Springboard - DSC

Capstone Project II

Detecting Potential Candidates Who are Looking for a New Job

Final Report

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# 1 Introduction

Company XYZ is a training institute which conducts training for analytics/ data science. They want to expand their business to manpower recruitment (data science only) by connecting their enrollees with their clients who are looking to hire employees working in the same domain. Before that, they want to know among the large number of signups, which of these candidates are looking for a new employment. To understand the factors that lead the enrollees to look for a job change, Company XYZ wants to build a model based on the current credentials/demographic/experience data they collected from the enrollee to predict the probability of them to look for a new job. By identifying the target enrollee (potential candidate) as many as possible from all enrollee registered on the training platform, the recruiting team in company XYZ could take further approach to their targets more efficiently and effectively.

## 

## 1.1 Objective

The objectives of this project are:

* To explore and analyze enrollee data for XYZ training institute
* To identify the key features that lead the enrollee to look for new employment.
* To develop machine learning models that predict the probability of enrollee looking for a new job
* To identify the final model that captures the most target enrollees within the top 20%, top 50% of the test dataset ordered by their prediction scores (in descending order)

This report is divided into the following sections:

* Section 2: Dataset description
* Section 3: Package introduction
* Section 4: Data cleaning and wrangling process
* Section 5: Data visualization and analysis
* Section 6: Machine learning and model evaluation
* Section 7: Hyper parameters tuning
* Section 8: Conclusion
* The programming codes used for this report can be found in this Github Repository [Detecting\_Potential\_Candidate\_Springboard\_Capstone2](https://github.com/yoyo6022/Springboard_Capstone/tree/master/notebooks).

## 1.2 Significance

By thoroughly explore the dataset, we will identify the important features that affect the enrollee’s decision of career change. We will also develop machine learning models that can be used by the recruiting team of company XYZ to filter out the potential candidates from the user data base and approach them with better efficiency and accuracy.

# 2 Dataset

## 2.1 Data Description

The datasets are sourced from the website [kaggle](https://www.kaggle.com/), a subsidiary of Google LLC, is an online community of data scientists and machine learning practitioners that allows users to find and publish datasets, explore and build models in a web-based data-science environment. The dataset [train.csv](https://www.kaggle.com/aswathrao/hr-analysis?select=train.csv) used in this project, was collected on August 12, 2020. It consists of 18,359 rows and 14 columns, 4 of them are numerical columns and 10 of them are categorical columns. Each row contains credentials/demographic/experience data for each unique enrollee. A description of each of the 14 columns is provided in *Table 1.1*

*Table 1.1 Description of dataset*

|  |  |  |  |
| --- | --- | --- | --- |
| No. | Variable Name | Variable Description | Data Summary |
| 1 | enrollee\_id | unique ID for enrollees | integer, 18359 unique values |
| 2 | city | city code | object, 123 unique values |
|  |  |  |  |
| 3 | city\_development\_index | development index of the city (scaled) | float, 93 unique values |
| 4 | gender | gender | object, 3 unique values |
| 5 | relevent[[1]](#footnote-1)\_experience | relevant experience in analytics, data science | object, 2 unique values |
| 6 | enrolled\_university | type of University course enrolled if any | object, 3 unique values |
| 7 | education\_level | education level | object, 5 unique values |
| 8 | major\_discipline | major discipline | object, 6 unique values |
| 9 | experience | total working experience in years | object, 22 unique values |
| 10 | company\_size | number of employees in current employer's company | object, 8 unique values |
| 11 | company\_type | type of current employer | object, 6 unique values |
| 12 | last\_new\_job | difference in years between previous job and current job | object, 6 unique values |
| 13 | training\_hours | training hours completed | integer, 241 unique values |
|  |  |  |  |
| 14 | target | looking for job change or not | Integer, 0=not looking for job change, 1=Looking for a job change |

## 2.2 Dataset Characteristic: Class Imbalance and Feature Space Overlap

A distinctive characteristic of this dataset is its class imbalance. In the original dataset [train.csv](https://www.kaggle.com/aswathrao/hr-analysis?select=train.csv), there is 15,934 negative classes and 2425 positive classes in column ‘target’.

Value 0 represents the negative class which means the enrollee is not open for career change, we will define this class as ‘non-Target’ enrollee in this study. While value 1 represents the positive class, means the enrollee is open for career change, we will define this class ‘Target’ enrollee in this study, using capitalized ‘Target’ to distinguish it from column ‘target’. A breakdown of non-Target enrollee and Target enrollee is provided in *Table 2.1*.

*Table 2.1 Number of non-Target and Target enrollee*

|  |  |  |  |
| --- | --- | --- | --- |
|  | Label | Counts | Percentage |
| 0 | non-Target | 15934 | 86.79 |
| 1 | Target | 2425 | 13.21 |

We can see there is an approximately 6:1 ratio of non-Target enrollee to Target enrollee. The much smaller proportion of Target enrollees would cause the baseline models tend to only predict the majority class (non-Target enrollee) as the features of the minority class (Target enrollee) are treated as noise. As a matter of fact, most of the base line models we selected for this study misclassified almost all the Target enrollee in the test set (the baseline models’ Recall on Target enrollee is very low or was zero). Therefore, we will address this issue in the further section (Section 5) with introduction of oversampling technique.

Another issue of this dataset is high degree of feature overlap between classes. Many Target enrollee have feature values that are very identical to feature values of non-Target enrollee. This could bring difficulty for the models to predict Target enrollee without increasing False Positive (non-Target enrollee misclassified as Target enrollee).

Chart

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*Figure 2.2 Normalized histogram for Target and non-Target enrollee after PCA reduction of features to 1 component*

*\*categorical variables were converted to numerical in this plot.*

By applying PCA to observe variables onto two dimensional spaces, we observed a lack of distinction between Target enrollee and non-Target enrollee. In *Figure 2.2*, the 2 classes are seen to have significant amount of overlap and indistinguishable distribution across all features.

# 3 Package Introduction

In this study we used [JupyterLab](https://jupyterlab.readthedocs.io/en/stable/getting_started/overview.html) (2.1.5) to run all the code. Numpy (1.18.5),

Pandas (1.0.5), Matplotlib (3.2.2), Seaborn (0.11.0) were installed as basic package. Scikit-learn (0.23.1) was installed as the machine learning library. Imblearn (0.7.0) was installed for data oversampling. Scikitplot (0.3.7) was installed for plotting Cumulative Lift.

