrast, the Hilltop Pre-AH Model™ risk score is designed to estimate, as closely as possible, event risk: that is, an *individual's* risk of an avoidable hospital event in the following months.

There are also differences in the time horizons of each risk score. CMS HCC "final risk scores are generally available 16-18 months after the close of the base year. For example, 2017 risk scores (based on 2016 diagnoses) will be available in the spring of 2018" (Center for Medicare & Medicaid Innovation, 2017, p. 26). The Hilltop Pre-AH Model™ risk scores, however, are updated monthly and use patient-level risk factor information current to the **most recently available month of Medicare claims in order to generate risk scores**. This is a strength of the Hilltop Pre- AH Model™: these risk scores reflect the underlying patient condition with a lag of only, at most, three months.[3] Finally, by definition, avoidable hospital events are preventable through timely primary care and so, in principle, the identification and management of individuals at high risk of incurring an avoidable hospitalization may result in the avoidance of that particular hospitalization event. High medical expenditures, however, may reflect underlying morbidities that would necessitate utilization *regardless* of primary care intervention.

b. Use Case Example

In order to illustrate the intended use of the Hilltop Pre-AH Model™ risk scores, we have created a hypothetical clinical vignette for an MDPCP Track 1 practice. For the sake of exposition, the patient panel consists of thirteen patients, each of which represents ten similar patients. Table 1

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[2] Internal testing shows a limited degree of substitutability between the two sets of risk scores. Specifically, we find that the Hilltop Pre-AH Model™ outperforms the CMS HCC risk score in predicting avoidable hospitalization in the following month: of the top 10 percent riskiest individuals ranked by each risk score, the Hilltop Pre-AH Model™ correctly identifies 45-50 percent of all avoidable hospital events, while the CMS HCC risk score identifies approximately 30 percent. Both concentration curves are presented in Section 4.3 of *Maryland Primary Care Program (MDPCP) Pre-AH Risk Score Specifications and Codebook, Version 2*.

[3] This lag is related to the unavoidable delay in obtaining and processing Medicare CCLF claims data; for example, claims data delivered to Hilltop in late October 2019 reflect utilization through mid-September 2019. Hilltop uses these data to identify individual-level risk factors using all available healthcare claims and applies the model scoring coefficients in order to estimate the risk of an avoidable hospital event for each patient in October 2019. These risk scores are then provided by CRISP to participating practices in mid-November 2019, to be used until the next scores are provided in mid-December 2019. This raises two potential issues: first, that the risk scores do not reflect the most recent utilization for patients, and second, that the risk scores are "outdated" by the time they are received by practices. Internal testing has demonstrated that the risk ranking persists across multiple months and the predictive value of the tool remains strong. We discuss this point further in Section 4.4 of *Maryland Primary Care Program (MDPCP) Pre-AH Risk Score Specifications and Codebook, Version 2*.

displays the patient panel, along with each patient's (hypothetical) Hilltop Pre-AH Model™ risk score and CMS Risk Tier.

Table 1. Hypothetical Patient Panel

Patient Name	Pre-AH Risk Score (%)	CMS Risk Tier
Patient 1	75%	Complex[4]
Patient 2	15%	Complex
Patient 3	5%	Tier 4
Patient 4	4%	Complex
Patient 5	2%	Tier 3
Patient 6	1%	Tier 3
Patient 7	Less than 1%	Tier 2
Patient 8	Less than 1%	Tier 2
Patient 9	Less than 1%	Tier 1
Patient 10	Less than 1%	Tier 2
Patient 11	Less than 1%	Tier 1
Patient 12	Less than 1%	Tier 1
Patient 13	Less than 1%	Tier 1

Patients in this practice are listed in descending order of risk. Based on the most recently available month of risk factors spanning diagnoses, procedures, medications, utilization, demographics, and geographic information, in conjunction with risk coefficients derived from training data, Patient 1 (or, equivalently, the ten patients represented by Patient 1) has a 75 percent chance of incurring an avoidable hospital event in the near future.[5] Patient 2 is the next riskiest, and has a 15 percent chance of incurring an avoidable hospital event. Patient 3 is the next riskiest, with a 5 percent chance. The distribution of risk is highly skewed: the majority of the practice's panel has less than 1 percent chance of incurring an avoidable hospital event, and all but two of the patients have under a 6 percent event risk.[6]

