README.md

Vaccine Hesitancy Prediction

Deliverables

- Presentation to stakeholders
- Jupyter Notebook
- GitHub Repository

Repository Navigation

- /data - CDC 2009 National Health Flu Survey and CDC disclaimer
- /images - contains image files
- Notebook.ipynb - Jupyter notebook
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Overview

Moderna, Inc. is a biotechnology company based in Cambridge, Massachusetts focused on RNA therapeutics such as messenger RNA (mRNA) vaccines. Their use of RNA technology speeds up design and production as compared to traditional vaccines. Moderna's only current commercial product is Spikevax, a vaccine for SARS-CoV-2, the causative agent of COVID-19. With the success of Spikevax, Moderna has been developing other RNA-based vaccines for pathogens and diseases such as influenza, HIV, and various cancers. Moderna currently has 44 vaccines and treatments in their production pipeline, of which 22 are in clinical trials. One of these vaccines in Phase 3 trials is a single-injection SARS-CoV-2 and influenza vaccine, called mRNA-1073, to prevent severe reactions and hospitalization to the seasonal influenza virus and COVID-19.

The RNA technology that Moderna is using to create and deliver their vaccines has shown 90+% efficacy but vaccines work only if a person is willing to take it. This repository uses machine learning to identify the most important variables that lead a person to become vaccinated or not. The best machine learning model developed in this analysis has a specificity of 81% and sensitivity (recall) of 76%.

Business Problem

Moderna, Inc. is using mRNA science to create a new generation of transformative medicines for patients. One of these therapies is a vaccine to prevent serious illness from both the seasonal flu and COVID-19. Currently, in Stage 3 trials, this vaccination will reduce the number of vaccinations a person must get to be protected from the seasonal flu and COVID-19 and also increase the efficacy as the current seasonal flu vaccine is between 40-60% effective.

Stakeholders

For this combined vaccination to be effective, Moderna's executives and pharmaceutical representatives need to understand what variables lead people to choose to be vaccinated or unvaccinated. The stakeholders of this analysis are Moderna's executives and pharmaceutical representatives that work with doctors and other health care professionals to promote Moderna's vaccines.

Data

The data used for this analysis was the 2009 National Health Flu Survey (NHFS) conducted by the CDC. This phone survey asked respondents whether they had received the H1N1 influenza and seasonal influenza vaccines and additional questions covering their demographic background, opinions on risks of illness, opinions of vaccine effectiveness, and behaviors towards mitigating transmission.

This survey was in reaction to a novel influenza virus, H1N1 or 'swine flu', beginning to circulate in the United States. A vaccine for H1N1 was developed and available to the public by the end of 2009. This vaccine was separate from the traditional influenza vaccine because H1N1 emerged too late to be included in the trivalent seasonal influenza vaccine for 2009.

A partially cleaned version of the 2009 NHFS survey was obtained from Driven Data. The final cleaned version used for analysis contains 33 variables and 26,707 observations.

Suitability of Data

While this data is over ten years old and targets only part of the potential vaccine cocktail Moderna, Inc. will include with their combined seasonal flu and COVID-19 vaccine, this dataset is suitable to build a predictive model in line with Moderna's needs.

Moderna Inc. wants to have a predictive model to identify individuals that will or will not be vaccinated against influenza and COVID-19 in a combined vaccine. The last time there was a serious novel respiratory virus pandemic like COVID-19 was in 2009 during the H1N1 pandemic. This time period accurately reflects our current period of having a regular seasonal flu vaccine and a separate novel respiratory virus circulating.

Modeling

Moderna's business problem is to get more people vaccinated. This is a classification problem and a machine learning algorithm can create a model to predict if someone will be vaccinated or not and identify the most important variables that lead to this behavior. The classification solution uses machine learning algorithms such as decision trees, random forests, and XGBoost are used to create predictive models and assess the most important variables from this dataset.

Model 1: Baseline Decision Tree

A decision tree is a machine learning algorithm that is a collection of if-else statements. It was chosen for this analysis because it is powerful, solves classification problems, and is easy to interpret. The training data is partitioned into two or more groups that satisfy a condition. For example, if a respondent has health insurance or not. The variables chosen to split based on a condition is chosen using the amount of information gained for this split.