# 4 Data Wrangling

## 4.1 Dataset Information

Please find the general information of the original dataset from *Table 4.1,* sorted by the count of unique valuein each variable in descending order. It contains columns of original variable index, variable name, counts of unique values, percentage of unique value, percentage of missing value and data type of each variable.

*Table 4.1 General information of dataset*

| Index | Variable Name | Counts | Unique  Value Percentage | Missing Value Percentage | Data Type |
| --- | --- | --- | --- | --- | --- |
| 0 | enrollee\_id | 18359 | 100.00 | 0.00 | int64 |
| 12 | training\_hours | 241 | 1.31 | 0.00 | int64 |
| 1 | city | 123 | 0.67 | 0.00 | object |
| 2 | city\_development\_index | 93 | 0.51 | 0.00 | float64 |
| 8 | experience | 22 | 0.12 | 0.32 | object |
| 9 | company\_size | 8 | 0.04 | 26.03 | object |
| 7 | major\_discipline | 6 | 0.03 | 15.46 | object |
| 10 | company\_type | 6 | 0.03 | 27.45 | object |
| 11 | last\_new\_job | 6 | 0.03 | 2.00 | object |
| 6 | education\_level | 5 | 0.03 | 2.49 | object |
| 3 | gender | 3 | 0.02 | 22.32 | object |
| 5 | enrolled\_university | 3 | 0.02 | 1.86 | object |
| 4 | relevent\_experience | 2 | 0.01 | 0.00 | object |
| 13 | target | 2 | 0.01 | 0.00 | int64 |

According to the information we summarized in *Table 4.1*, 10 out of 14 variables are categorical variables, 8 out of 14 variables have missing values, and the missing value ratios in variable ***company\_type, company\_size, gender*** are all higher than 20%.

## 4.2 Data Processing

After examining all the variables, we decided to group variables 6 groups based on their features (we will exclude 'enrollee\_id' and 'target' from the grouping process). Then we chose the optimal data processing method for each group based on their variables’ characteristics. The detailed explanation of process we took for each group will be find in *Table 4.2.*

*Tabel 4.2 Data processing method on each variable*

| Group | Variable Feature | Variable Names | Missing Value Percentage | Process Method |
| --- | --- | --- | --- | --- |
| Group 1 | experience related variables | relevent\_experience | 0 | data type correction |
| experience | 0.32 | data type correction, missing value imputation (fill with mode) |
| last\_new\_job | 2 | data type correction, missing value imputation (fill with mode) |
| Group 2 | employer related variables | company\_type, | 27.45 | data grouping, missing value imputation (fill with KNN imputation) \*KNN imputation will automatically convert the variable’s data type to float |
| company\_size | 26.03 | data grouping, missing value imputation (fill with KNN imputation) |
| Group 3 | education related variables | education\_level, | 2.49 | data grouping, data type correction, missing value imputation (fill with 0) |
| major\_discipline | 15.46 | data grouping, data type correction, missing value imputation (fill with 0 or mode) \*when education\_level equals to 0 (None) or 1 (high school or primary school)  fill missing value with 0, then fill the rest with 0 |
| enrolled\_university | 1.86 | fill with mode |
| Group 4 | gender | gender | 22.32 | data type correction, missing value imputation (fill with mode) |
| Group 5 | city related variables | city | - | data grouping, data type correction (dummy encoding) |
| city\_development\_index | - | - |
| Group 6 | training related variables | training\_hours | - | - |

\*This grouping is purely used for data processing, not for analysis or other purpose.

In the cases that the variable has a missing value percentage higher than 25%, we chose KNN imputation over filling the missing value with 0 or with mode value, in order to avoid introducing a certain type of bias to the dataset. The cleaned data contains 18,359 rows and 23 columns. You can find more details about the cleaning process from this jupyter notebook [Detecting Potential Candidate\_Part1(01.01-06.04.03).ipynb](https://github.com/yoyo6022/Springboard_Capstone/blob/master/notebooks/Detecting%20Potential%20Candidate_Part1(01.01-06.04.03).ipynb). (part 04.06 Variable Grouping)

# 5 Exploratory Data Analysis

## 5.1 Summary Statistic

The statistic including mean, standard deviation, minimum values, maximum values and percentile for each variable were summarized in *Table 5.1*

*Table 5.1 Summary statistics*

| variable name | count | mean | std | min | 25% | 50% | 75% | max |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| city\_development\_index | 18359.0 | 0.847140 | 0.110189 | 0.448 | 0.796 | 0.91 | 0.92 | 0.949 |
| gender | 18359.0 | 1.085299 | 0.314034 | 1.000 | 1.000 | 1.00 | 1.00 | 3.000 |
| relevent\_experience | 18359.0 | 0.740563 | 0.438338 | 0.000 | 0.000 | 1.00 | 1.00 | 1.000 |
| enrolled\_university | 18359.0 | 0.237377 | 0.425487 | 0.000 | 0.000 | 0.00 | 0.00 | 1.000 |
| education\_level | 18359.0 | 2.082194 | 0.693807 | 0.000 | 2.000 | 2.00 | 3.00 | 3.000 |
| major\_discipline | 18359.0 | 1.585326 | 0.755994 | 0.000 | 1.000 | 2.00 | 2.00 | 2.000 |
| experience | 18359.0 | 10.647040 | 6.769905 | 0.000 | 5.000 | 9.00 | 16.00 | 21.000 |
| company\_size | 18359.0 | 1.895419 | 0.730158 | 1.000 | 1.000 | 2.00 | 2.00 | 3.000 |
| company\_type | 18359.0 | 2.700147 | 0.621645 | 1.000 | 3.000 | 3.00 | 3.00 | 3.000 |
| last\_new\_job | 18359.0 | 2.044338 | 1.680945 | 0.000 | 1.000 | 1.00 | 3.00 | 5.000 |
| training\_hours | 18359.0 | 65.899014 | 60.885300 | 1.000 | 23.000 | 47.00 | 89.00 | 336.000 |
| target | 18359.0 | 0.132088 | 0.338595 | 0.000 | 0.000 | 0.00 | 0.00 | 1.000 |

## 5.2 Overall Distribution

The overall distribution of numerical variables was visualized in *Figure 5.1*. Unique values and their counts breakdown by non-Target and Target enrollee for each categorical variable were visualized in *Figure 5.2*

A screenshot of text

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*Figure 5.1 Distributions of numerical variables*

*please note that this was visualized after data grouping and data type correction for categorical variables*

Graphical user interface, website

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*Figure 5.2 Barplots of categorical variables break down by non-Target and Target enrollee*

*please note that this was visualized after data grouping*

From *Figure 5.2*, we observed the relation between target and most of the variables (expect variable *experience, city\_development\_index, training\_hours*). We noticed that about 42% of the enrollees in the dataset are from city\_103, city\_21, city\_16, and Target enrollees from these 3 cities contributed approximately 48% of all the Target enrollees in the dataset. We also noticed that Male is very dominant in the gender variable, Graduate is the most common education level among all the enrollees and the Target enrollees. Most Target enrollee have majored in STEM, worked for medium large size companies with comparatively shorter period of time (1 year) between their current job and last job.

