In [1]:
```
from imblearn.under_sampling import RandomUnderSampler
from sklearn.ensemble import RandomForestClassifier
from xgboost import XGBClassifier
from sklearn.model_selection import train_test_split
from sklearn.metrics import classification_report, roc_curve, auc
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import os
import numpy as np
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
import networkx as nx
from collections import defaultdict
import plotly.graph_objects as go
from imblearn.over_sampling import SMOTE
from sklearn.model_selection import train_test_split
from sklearn.metrics import classification_report
from xgboost import XGBClassifier
import pandas as pd
from sklearn.preprocessing import StandardScaler
from sklearn.decomposition import PCA
```

In [2]:
```
enhanced_Interaction_Customer_Transaction_Login = pd.read_csv("enhanced_cust
```

In [3]:
```
enhanced_Interaction_Customer_Transaction_Login
```

Out[3]:

| | CustomerID | Age | ChurnStatus | Zscore_Genderdiff | Zscore_Age_rangediff |
|---|---|---|---|---|---|
| **0** | 1 | 62 | 0 | 21.898796 | 3.071478 |
| **1** | 2 | 65 | 1 | 21.898796 | 3.071478 |
| **2** | 3 | 18 | 0 | 21.898796 | 2.238200 |
| **3** | 4 | 21 | 0 | 21.898796 | -17.033005 |
| **4** | 5 | 21 | 0 | 21.898796 | -17.033005 |
| **...** | ... | ... | ... | ... | ... |
| **995** | 996 | 54 | 0 | -23.096539 | 20.951841 |
| **996** | 997 | 19 | 0 | 21.898796 | 2.238200 |
| **997** | 998 | 47 | 0 | 21.898796 | 6.257337 |
| **998** | 999 | 23 | 0 | 21.898796 | -17.033005 |
| **999** | 1000 | 34 | 0 | 21.898796 | -19.062154 |

1000 rows × 58 columns

In [4]:
```
enhanced_Interaction_Customer_Transaction_Login.columns
```

Out[4]:
```
Index(['CustomerID', 'Age', 'ChurnStatus', 'Zscore_Genderdiff',
       'Zscore_Age_rangediff', 'Zscore_MaritalStatusdiff',
       'Zscore_IncomeLeveldiff', 'Gender_M', 'Age_range_20-30',
       'Age_range_30-40', 'Age_range_40-50', 'Age_range_50-60',
       'Age_range_60+', 'MaritalStatus_Married', 'MaritalStatus_Single',
       'MaritalStatus_Widowed', 'IncomeLevel_Low', 'IncomeLevel_Medium',
       'Duration_Interation', 'Markov_Churn_prob', 'Complaint', 'Feedback',
       'Inquiry', 'Resolved', 'Unresolved', 'Rolling_7D_Sum',
       'Rolling_7D_0-200', 'Rolling_7D_200-400', 'Rolling_7D_400-600',
       'Rolling_7D_600+', 'Rolling_7D_Books', 'Rolling_7D_Clothing',
       'Rolling_7D_Electronics', 'Rolling_7D_Furniture',
       'Rolling_7D_Groceries',
       'Rolling_7D_Furniture_bined_Rolling_7D_Furniture_210',
       'Rolling_7D_Furniture_bined_Rolling_7D_Furniture_210+',
       'Rolling_7D_Electronics_bined_Rolling_7D_Electronics_310',
       'Rolling_7D_Electronics_bined_Rolling_7D_Electronics_360',
       'Rolling_7D_Electronics_bined_Rolling_7D_Electronics_440',
       'Rolling_7D_Electronics_bined_Rolling_7D_Electronics_440+',
       'Rolling_7D_Books_bined_Rolling_7D_Books_220+',
       'Rolling_7D_Books_bined_Rolling_7D_Books_80',
       'Rolling_7D_Groceries_bined_Rolling_7D_Groceries_280',
       'Rolling_7D_Groceries_bined_Rolling_7D_Groceries_320',
       'Rolling_7D_Groceries_bined_Rolling_7D_Groceries_380',
       'Rolling_7D_Groceries_bined_Rolling_7D_Groceries_410+',
       'Rolling_7D_Groceries_bined_Rolling_7D_Groceries_80',
       'Rolling_7D_Clothing_bined_Rolling_7D_Clothing_150+',
       'Rolling_7D_Clothing_bined_Rolling_7D_Clothing_40', 'LoginFrequenc
y',
       'DaysSinceLastLogin', 'LoginFrequency_Ratio',
       'ServiceUsage_Online Banking', 'ServiceUsage_Website',
       'LoginCategory_Medium', 'LoginCategory_High', 'LoginCategory_VeryHig
h'],
      dtype='object')
```

In [50]:
```
baseline_data = (enhanced_Interaction_Customer_Transaction_Login.copy()[['Cu
```

In [51]:
```
baseline_data.columns
```

Out[51]:
```
Index(['CustomerID', 'Age', 'ChurnStatus', 'Duration_Interation', 'Gender_
M',
       'MaritalStatus_Married', 'MaritalStatus_Single',
       'MaritalStatus_Widowed', 'IncomeLevel_Low', 'IncomeLevel_Medium',
       'Age_range_20-30', 'Age_range_30-40', 'Age_range_40-50',
       'Age_range_50-60', 'Age_range_60+', 'LoginFrequency',
       'DaysSinceLastLogin', 'ServiceUsage_Online Banking',
       'ServiceUsage_Website', 'LoginCategory_Medium', 'LoginCategory_Hig
h',
       'LoginCategory_VeryHigh'],
      dtype='object')
```