This model used the default values and the splitting criterion was Gini-index.

As shown under Evaluation, this was the worst performing model in terms of accuracy, precision, recall, and F1-score. To improve the model's predictions the hyperparameters must be tuned to prevent overfitting.

Model 2: Hyperparameter Tuned Decision Tree

To properly tune the hyperparemeters of this decision tree two steps were done. The first was to use a broad random search of possible hyperparemeters to identify the best. This was then fed into a systematic grid search to narrow down the best possible hyperparameters.

Hyperparameter Search Grid

```
dt_param_grid = {'criterion': ['gini', 'entropy', 'log-loss'],
                 'splitter': ['best', 'random'],
                 # Number of features to consider at every split
                 'max_features': ['auto', 'sqrt', 'log2'],
                 # Maximum number of levels in tree
                 'max_depth': [int(x) for x in range(0, 55, 5)].append(None),
                 # Minimum number of samples required to split a node
                 'min_samples_split': [int(x) for x in range(2, 22, 2)],
                 # Minimum number of samples required at each leaf node
                 'min_samples_leaf': [int(x) for x in range(5, 50, 5)]}
```

As shown in the Evaluation section, Model 2 performed much better than baseline model 1 but was still only in the 70% range for accuracy, precision, recall, F1, specificity, and Negative Predictive Value (NPV).

Model 3: Baseline Random Forest

A decision tree will maximize the information gain at every branch. This may lead to overfitting.

Random Forest is a machine learning algorithm that uses a bagging technique. This bagging technique uses various decision trees on subsets of the dataset. So instead of relying on one decision tree, the model from the Random Forest algorithm finds the prediction from each tree and the final output is based on the majority vote of all the decision trees in the forest. This leads to a reduction of overfitting.

The hyperparameters used were the best hyperparameters found during the search in model 2.

```
{'criterion': 'gini',
 'max_depth': 15,
 'max_features': 'auto',
 'min_samples_leaf': 28,
 'min_samples_split': 2,
 'splitter': 'best'}
```

As shown in the Evaluation section, there is an increase in all metrics except as compared to model 1 and model 2. Most importantly was an increase in specificity which is important for our model as it is more detrimental to predict a false positive (someone who is predicted to get a vaccine but does not) than a false negative (someone that is predicted to not get the vaccine but actually does).

Model 4: Hyperparameter Tuned Random Forest

The hyperparameters were tuned for the Random Forest algorithm again using a randomized search due to computational complexity. All metrics increased from model 3 although not as dramatically as seen between model 2 and model 3.

Hyperparameter Search Grid

```
random_grid_rf = {
    # Number of trees in the forest
    'n_estimators': [100, 500, 1000],
    # Number of features to consider when looking for the best split
    'max_features': ['auto', 'sqrt', 'log2', None],
    # Maximum number of levels in tree
    'max_depth': [int(x) for x in range(0, 55, 5)].append(None),
    # Minimum number of samples required to split a node
    'min_samples_split': [int(x) for x in range(2, 22, 2)],
    # Minimum number of samples required at each leaf node
    'min_samples_leaf': [int(x) for x in range(5, 50, 5)],
    # If bootstrapped samples are used to build trees
    'bootstrap': [True, False]}
```

Model 5: Hyperparameter Tuned XGBoost

The final algorithm used is Gradient Boosting (XGBoost). In this case, the algorithm uses an ensemble of weak decision trees. The algorithm uses gradient descent to minimize the loss function of the model and concentrates on where the model went wrong and creates new learners. XGBoost has been found to outperform Random Forests in many instances.

Hyperparameter Search Grid

```
param_grid = {
    'base_score': [0.25, 0.5, 0.75, 1],
    'learning_rate': [0.01, 0.1, 0.5, 1],
    'max_depth': [1, 10, 100],
    'min_child_weight': [1, 2],
    'subsample': [0.5, 0.75, 1],
    'n_estimators': [10, 100, 1000],
}
```

The Evaluation section shows that model 5 outperformed model 4 in all metrics but only with a percentage point from model 4.