## 5.3 Experience vs. Target

You may have noticed that variable ‘experience’ is excluded from *Figure 5.2*, as we consider *Table 5.2* and *Figure 5.3* (boxplot) to be a better option to visualize this variable.

*Table 5.2 Experience summary statistic break down by variable* ***target***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| target | count | mean | std | min | 25% | 50% | 75% | max |
| non-Target | 15934.0 | 10.872725 | 6.763342 | 0.0 | 5.0 | 10.0 | 17.0 | 21.0 |
| Target | 2425.0 | 9.164124 | 6.625679 | 0.0 | 4.0 | 7.0 | 14.0 | 21.0 |

Chart, box and whisker chart

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*Figure 5.3 boxplot for variable target and experience*

We can see that non-Target enrollee compares to Target enrollee, has slightly longer average working years and wider range of working experience in years.

## 5.4 City vs. Target

By plotting the distribution of two classes in *Figure 5.4,* we noticed, regardless of non-Target enrollee or Target enrollee, there are 2 peaks in the distribution located at city\_development\_index that equals 0.92 (city\_103 and city\_160) and 0.62 (city\_21).

This would explain why out of 2425 Target enrollee in our dataset, 1114 of them were from city\_103, city\_160 and city\_21, which shares almost 46% of the total number.

Chart

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*Figure 5.4 city\_development\_index distribution breakdown by non-Target and Target enrollee*

Chart, bar chart

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*Figure 5.5 city barplot breakdown by non-target and Target enrollee*

## 5.5 Training Hours vs. Target

*Table 5.3 Training hours summary statistic break down by variable* ***target***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| target | count | mean | std | min | 0.25 | 0.50 | 0.75 | max |
| non-Target | 15934 | 66.01 | 60.91 | 1.00 | 23.00 | 47.00 | 89.00 | 336.00 |
| Target | 2425 | 65.16 | 60.74 | 1.00 | 23.00 | 47.00 | 87.00 | 336.00 |

Normalized distribution

Chart, histogram

Description automatically generatedChart

Description automatically generated

*Figure 5.6 Training hours distribution breakdown by non-Target and Target enrollee before and after normalization*

From *Figure 5.6*, we observed regardless of the class, the training time distribution is skewed right with a wide range of training time from 1 hour to 336 hours. From *Table 5.3* we noticed the two classes share lots of similarities in terms of summary statistic. The average training hours for Target and non-Target enrollee only has less than 1hour difference.

## 5.6 Variable Correlation Coefficient

After plotting heatmap *Figure 5.7*, we ca see no significant correlation coefficient was found among variables.

Chart

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*Figure 5.7 Heatmap of correlation coefficients between variables*

# 6 Machine Learning

## 6.1 Data Preprocessing and Feature Selection

Dummy features were created for categorical variable city. As we already corrected the data type for all the other categorical variables in Section 4 Data Wrangling, so we only needed to dummy encode variable city in this step. This process increased the number of variables from 14 to 24. Then we dropped variable enrollee\_id and trained our models with the rest 23 features.

The data was split into 70%/30% training/testing sets and stratified on the ‘target’ variable to ensure an equal percentage of Target enrollee samples in each set, respectively. More details could be found in this jupyter notebook [Detecting Potential Candidate\_Part1(01.01-06.04.03).ipynb](https://github.com/yoyo6022/Springboard_Capstone/blob/master/notebooks/Detecting%20Potential%20Candidate_Part1(01.01-06.04.03).ipynb).(part 06.01Data Preprocessing and Feature Selection)

*Tabel 6.1 Stratified training and testing sets*

|  |  |  |  |
| --- | --- | --- | --- |
|  | non-Target Count | Target Count | Target % |
| Full Dataset | 15,934 | 2,425 | 13.209 |
| Training set | 11,154 | 1,697 | 13.205 |
| Testing set | 4,780 | 728 | 13.217 |

## 6.2 Model Selection

In this section we studied the performance of 10 classification models: Logistic Regression, Gaussian Naïve Bayes, k-Nearest Neighbors, Support Vector Machine, Decision Tree, Random Forest, Gradient Boosting, XGBoost, LightGBM, CatBoost. The pros and cons of each models are summarized in *Table 6.2*

*Table 6.2 Overview of classifier (need to summarize this table)*

| No. | Binary Classifier | Advantages | Disadvantages |
| --- | --- | --- | --- |
| 1 | Logistic Regression | * East to interpret * Small number of hyperparameters * Overfitting can be addressed though regularization | * May overfit when provided with large numbers of features * Can only learn linear hypothesis functions * Input data might need scaling * May not handle irrelevant features well |
| 2 | Gaussian Naïve Bayes | * No training involved * Very little parameter tuning is required * Features do not need scaling | * Assumes that the features are independent, which is rarely true |
| 3 | k-Nearest Neighbors | * No training involved, easy to implement * Only one hyperparameter | * Need to find optimal number of K * Slow to predict * Outlier sensitivity |
| 4 | Support Vector Machine | * Accuracy * Works well on smaller cleaner datasets * Is effective when umber of dimensions is greater than the number of samples. | * Isn’t suited to larger datasets as the training time can be high * Less effective on noisier datasets with overlapping classes |
| 5 | Decision Tree | * Easy to interpret * Work with numerical and categorical features. * Requires little data preprocessing * Performs well on large datasets * Doesn’t require normalization | * Overfitting * Unable to predict continuous values * Doesn’t work well with lots of features and complex large dataset |
| 6 | Random Forest | * Excellent predictive power * Requires little data preprocessing * Doesn’t require normalization * Suitable for large dataset * Plenty of optimization options | * Overfitting risk * Parameter complexity * Limited with regression |
| 7 | Gradient Boosting | * Excellent predictive accuracy * Can optimize on different loss functions * Provides several hyperparameter tuning options that make the function fit very flexible. | * Overfitting risk * Computationally expensive * Parameter complexity |
| 8 | XGBoost | * Regularization to prevent overfitting * Computational efficiency and often better model performance * Can handle missing value | * Difficult to interpret and visualize * Parameter complexity * Time consuming when dataset is large |
| 9 | LightGBM | * High speed, high accuracy * Can handle missing value and categorical value * Low memory usage * Compatibility with large dataset | * Parameter complexity * Overfitting risk |
| 10 | CatBoost | * Can handle missing value and categorical value * Work well with both small and large dataset * Can monitor loss function | * Prevent overfitting * Normally doesn’t need to tune hyperparameters to gain better result |