Based on the MDPCP Care Management Fee (CMF) structure, this practice would receive$2,600

[4] It is important to note that while the CMS risk tier is correlated with Hilltop Pre-AH Model™ risk scores, the correlation is not perfect for two reasons: first, CMS risk tiers are based on underlying HCC score, which is conceptually distinct from the Pre-AH risk score. Second, certain groups of patients are automatically assigned to certain CMS risk tiers, which further reduces the correlation between the two measures. In particular, beneficiaries without sufficiently long clinical histories are assigned to CMS risk tier 2, while beneficiaries with "a diagnosis of dementia, substance use disorder, or severe and persistent mental illness" are assigned to the Complex tier, regardless of their HCC score (CMMI, 2019). These individuals may, in turn, have relatively low (or high) risk of avoidable hospitalizations, meaning that an individual in, for example, the Complex CMS risk tier may have a low Pre-AH risk score. We highlight this point in this table by presenting a non-monotonic relationship between Pre-AH risk score and CMS risk tier.

[5] See Section 3.3 of *Maryland Primary Care Program (MDPCP) Pre-AH Risk Score Specifications and Codebook, Version 2,* for a more detailed discussion of the training and scoring process.

[6] While the data for this clinical vignette are hypothetical, the Hilltop Pre-AH Model™ risk scores are, in actuality, even more skewed: the average probability of incurring a future hospitalization is roughly 0.5 percent, while the maximum probability in the MDPCP cohort is greater than 99 percent.

each month.[7] Distributing the CMF revenue equally in care support of all 130 underlying patients would result in each patient receiving $20.00 of advanced primary care services each month. This distribution is unlikely to have a significant impact on patient outcomes: the low-risk individuals would be low-risk even without the advanced primary care intervention, and the high-risk individuals may require more resource-intensive interventions in order to experience improvement in outcomes.[8] The Pre-AH Model™ risk scores, used in conjunction with provider clinical guidance, are intended to help practices improve the efficiency of care resource allocation by matching the distribution of resources with the distribution of risk.

For details on the user interface of the Hilltop Pre-AH Model™ risk scores, readers should see the CRISP user manual.[9]

c. Reason for Risk

As of January 11, 2020, the Hilltop Pre-AH model™ will display to practices the top actionable risk factors underlying each patient's risk of incurring a future avoidable hospital event. The intention of this update is to augment the information provided to practices in order to further facilitate patient-specific advanced primary care. For example, in addition to a risk score of 3.2 percent for a particular patient, care managers will also be able to drill down on the CRISP Pre-AH dashboard to see the factors that most contribute to the patient's risk of incurring an avoidable hospital event. While a patient may have many risk factors, Hilltop only displays the most predictive, intervene-able risk factors in order to allow care mangers to focus their attention on the most pressing patient needs.

The reasons for risk are the top actionable risk factors underlying each patient's predicted risk of incurring a future avoidable hospital event. It is important to note that these are not necessarily causal; that is, just because a patient has a certain risk factor does not mean that the risk factor *causes* her to have increased risk of incurring an avoidable hospital event. However, these risk factors have been statistically validated as being strongly *associated* with increased risk of incurring an avoidable hospital event and can equip providers and care managers with a useful starting point in the delivery of advanced primary care to high-risk patients.

While the baseline model contains approximately 190 risk factors, only a subset of these are

[7] $50 for each of the 30 patients in the Complex tier; $30 for each of the 10 patients in Tier 4; $16 for each of the 20 patients in Tier 3; $8 for each of the 30 patients in Tier 2; and $6 for each of the 40 patients in Tier 1. For the purposes of this clinical vignette, we do not account for the Performance-Based Incentive Payment (PBIP), although this would potentially add $325 per month to this practice's MDPCP revenues.

[8] Liaw et al. (2015) conclude that, based on a review of four CMS-funded demonstrations involving care management fees, "to generate savings, resource allocation cannot be homogeneous. Instead, practices must focus more intensely on those at highest risk of utilization" (p. 557). Indeed, this may (partly) explain the varying effectiveness of care management, care coordination, and intensive primary care interventions as documented in the academic literature; many patients have low underlying risk of adverse outcomes, thus obviating the need for intervention, and the few high-risk patients may require significant intervention resources. For summaries of the literature on this subject, see Edwards et al. (2017) and Baker et al. (2018).