Evaluation

While many metrics are shown below, the most important metric is specificity. Specificity, also known as the True Negative Value, refers to the probability that a negative prediction is actually negative. In this case it states the probability that a predicted not vaccinated person is actually not vaccinated.

Moderna, Inc. wants to vaccinate people against the seasonal flu and COVID-19. If our model predicted a person as having the vaccine when in fact they will not get vaccinated, then this is very harmful to Moderna's needs. People that are accurately predicted to be not vaccinated will be given more information based on the most important variables as indicated in the model. Those that are predicted to be vaccinated would not receive this extra information and the false positive predictions would not have the extra information to become vaccinated.

Table 1: Metric Scores for the Machine Learning Models

Model	Accuracy	Precision	Recall	F1-score	Specificity	NPV
M1: Baseline Decision Tree	68%	65%	67%	66%	69%	70%
M2: Tuned Decision Tree	74%	72%	70%	71%	77%	76%
M3: Random Forest	78%	76%	75%	75%	80%	79%
M4: Tuned Random Forest	77%	78%	68%	72%	84%	76%
M5: Tuned XGBoost	79%	77%	75%	76%	82%	80%

While model 4 and model 5 are very similar in scoring I would choose model 5 (XGBoost) as the best model. It has slightly higher scores in all metrics reported and fitting this model takes less time than model 4.

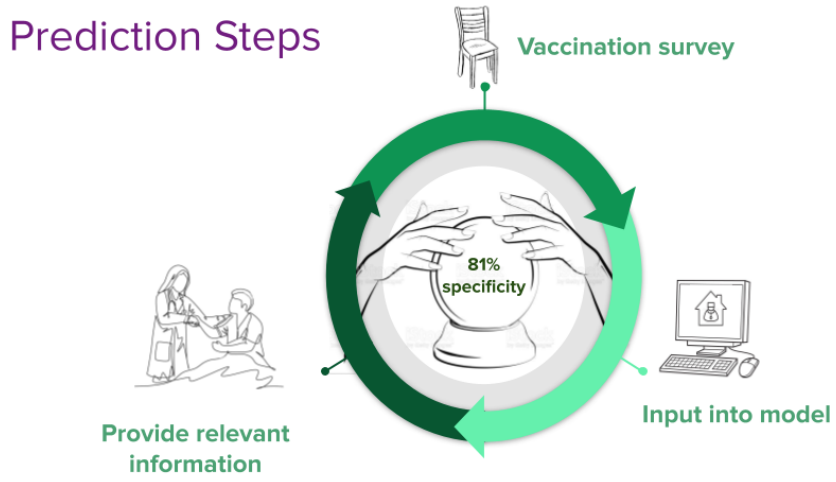
The top ten important variables as defined by Model 5: XGBoost can be categorized in the following groups:

- Opinion of vaccine effectiveness
- Opinion of risk of infection
- Access to healthcare
- Age group

Conclusion

This analysis shows that it is possible with 76% sensitivity (recall) and 81% specificity to predict whether a person will be vaccinated or not. This model can help improve vaccination rates when used in the right settings.

Moderna's pharmaceutical representatives would work in conjunction with their healthcare and government partners to implement this model in healthcare facilities. A patient would take a survey when they visit a healthcare professional. The survey would be inputted into the model and a prediction would be made which is shared with the healthcare professional.



Using the variable importance, relevant information would be provided to the patient based on the vaccination prediction. A person predicted to be vaccinated would be given the option to have get the vaccine and have a follow-up to check the patients vaccination status. A person predicted to not be vaccinated and under the age of 55 would be given information on the effectivness of the vaccine. For those predicted to be unvaccinated and over the age of 55 would be given information based on the risk of illness. The CDC recommends all people over 6 months of age to be vaccinated against the Flu and COVID-19. Children and people over the age of 65 are more likely to develop severe health complications while people between these age groups are more likely to transmitt the viruses. With this information the patient can make a more informed decision. A follow-up call would be given to check the patient's vaccination status.