## 6.3 Baseline Model Evaluation

**Step1:** Firstly, we trained all the model with the baseline implementation, meaning all the hyperparameters of the models were left as the default value in the scikit-learn APIs. The evaluations are all conducted over the same Training set (70%) with 5Folds Cross Validation. The average performance on the test folds for each model can be found from *Table 6.3* and *Figure 6.1.*

*Table 6.3 Average of baseline model performance on 5 test folds. (dataset: Training set)*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | model | fit\_time | score\_time | test\_accuracy | test\_precision | test\_recall | test\_f1\_score | test\_roc\_auc |
| 0 | LR | 0.077 | 0.007 | 0.868 | 0.000 | 0.000 | 0.000 | 0.637 |
| 1 | GNB | 0.004 | 0.008 | 0.754 | 0.233 | 0.373 | 0.286 | 0.629 |
| 2 | KNN | 0.009 | 0.096 | 0.853 | 0.204 | 0.038 | 0.064 | 0.535 |
| 3 | SVC | 6.286 | 0.379 | 0.868 | 0.000 | 0.000 | 0.000 | 0.499 |
| 4 | DT | 0.029 | 0.006 | 0.767 | 0.178 | 0.210 | 0.193 | 0.531 |
| 5 | RF | 0.630 | 0.090 | 0.858 | 0.278 | 0.047 | 0.080 | 0.603 |
| 6 | GB | 0.730 | 0.013 | 0.868 | 0.434 | 0.006 | 0.012 | 0.642 |
| 7 | XGB | 0.398 | 0.016 | 0.861 | 0.320 | 0.049 | 0.085 | 0.611 |
| 8 | LightGB | 0.097 | 0.014 | 0.867 | 0.358 | 0.019 | 0.036 | 0.626 |
| 9 | CatBoost | 6.673 | 0.022 | 0.868 | 0.449 | 0.025 | 0.047 | 0.638 |

Graphical user interface

Description automatically generated

*Figure 6.1 Bar plot for Average of baseline model performance on 5 test folds. (dataset: Training set)*

As we can see from above, most of the models have very good accuracy score (0.868 as the highest, 0.754 as the lowest). But only focusing on accuracy could be misleading in the case of this dataset due to the imbalance class problem. For instance, Logistic Regression results the top in accuracy, but Precision and Recall are all zero, meaning no positive class was predicted from the model. However, in this business case, we need to capture the Target enrollees (positive class) as many as possible. Therefore, instead of accuracy, we need to focus on Recall, as Recall measures the percentage of the positive class accurately predicted by the model out of all the positive classes in the dataset. Below you can find the detailed explanation of the rest of the 3 steps we took to define our model evaluation metrics, test model with Training and Testing set, record the performance result.

**Step 2**: On the top of the common metrics provided by scikit-learn, we created 2 new metrics specifically for this business case:

* 1. Target in top 20%: the number of positive classes the model is able to catch within the top 20% of the test dataset when you sort the test dataset by their prediction scores (predicted probabilities) in descending order.
  2. Target in top 50%: the number of the positive classes the model is able to catch within the top 50% of the dataset when you sort the test dataset by their prediction scores (predicted probabilities) in descending order.

\*Instead of the predicted class, we use the prediction scores here.

\*There are 728 positive classes (Target) in the Testing set

**Step 3**: In this step, we fed the Training (70%) set to each model that we trained previously in Step 1, recorded the scores for Precision, Recall, F1score, ROC\_AUC, Target in top 20%, Target in top 50% and Cumulative Lift for each model. Additionally, we plotted the prediction scores distribution breakdown by Target and non-Target classes.

**Step 4**: Last, we fed the Testing (30%) set to each model that we trained previously in Step 1, recorded the scores for Precision, Recall, F1score, ROC\_AUC, Target in top 20%, Target in top 50% and Cumulative Lift for each model. Additionally, we have plotted the prediction scores distribution breakdown by Target and non-Target classes.

The performance result in Step 2 and Step 3 for each model could be found from this jupyter notebook [Detecting Potential Candidate\_Part1(01.01-06.04.03).ipynb](https://github.com/yoyo6022/Springboard_Capstone/blob/master/notebooks/Detecting%20Potential%20Candidate_Part1(01.01-06.04.03).ipynb). (part 06.03.02 Model Performance on Training and Testing set)

Here in this report, we will show you the result of Testing set. *Precision, Recall, F1score, ROC\_AUC, Target in top 20%, Target in top 50%*, these 6 metrics for the 10 models on Testing set could be found from *Table 6.4.*

*Table 6.4 Model performance on Testing (30%) set (sorted by Target in top 20%)*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Model | Precision | Recall | F1score | ROC\_AUC | Target in top 20% | Target in top 50% |
| LR | 0 | 0 | 0 | 0.629 | 262 | 483 |
| CatBoost | 0.244 | 0.014 | 0.026 | 0.630 | 261 | 482 |
| GB | 0.286 | 0.003 | 0.005 | 0.645 | 259 | 493 |
| GaussianNB | 0.230 | 0.337 | 0.274 | 0.608 | 251 | 458 |
| LightGB | 0.333 | 0.016 | 0.031 | 0.618 | 237 | 473 |
| XGB | 0.220 | 0.037 | 0.063 | 0.599 | 225 | 456 |
| RF | 0.270 | 0.051 | 0.086 | 0.594 | 211 | 456 |
| KNN | 0.210 | 0.041 | 0.069 | 0.550 | 189 | 413 |
| DT | 0.179 | 0.220 | 0.197 | 0.533 | 186 | 391 |
| SVC | 0 | 0 | 0 | 0.507 | 152 | 364 |