[9] https://crisphealth.org/resources/training-materials/

included in the pool of potential reasons for risk for reasons of statistical interpretation and clinical utility. Most non-binary and non-count risk factors are excluded because these cannot easily be translated into reason for risk contributions for lack of a meaningful reference group. Additionally, based on the feedback from stakeholders, Hilltop excludes risk factors that are not potentially modifiable; that is, for which the effects cannot be meaningfully modified by clinical intervention (like, for example, area income). Finally, risk factors that are not positive and statistically significant are also excluded.

In the CRISP dashboard, users can also see the relative contribution of each risk factor category (Condition, Demographic, Pharmacy, Utilization, and Environmental) in percentage terms. These are intended to provide a high-level description of the contribution of various types of risk factors that are positive and significant for an individual. The contribution for a given category is calculated as the sum of (risk factor level * coefficient) for all reasons for risk in that category, divided by the sum of (risk factor level * coefficient) for all positive, statistically significant reasons for risk. This is an important point: an individual's *overall* risk is a function of **all** risk factors, including those that are not included as potential reasons for risk. The category contributions, however, are only interpretable relative to the reason for risk factor pool, which is restricted to the clinically modifiable risk factors.

2. Technical Implementation

This section presents details on data sources, risk factors, and methodology.

a. Data Sources

The Hilltop Pre-AH Model™ relies largely on data from Claim and Claim Line Feed (CCLF) Medicare claims files, supplemented with various publicly available environmental data sets used to generate the environmental risk factors. These data sources are detailed below.

i. CCLF Data

The majority of the risk factors in the Hilltop Pre-AH Model™ are derived from CCLF Medicare Parts A, B, and D claims files. Each month, Hilltop receives Part A claims, Part A revenue centers, Part A procedure codes, Part A diagnosis codes, Part B claim lines, Part B durable medical equipment claims, Part D claims, and patient demographic information (which also includes eligibility information) from CMS.[10] Additionally, Hilltop receives beneficiary attribution files and practice rosters each quarter.

Upon receipt of the monthly claims files, Hilltop first performs automated data validity checks in order to assess the integrity of the CCLF data files, followed by a data reduction step that subsets the claims files against the beneficiary attribution file. The resulting files retain the raw claims data that are inputs to the risk factor feature engineering process, but discard the claims for

[10] For detailed documentation of these files, please see "Maryland Primary Care Program (MDPCP) CRISP Extract" (June 2019).

individuals that are not in the MDPCP population. The resulting data comprise approximately 210,000 individuals across almost 400 practices. These individuals incurred approximately 2.0 million part A claims, 35.7 million part B claim lines, and 12.2 million part D claims in the three-year period of November 2016 to October 2019.

Using SAS 9.4, Hilltop creates the model using risk factors identified in the literature review.[11] The risk factors are described in Section 3.2 and in greater detail in Appendix 1 in *Maryland Primary Care Program (MDPCP) Pre-AH Risk Score Specifications and Codebook, Version 2*.

ii. Social Determinants of Health Data Set

In order to control for environmental factors that may affect patients' probabilities of incurring avoidable hospitalizations, the risk model includes a rich set of area-level covariates derived from publicly available sources. Based on the "beneficiary ZIP code as per Medicare enrollment" (BENE_ZIP_CD), each attributed beneficiary is linked to environmental characteristics in his or her residential area.