As we can see despite the poor Recall and Precision score, Linear Regression (LR) performed the best in terms of capturing Target enrollee in the top 20% in the Testing set. CatBoost, Gradient Boosting (GB) are the second and third best performed models in terms of capturing Target enrollee in the top 20%. Gradient Boosting outperformed Linear Regression and CatBoost in terms of capturing Target enrollee in the top 50% from the Testing set. Overall, all models scored poorly in terms of Recall. This is due to the class imbalance issue that we have mentioned in previous section. In the case of this dataset, the negative class is roughly about 6 times more than the positive class. While models are fed with this type of imbalanced data, to ensure model accuracy, the models are going to predict the negative class as much as possible. Which could cause the increase of False Negative or the lack of positive class being predicted.

To address this issue, we will introduce oversampling method in the next section and see if the model performance will be improved after we train models with oversampled data.

# 6.4 Oversampling (SMOTE)

A problem with imbalanced classification is that there are too few examples of the minority class for a model to effectively learn. One way to solve this problem is to oversample the datapoints in the minority class. There are different approaches to achieve this, in this study we used **Synthetic Minority Oversampling Technique**, or SMOTE for short. This technique was described by [Nitesh Chawla](https://www3.nd.edu/~nchawla/), et al. in their 2002 paper named for the technique titled “[SMOTE: Synthetic Minority Over-sampling Technique](https://arxiv.org/abs/1106.1813).” SMOTE works by selecting examples that are close in the feature space, drawing a line between the examples in the feature space and drawing a new sample at a point along that line. Specifically, a random example from the minority class is first chosen. Then *k* of the nearest neighbors for that example are found (typically *k=5*). A randomly selected neighbor is chosen and a synthetic example is created at a randomly selected point between the two examples in feature space.

In this section we applied SMOTE only to the train folds in the 5 Folds Cross Validation using the Training set (70%), because we want the test folds to approximate the data distribution in practice. After applying SMOTE to each train fold, the ratio of the majority class (non-Target enrollee) and minority class (Target enrollee) decreased from 6:1 to 1:1.

Then we tested the SMOTE – 5 Folds CV models on the Training set (70%) and Testing set (30%), you can find more details of the test results from this jupyter notebook [Detecting Potential Candidate\_Part1(01.01-06.04.03).ipynb](https://github.com/yoyo6022/Springboard_Capstone/blob/master/notebooks/Detecting%20Potential%20Candidate_Part1(01.01-06.04.03).ipynb). (part 06.04.02 Model Performance on Training and Testing set After Oversampling)

### 6.4.1 Model Comparison after SMOTE

In this report we will show you the result of Testing set.

*Precision, Recall, F1score, ROC\_AUC, Target in top 20%, Target in top 50%*, these 6 metrics for the 10 models on Testing set could be found from *Table 6.5*

*Table 6.5 Model performance after SMOTE on Testing (30%) set (sorted by Target in top 20%)*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Model | Precision | Recall | F1score | ROC\_AUC | Target in top 20% | Target in top 50% |
| GB | 0.381 | 0.033 | 0.061 | 0.633 | 260 | 475 |
| LR | 0.192 | 0.521 | 0.281 | 0.623 | 253 | 480 |
| GaussianNB | 0.151 | 0.674 | 0.246 | 0.598 | 251 | 441 |
| CatBoost | 0.315 | 0.040 | 0.071 | 0.623 | 247 | 481 |
| LightGB | 0.309 | 0.029 | 0.053 | 0.628 | 236 | 484 |
| XGB | 0.257 | 0.038 | 0.067 | 0.600 | 215 | 450 |
| SVC | 0.153 | 0.647 | 0.247 | 0.580 | 212 | 440 |
| RF | 0.237 | 0.065 | 0.102 | 0.588 | 206 | 450 |
| KNN | 0.144 | 0.455 | 0.218 | 0.541 | 182 | 391 |
| DT | 0.162 | 0.195 | 0.177 | 0.520 | 171 | 387 |

As we can see from above, after we trained the models by applying SMOTE to each train fold split in the Training set, and test the model on the Testing set, Recalls of some of the models drastically improved. For instance, Logistic Regression (LR) and Support Vector Classifier (SVC) before oversampling, predicted zero Target enrollee (Recall was zero). However, after oversampling, their Recall became the second (SVC) and the third (LR) highest comparing to other models. Gaussian Naïve Bayes (GNB) has the best Recall, scored 0.674. What about other metrics? How much did they improve after oversampling? Please find the answer *in Table 6.6* below.

*Table 6.6 Metrics percentage change after SMOTE*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Model | Precision | Recall | F1score | ROC\_AUC | Target in top 20% | Target in top 50% |
| XGB | 16.82 | 2.70 | 6.35 | 0.17 | -4.44 | -1.32 |
| SVC | ∞ | ∞ | ∞ | 14.40 | 39.47 | 20.60 |
| RF | -15.19 | 17.65 | 11.63 | 0.67 | -0.95 | -0.44 |
| LR | ∞ | ∞ | ∞ | -0.95 | -3.44 | -0.62 |
| LightGB | -7.21 | 81.25 | 70.97 | 1.62 | -0.42 | 2.33 |
| KNN | -31.43 | 1009.76 | 215.94 | -1.64 | -3.70 | -5.33 |
| GB | 33.22 | 1000.00 | 1120.00 | -1.86 | 0.39 | -3.65 |
| GaussianNB | -34.35 | 100.00 | -10.22 | -1.64 | 0.00 | -3.71 |
| DT | -9.50 | -10.00 | -9.64 | -2.25 | -9.14 | -1.28 |
| CatBoost | 29.10 | 185.71 | 173.08 | -1.11 | -5.36 | -0.21 |

\***∞** represents where the previous metric (before oversampling) was zero

\* red text represents where metrics decreased after oversampling

From *Table 6.6* we can see despite the drastic improvement in Recall, oversampling is more likely to cause a decline in other metrics. The Top 3 highest number of *Target in top 20%* and *Target in top 50%* both dropped after oversampling. Previously, before applying SMOTE, Logistic Regression was able to capture 262 Target enrollees out from 1101 data samples of Testing set, Gradient Boosting was able to capture 493 Target enrollees out from 2754 data samples of Testing set. After applied SMOTE, the highest number for the 2 metrics decreased to 260 (GB) and 480 (LR) respectively. Let’s take a closer look at how did Top 3 highest number of *Target in top 20%* and *Target in top 50%* dropped in *Table 6.7*.

(\*There are 5508 data samples in Testing set and the top 20% from Testing set contains 1101 data samples, top 50% from Testing set contains 2754 data samples)

*Table 6.7 Top 3 best result of capturing Target in top 20% and 50% before vs. after SMOTE*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Before SMOTE Target in top  20% | After SMOTE Target in top  20% |  | Before SMOTE Target in top  50% | After SMOTE Target in top  50% |
| 262 (LR) | 260 (GB) |  | 493 (GB) | 480 (LR) |
| 261 (CatBoost) | 253 (LR) |  | 483 (LR) | 475 (GB) |
| 259 (GB) | 251 (GNB) |  | 482 (CatBoost) | 441 (GNB) |

### 6.4.2 Model and key Metric Selection

So, now we want to ask two questions.

First one: which model is the best for this business case? Shall we choose the model has the highest Recall after oversampling? Or shall we go with the model that can capture the most Target enrollee in Top 50% from the Testing set?

Let’s break this question down by doing a comparison calculation.

If we choose the model that provides the best Recall after oversampling, then it should be model Gaussian Naïve Bayes as it has the best Recall 0.674. Let’s assume we use this model and predicted the result for our Testing set and get the confusion matrix result:

*Confusion matrix of model Gaussian Naïve Bayes after applying SMOTE*

|  |  |  |
| --- | --- | --- |
|  | Predicted Target | Predicted  non-Target |
| Target | TP: 491 | FN:237 |
| non-Target | FP: 2770 | TN: 2010 |

In this case, we would provide the final Predicted Target list to the recruiting team for further action. For instance, sending out email to this Target list. As we can see from the confusion matrix, this Target list would be a list that contains 3261 (491 + 2770) enrollees while 491 of them are the real Target enrollee.

Now let’s take a look at the model that could capture the most Target enrollees in the top 50% from the Testing data. This will be model Gradient Boosting before oversampling, which captured 493 Target enrollees in the top 50% of Testing set. In this case what we would do is provide the top 50% list to the recruiting team, this list contains as we explained previously, 2754 enrollees. Which means the recruiting team would only need to send out 2754 emails and they would be able to reach out to 493 real Target enrollees.

Which one is more efficient and economic? 491 out of 3261 or 493 out of 2754? The answer is obvious. Therefore, we could come to 3 conclusions after the study in this section:

* 1. Oversampling (SMOTE) is very effective in terms of improving models’ ability to predict Positive classes. But when the dataset has high degree of feature overlap between classes, applying oversampling method may consequently cause an increase in False Positive classes (Precision will decrease).
  2. Depends on the approach we take after the prediction the increase of False Positive classes may cause negative impact in ROI.
  3. In this business case, metrics Target in top 50% is our key metrics in terms of model comparison.
  4. Model Gradient Boosting before oversampling would be the best solution to this business case.

Lastly, in this section let’s take a look at how SMOTE method affected performance of the best model Gradient Boosting. The result of *Precision, Recall, F1score, ROC\_AUC, Target in top 20%, Target% in top 20%[[2]](#footnote-2), Target in top 50%, Target% in top 50%*, before and after SMOTE oversampling are provided in *Table 6.8.*

Cumulative Lift[[3]](#footnote-3)plot before and afterSMOTE oversampling are provided *in Figure 6.2.* Prediction scores distribution before and after SMOTE oversampling are provided in *Figure 6.3.*

*Table 6.8 Gradient Boosting model performance on Testing set before and after SMOTE*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model | Precision | Recall | F1score | ROC\_AUC | Target in top 20% | Target% in top 20% | Target in top 50% | Target% in top 50% |
| GB before | 0.286 | 0.003 | 0.005 | 0.645 | 259 | 35.6% | 493 | 67.7% |
| GB after | 0.381 | 0.033 | 0.061 | 0.633 | 260 | 35.7% | 475 | 65.2% |

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*Figure 6.2 Gradient Boosting model Cumulative Lift before and after SMOTE oversampling*

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Before SMOTE

After SMOTE

*Figure 6.3 Gradient Boosting model prediction scores distribution plot before and after SMOTE oversampling*

As we can see from above, oversampling did improve our model’s ability to predict Target enrollee as the count of probabilities (predicted by model) over 0.5 slightly increased comparing to the distribution before oversampling, this explained the increase in Recall. Also, we observed a decline in the number of False Positive after oversampling, this explained the increase in Precision. However, it’s still obvious that our model is having difficulties in terms of separating the two classes as the two classes can be seen to have almost indistinguishable distributions across prediction scores. Furthermore, our key metric *Target in top 50%* dropped from 493 (67.7%) to 475 (65.2%) after oversampling.

After achieved the best result from model Gradient Boosting (before SMOTE), our study didn’t end here. As we are still wondering if that is the best model for us. If we take a look back at the models we selected in our list, some of them as a matter of fact don’t require us to fill in missing value or encode categorical variables. For instance, Xgboost Classifier is able to handle missing value and CatBoost Classifier is able to handle both missing value and categorical variables. So here we want to ask the second question: will the 2 models’ performance get improved if we train Xgboost Classifier without filling in missing values, or train CatBoost Classifier with our original dataset (with missing values and categorical variables)? If they do get improved, is it possible that we build a model that will outperform the best model we have so far? We will explore more about this in the next 2 sections.

## 6.5 Experiment with Model Xgboost Classifier

In this section:

* 1. We used the same data set which contains 18,359 rows and 14 columns, and grouped the variables, corrected their data type. The process of grouping and data type correction is exactly the same with the one we explained in Section 4.2 Data Processing, the only difference is we didn’t fill in the missing values.
  2. Then we preprocessed the data taking the same steps that we took in Section 6.1 Data Preprocessing and Feature Selection.
  3. Trained our model Xgboost Classifier with default hyperparameter settings with 5 Folds Cross Validation on Training set (70%) and tested the model on the Testing set (30%).
  4. Recorded *Precision, Recall, F1score, ROC\_AUC, Target in top 20%, Target in top 50%.*
  5. Compared the recorded result with the result we obtained from Xgboost Classifier in Section 6.3 Baseline Model Evaluation.