- **USDA rural-urban commuting data** are Version 3.10 of the ZIP code Rural-Urban Commuting Areas (RUCA) taxonomy. Census tract level data and documentation are here: https://www.ers.usda.gov/data-products/rural-urban- commuting-area-codes/.
- **Neighborhood Atlas data** are from the University of Wisconsin School of Medicine. 2015 Area Deprivation Index (ADI) data were obtained at the Block Group level from https://www.neighborhoodatlas.medicine.wisc.edu/download.
- **CMS provider locations** are from the December 2018 Public Use Provider of Services file (https://www.cms.gov/Research-Statistics-Data-and-Systems/Downloadable-Public-Use-Files/Provider-of-Services/).
- **Veterans Affairs provider locations** are from the VA directory (https://www.va.gov/directory/guide/rpt_fac_list.cfm).
- **AMA data** are "Census tract layer attributes for American Medical Association Primary Care Physician Data, 2011," published by the Health Resources and Service Administration (HRSA) data warehouse. Specific source: https://data.hrsa.gov/DataDownload/PCSA/2010/t_ama2011_060614.dbf.
- **Land area** is from the 2018 Census Gazetteer (https://www.census.gov/geographies/reference-files/time-series/geo/gazetteer-files.html). Area is in square miles.
- **Area Health Resources File** (https://data.hrsa.gov/data/download) contains county-level data on a variety of health-related topics. Hilltop links this to ZCTAs using a ZCTA-county crosswalk (available from https://www2.census.gov/geo/docs/maps-data/data/rel/zcta_county_rel_10.txt).
- **ACS individual-level data** are from IPUMS (https://usa.ipums.org/usa/index.shtml). Individual-level microdata are filtered to retain only certain occupations and then aggregated to the county level. The variables derived from this data set—"Social Workers

[11] Certain risk factors identified in the literature review were not ultimately operationalizable in Phase 1 of the Hilltop Pre-AH Model™. We will incorporate additional risk factors in future iterations of the model.

per 1,000 population" and "Percent Physician Diversity"—are populated only for a subset of counties covering approximately 1/3 of ZCTAs nationally.

b. Risk Factors

Based on the literature review, Hilltop identified and operationalized approximately 190 risk factors to be included in the risk model. While some of these risk factors are eliminated in the variable selection step due to insufficient predictive power, this process is data-driven, and all risk factors are included in the pool of *potential* risk factors to be used in the model.

i. Literature Review

As a first step in the development process for the Hilltop Pre-AH Model™, Hilltop conducted a comprehensive literature review. The goal of the review was to find peer-reviewed academic journal articles that identified risk factors for potentially avoidable hospital events, thus providing a basis for risk factor extraction and feature creation. Identified risk factors were coded using CCLF and other publicly available data sources and included in the final risk model as potential predictors of avoidable hospitalization or ED use. The literature review provided the foundation for the risk model and was a crucial step in the modeling process. Using inclusion and exclusion criteria designed to reflect the MDPCP patient population, the Hilltop team screened over 3,300 articles in both a primary and secondary literature search, ultimately selecting 211 articles for risk factor extraction. For additional detail, see Pelser et al. (2019).

ii. Part A, B, and D Risk Factors

Risk factors based on Part A claims cover information on admissions over the past 12 months; nursing home stays over the past 12 months; and certain procedures. Additionally, the Part A claims are used in order to construct the avoidable hospital event outcome, as well as the diagnostic condition flags. These condition flags rely on diagnostic information from Part A and Part B claims in conjunction with Chronic Conditions Data Warehouse (CCW) coding specifications in order to generate beneficiary-level risk factors that represent underlying disease states.[12]

Risk factors based on Part B claims cover utilization of certain services (such as vaccinations, lab tests, or J-code procedures), place of service (for example, urgent care or rural health clinic), and provider specialty (for example, endocrinology or oncology). Hilltop also created risk factors to capture a beneficiary's primary care utilization and continuity of care. Finally, as above, the Part B claims are used in order to construct the avoidable hospital event outcome, as well as the diagnostic condition flags.

Using Medicare Part D claims, Hilltop flags utilization of drugs identified in its literature review as potential risk factors for potentially avoidable hospital events. In order to capture compound

[12] Additional detail on the CCW condition flag specifications can be found here: https://www.ccwdata.org/documents/10280/19139421/ccw-chronic-condition-algorithms.pdf, https://www.ccwdata.org/documents/10280/19139421/ccw-chronic-condition-algorithms-reference-list.pdf

drugs, which are drugs that contain multiple active ingredients, Hilltop relies largely on text-based, "contains"-type searches of the FDA's "National Drug Code Directory."[13]

iii. Environmental Risk Factors

Several of the risk factors Hilltop identified during the literature review were individual-level demographic and socioeconomic factors that are unavailable in the CCLF data (for example, marital status). Consequently, corresponding area-level risk factors (for example, the percentage of the population aged 15+ that is currently married) are included in the risk model in order to proxy for the unobserved individual-level variables. Other environmental risk factors (for example, the area poverty rate) are intended to capture the social determinants of health: the neighborhood conditions in which people live and age that may affect health outcomes.