The more details of step1~ step 5 are provided in this jupyter notebook: [Detecting Potential Candidate\_Part2\_Model XGB.ipynb](https://github.com/yoyo6022/Springboard_Capstone/blob/master/notebooks/Detecting%20Potential%20Candidate_Part2_Model%20XGB.ipynb). Please find the performance comparison in step 5 from *Table 6.9*, *Figure 6.4* and *Figure 6.5*

*Table 6.9 Xgboost model performance on Testing set*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model | Precision | Recall | F1score | ROC\_AUC | Target in top 20% | Target% in top 20% | Target in top 50% | Target% in top 50% |
| Null imputed | 0.220 | 0.037 | 0.063 | 0.599 | 225 | 30.9% | 456 | 62.6% |
| Null not imputed | 0.263 | 0.060 | 0.098 | 0.611 | 244 | 33.5% | 454 | 62.4% |

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*Figure 6.4 Xgboost model Cumulative Lift with and without missing value imputation*

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*Figure 6.5 Xgboost model prediction scores distribution with missing value imputation and no missing value imputation*

The results above show that train Xgboost Classifier without missing value imputation did enhance the model performance in multiple ways. Besides metric *Target in top 50%*, we observed the improvement in all the other metrics. However, our conclusion after this experiment is that this model does not perform better than Gradient Boosting model before SMOTE, which could capture 259 (35.6%) and 493 (67.7%) Target enrollees out of the top 20% and top 50% of the Testing set respectively.

## 6.6 Experiment with Model CatBoost Classifier

In this section:

* 1. We used the same data set which contains 18,359 rows and 14 columns. We replaced the missing value in the categorical variables with value ‘None’. \*Although CatBoost Classifier is supposed to handle null values, but categorical variables cannot contain null values.
  2. Then we preprocessed the data taking the same steps that we took in Section 6.1 Data Preprocessing and Feature Selection.
  3. Trained our model CatBoost Classifier with default hyperparameter settings with 5 Folds Cross Validation on Training set (70%) and tested the model on the Testing set (30%).
  4. Recorded *Precision, Recall, F1score, ROC\_AUC, Target in top 20%, Target in top 50%.*
  5. Compared the recorded result with the result we obtained from CatBoost Classifier in Section 6.3 Baseline Model Evaluation.

The more details are provided in this jupyter notebook: [Detecting Potential Candidate\_Part3\_Model CatBoost.ipynb](https://github.com/yoyo6022/Springboard_Capstone/blob/master/notebooks/Detecting%20Potential%20Candidate_Part3_Model%20CatBoost.ipynb). Please find the performance comparison in step 5 from *Table 6.10*, *Figure 6.6* and *Figure 6.7.*

*Table 6.10 CatBoost model performance on Testing set*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model | Precision | Recall | F1score | ROC\_AUC | Target in top 20% | Target% in top 20% | Target in top 50% | Target% in top 50% |
| Data processed | 0.244 | 0.014 | 0.026 | 0.630 | 261 | 35.9% | 482 | 66.2% |
| Data Not processed | 0.500 | 0.005 | 0.011 | 0.662 | 275 | 37.8% | 514 | 70.6% |

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*Figure 6.6 CatBoost model Cumulative Lift with data processing and no data processing*

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*Figure 6.7 CatBoost model prediction scores distribution with data processing and no data processing*

The result above show that train CatBoost Classifier without imputing missing value or encoding categorical variable, did enhance the model performance in terms of reducing False Positive. Besides metric *F1score and Recall,* we can see a significant improvement in Cumulative Lift plot and all the other metrics. The most significant improvement is, this model enabled us to capture 275, which is 37.8% of Target enrollees and 514, which is 70.6% of Target enrollees, out of the top 20% and top 50% of the Testing set respectively. This is the best achievement we had so far.

# 7 Final Model Selection and Hyperparameters Tuning

Through Section 6.6 Experiment with Model CatBoost Classifier, we should be able to identify the best solution for our business case this time is

* 1. Firstly, feed Catboost Classifier with the original dataset without any missing value imputation or categorical variable encoding.
  2. We then train the model with 5 Folds Cross Validation on Training set (70%).

As this solution outperformed all the other solution we tested in this study, furthermore it would save us lots of time by cutting off all the data processing part.

After identifying CatBoost Classifier as our best model, we applied hyperparameter tuning via random search Cross Validation (3 Folds) to the model and obtained our optimized model by adjusting 3 hyperparameters: iterations, depth and learning\_rate to [iterations=988, depth=2, learning\_rate=0.072]. A comparison of model performance with and without hyperparameter tuning is provided in *Table 7.1, Figure 7.1 and Figure 7.2.*

*Table 7.1 Model performance on Testing set with and without hyperparameter tuning*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model | Precision | Recall | F1score | ROC\_AUC | Target in top 20% | Target% in top 20% | Target in top 50% | Target% in top 50% |
| CatBoost | 0.500 | 0.005 | 0.011 | 0.662 | 275 | 37.8% | 514 | 70.6% |
| CatBoost\_tuned | 0.571 | 0.005 | 0.011 | 0.664 | 283 | 38.9% | 515 | 70.7% |

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*Figure 7.1 CatBoost model Cumulative Lift before and after hyperparameter tuning*

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*Figure 7.2 CatBoost Model prediction scores distribution before and after hyperparameter*

*tuning*

We can see from *Figure 7.2*, after tuning hyperparameters there was no significant change in prediction scores distribution. On the other hand, the result of *Table 7.1* is showing after hyperparameter tuning, Target enrollee captured in top 20% and top 50% from the Testing set increased by 2% and 0.1% due to the improvement in Lift [[4]](#footnote-4) and Cumulative Lift (*Figure 7.1*).

And with tuned CatBoost model, we could capture almost 71% of Target enrollees from only 50% of the Testing set. Thus, we identify the tuned CatBoost Classifier as our final model. The Lift and Cumulative Lift table before and after tuned was provided in *Table 7.2*. ROC curve of the final model was provided in *Figure 7.3*, followed by *Figure 7.4* Feature importance based on tuned CatBoost Classifier.

*Table 7.2 Lift, Cum.Lift table before tune Tabel 7.3 Lift, Cum.Lift table after tune*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Decile | Target  count | non  Target  count | Lift | Cum\_Lift |
| 1st | 156 | 395 | 2.992 | 2.159 |
| 2nd | 118 | 433 | 2.065 | 1.891 |
| 3rd | 95 | 455 | 1.582 | 1.697 |
| 4th | 74 | 477 | 1.175 | 1.527 |
| 5th | 70 | 481 | 1.103 | 1.414 |
| 6th | 56 | 495 | 0.857 | 1.307 |
| 7th | 45 | 506 | 0.674 | 1.208 |
| 8th | 36 | 514 | 0.531 | 1.119 |
| 9th | 34 | 517 | 0.498 | 1.047 |
| 10th | 43 | 508 | 0.641 | 1.001 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Decile | Target  count | non Target count | Lift | Cum\_Lift |
| 1st | 156 | 395 | 2.992 | 2.145 |
| 2nd | 127 | 424 | 2.269 | 1.945 |
| 3rd | 86 | 464 | 1.404 | 1.692 |
| 4th | 80 | 471 | 1.287 | 1.544 |
| 5th | 66 | 485 | 1.031 | 1.417 |
| 6th | 55 | 496 | 0.840 | 1.307 |
| 7th | 48 | 503 | 0.723 | 1.214 |
| 8th | 40 | 510 | 0.594 | 1.131 |
| 9th | 28 | 523 | 0.406 | 1.048 |
| 10th | 42 | 509 | 0.625 | 1.001 |

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*Figure 7.1 Receiver Operating Characteristic (ROC) curve of final model*

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*Figure 7.2 Feature importance for tuned Catboost Classifier*

# 8 Conclusion

## 8.1 Dataset

After exploring the dataset provided by Company XYZ, we discovered there are a lot of feature similarities in Target and non-Target enrollees. This added challenges to the machine learning process as highly similar instances in datasets that have different target classes normally lead to poor model performance. On top of that, the dataset’s classes are imbalanced at a ratio of 6:1. This posed another challenge for predictive modeling as most of the machine learning algorithms used for classification were designed around the assumption of an equal number of examples for each class. This results in models that have poor predictive performance, specifically for the minority class, which is the Target enrollee in this case.

## 8.2 Models

* 1. In this study we selected 10 classification algorithms that contain probabilistic classifier (Logistic Regression, Gaussian Naïve Bayes), Instance-based learning algorithm (K-Nearest Neighbor), Support Vector Classifier, Tree-based models (Decision Tree, Random Forest, Gradient Boosting) and Optimized gradient boosting algorithms (XGBoost Classifier, LightGBM Classifier, CatBoost Classifier). Firstly, trained them on the Training set that contains 70% of the entire dataset, applied 5 Folds Cross Validation to the training process. While averaging the test folds performance, we noticed that almost all of the models performed reasonably good in terms of accuracy (0.754 ~ 0.868) but extremely poor in terms of Recall (0 ~ 0.373). Recall remained low when tested models on Testing set (contains the rest 30% instances of the dataset). Gaussian Naïve Bayes generated the best result with this dataset in terms of Recall (0.337).
  2. To enhance the model performance, we applied data oversampling method **Synthetic Minority Oversampling Technique** to each train fold when conducting 5Fold Cross Validation, decreased the imbalance class ration from 6:1 to 1:1. This method did significantly improve the models’ ability to predict Target enrollee (minority class, positive class), however it caused a drop in other metrics such as Precision, as the number of non-Target enrollees being misclassified as Target enrollee (False Positive) also increased together with the increase of correctly classified Target enrollee.
  3. Depends on the approach we take after the prediction the increase of False Positive classes may cause negative impact in ROI.
  4. After comparing metrics Recall with our customized metrics *Target in top 20%* and *Target in top 50%*, we came to the conclusion that in this business case, metrics Target in top 50% is our key metrics as it helps us to identify the model with the best ROI (Reach to the most true Target enrollees with the least financial and human resource investment).
  5. In terms of our customized metrics, models that enable training with missing values or categorical variables performed significantly better without data processing (missing value imputation, categorical variable encoding). CatBoost Classifier trained without data processing outperformed all the other models and was identified as our final model.

## 8.3 Feature Work

To solve the high degree of feature overlap between the two classes in this dataset, a good solution we would like to exam with is to add more features/variables in the dataset if possible. Features that will distance the distribution of the two classes. Currently, age, income and job title/level information are not included in the dataset but are worthy of further study in this business case.

The approach we took for oversampling was SMOTE method, there are some other resampling techniques we have not explored yet would like to dive deeper in the future. Such as ADASYN oversampling method, undersampling method (decrease the number of majority class to balance the classes), adjusting parameters of these resampling techniques we are able to set the target ratio of minority class to majority class (can make it to 2:1 as instance).

# **References**

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2. [John D. Kelleher](https://www.google.com/search?hl=en&sxsrf=ALeKk03XY9eF5QWlLUVRXmU37Eq89qYOcQ:1605820432153&q=inauthor:%22John+D.+Kelleher%22&tbm=bks), [Brian Mac Namee](https://www.google.com/search?hl=en&sxsrf=ALeKk03XY9eF5QWlLUVRXmU37Eq89qYOcQ:1605820432153&q=inauthor:%22Brian+Mac+Namee%22&tbm=bks), [Aoife D'Arcy](https://www.google.com/search?hl=en&sxsrf=ALeKk03XY9eF5QWlLUVRXmU37Eq89qYOcQ:1605820432153&q=inauthor:%22Aoife+D%27Arcy%22&tbm=bks). (2015) *Fundamentals of Machine Learning for Predictive Data Analytics*:  *Algorithms, Worked Examples, and Case Studies.* The MIT Press.
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5. https://en.wikipedia.org/wiki/Kaggle (assessed Nov. 11, 2020)
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1. The original dataset mis-spelled word ‘relevant’ as ‘relevent’. We used the mis-spelled one in this study. [↑](#footnote-ref-1)
2. = [↑](#footnote-ref-2)
3. To calculate Cumulative Lift, we rank the predictions made for the Testing set in descending order by prediction scores and then divide them into deciles. A decile is a group containing 10% of a dataset. The Cumulative Lift at decile dec is defined as in this study. [↑](#footnote-ref-3)
4. The Lift at decile dec is defined as in this study [↑](#footnote-ref-4)