c. Modeling

Methodologically, Hilltop relies on a discrete time survival model that uses current values of procedural, diagnostic, utilization-based, pharmacy, demographic, and environmental risk factors to predict the likelihood that an individual incurs an avoidable hospitalization or ED visit in the *following* month.[14] The parameter estimates generated in the model training are subsequently used to generate individual risk predictions in the scoring step. We assess the quality of our modeling using monthly concentration curves, which measure the cumulative share of all avoidable hospital events actually incurred by the riskiest (predicted) patients.

i. Avoidable Hospitalizations and Emergency Department Visits

The outcome measure in the Hilltop Pre-AH Model™ is a 0/1 indicator variable denoting whether an individual incurred an avoidable hospitalization or ED visit in a given month. In order to construct this measure, Hilltop relies on 2018 technical definitions provided by the Agency for Healthcare Research and Quality (AHRQ) as part of its prevention quality indicator (PQI) measures.[15] Diagnosis codes from Part A inpatient and ED claims are used to flag the following conditions, which are the basis for the composite PAH flag:[16]

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[13] For example, "Simcor" contains two active substances: Simvastatin and Niacin. This is flagged as a statin because one of its active ingredients is a statin. Source for the FDA NDC directory: https://www.fda.gov/drugs/drug-approvals-and-databases/national-drug-code-directory

[14] It is important to note that, while the model estimates the probability of an individual incurring an avoidable hospital event in the next month, these scores have high month-over-month persistence and therefore can be used to approximate risk over a longer time horizon.

[15] For more information, see https://www.qualityindicators.ahrq.gov/modules/pqi_resources.aspx.

[16] Specifically, Hilltop defines these claims as those with a claim type of either 60 or 61 (indicating an inpatient claim) or a claim type of 40 (indicating an outpatient claim) and revenue center codes of 0450-0459 and 0981. Source: https://www.resdac.org/articles/how-identify-hospital-claims-emergency-room-visits-medicare-claims-data. To the extent that claims for observation stays are coded in this manner in the CCLF Medicare claims, then observation stays are included in this outcome. Additionally, Hilltop did not include PQI #2 (Perforated Appendix) or PQI #9 (Low Birth Weight) in the composite outcome because these events were deemed to be not sufficiently modifiable by primary care providers and not relevant to the MDPCP cohort, respectively.

- PQI #1: Diabetes Short-Term Complications
- PQI #3: Diabetes Long-Term Complications
- PQI #5: COPD or Asthma in Older Adults
- PQI #7: Hypertension
- PQI #8: Heart Failure
- PQI #10: Dehydration
- PQI #11: Bacterial Pneumonia
- PQI #12: Urinary Tract Infection
- PQI #14: Uncontrolled diabetes
- PQI #15: Asthma in Younger Adults
- PQI #16: Lower-Extremity Amputation among Patients with Diabetes

This is implemented in the model as an indicator variable at the person-month level. If an individual incurs at least one avoidable hospitalization or ED visit in a given month, then that person receives a value of 1 for this variable—and 0 otherwise.

In order to estimate the concentration curve, the patient cohort is ordered from most to least risky (in terms of predicted risk) on the X axis, and the fraction of total *actual* avoidable hospital events captured by the riskiest patients on the Y axis. By comparing the predicted risk scores to the actual occurrence of the predicted events, it is possible to assess the predictive power of the model. The figure below shows the concentration curve for September 2019. In this month, the top 10 percent riskiest individuals as measured by the Hilltop Pre-AH™ risk predictions incurred approximately 50 percent of all actual avoidable hospitalizations, and the top 20 percent riskiest individuals incurred approximately two-thirds of all avoidable hospitalizations.

Note that the figure also displays a concentration curve estimated using the CMS HCC risk score instead of the Hilltop Pre-AH Model™ risk score. This curve indicates that the top 10 percent riskiest individuals as measured by HCC score incurred approximately 30 percent of all avoidable hospitalizations in September 2019. This comparison implies that an individual with a high Pre-AH Model™ risk score is more likely to incur an actual avoidable hospital event than an individual with a high HCC risk score. We interpret this as strong evidence for the utility of the Hilltop Pre-AH Model™ risk score in the care management process.

Concentration Curve as of September 2019