In [53]:
```
X = baseline_data.drop(columns=["ChurnStatus"])
y = baseline_data["ChurnStatus"].astype(int)
```

```
for col in X.columns:
    try:
        X[col] = pd.to_numeric(X[col] , errors='ignore')
    except:
        print(f"can not transform: {col}")


X_train, X_test_baseline, y_train, y_test_baseline = train_test_split(X, y,

xgb_model_baseline = XGBClassifier(
    n_estimators=100,
    max_depth=10,
    learning_rate=0.1,
    random_state=42
)



xgb_model_baseline.fit(X_train, y_train)

y_pred = xgb_model_baseline.predict(X_test_baseline)

report = classification_report(y_test_baseline, y_pred)
print("report:", report)
```

```
report:               precision    recall  f1-score   support

           0       0.80      0.93      0.86       159
           1       0.27      0.10      0.14        41

    accuracy                           0.76       200
   macro avg       0.53      0.51      0.50       200
weighted avg       0.69      0.76      0.71       200
```

```
/var/folders/pt/0nf2m3pj1f3b373wsyfc6glh0000gn/T/ipykernel_91558/2402704606.
py:7: FutureWarning: errors='ignore' is deprecated and will raise in a futur
e version. Use to_numeric without passing `errors` and catch exceptions expl
icitly instead
  X[col] = pd.to_numeric(X[col] , errors='ignore')
```

In [8]:
```
X = enhanced_Interaction_Customer_Transaction_Login.drop(columns=["ChurnStat
y = enhanced_Interaction_Customer_Transaction_Login["ChurnStatus"].astype(ir


for col in X.columns:
    try:
        X[col] = pd.to_numeric(X[col] , errors='ignore')
    except:
        print(f"can not transform {col}")


X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, rar
```

```
/var/folders/pt/0nf2m3pj1f3b373wsyfc6glh0000gn/T/ipykernel_91558/4119102381.
py:7: FutureWarning: errors='ignore' is deprecated and will raise in a futur
e version. Use to_numeric without passing `errors` and catch exceptions expl
icitly instead
  X[col] = pd.to_numeric(X[col] , errors='ignore')  # 'ignore' 让非数值列保持不
变
```

In [9]:
```python
def focal_loss(alpha, gamma):
    def focal_loss_func(y_pred, y_true):
        p_t = np.exp(-y_pred)
        loss = alpha * (1 - p_t) ** gamma * y_pred
        return "focal_loss", np.mean(loss)
    return focal_loss_func
```

In [10]:
```python
from sklearn.feature_selection import mutual_info_classif

mi_scores = mutual_info_classif(enhanced_Interaction_Customer_Transaction_Lo
, random_state=123)
mi_scores_df = pd.DataFrame({'Feature': enhanced_Interaction_Customer_Transa
mi_scores_df = mi_scores_df.sort_values(by="MI Score", ascending=False)

print(mi_scores_df.head(40))
```

| | Feature | MI Score |
|---|---|---|
| 53 | ServiceUsage_Website | 0.023989 |
| 30 | Rolling_7D_Clothing | 0.020915 |
| 54 | LoginCategory_Medium | 0.020584 |
| 4 | Zscore_MaritalStatusdiff | 0.019372 |
| 12 | MaritalStatus_Married | 0.018458 |
| 29 | Rolling_7D_Books | 0.018309 |
| 49 | LoginFrequency | 0.017536 |
| 8 | Age_range_30-40 | 0.016729 |
| 7 | Age_range_20-30 | 0.016718 |
| 26 | Rolling_7D_200-400 | 0.013307 |
| 46 | Rolling_7D_Groceries_bined_Rolling_7D_Grocerie... | 0.013058 |
| 36 | Rolling_7D_Electronics_bined_Rolling_7D_Electr... | 0.012295 |
| 37 | Rolling_7D_Electronics_bined_Rolling_7D_Electr... | 0.011920 |
| 51 | LoginFrequency_Ratio | 0.009713 |
| 10 | Age_range_50-60 | 0.007855 |
| 39 | Rolling_7D_Electronics_bined_Rolling_7D_Electr... | 0.007560 |
| 52 | ServiceUsage_Online Banking | 0.007440 |
| 27 | Rolling_7D_400-600 | 0.006443 |
| 23 | Unresolved | 0.006023 |
| 14 | MaritalStatus_Widowed | 0.004336 |
| 9 | Age_range_40-50 | 0.004278 |
| 11 | Age_range_60+ | 0.004106 |
| 0 | CustomerID | 0.003323 |
| 2 | Zscore_Genderdiff | 0.002922 |
| 22 | Resolved | 0.002770 |
| 17 | Duration_Interation | 0.001987 |
| 43 | Rolling_7D_Groceries_bined_Rolling_7D_Grocerie... | 0.000479 |
| 47 | Rolling_7D_Clothing_bined_Rolling_7D_Clothing_... | 0.000000 |
| 44 | Rolling_7D_Groceries_bined_Rolling_7D_Grocerie... | 0.000000 |
| 48 | Rolling_7D_Clothing_bined_Rolling_7D_Clothing_40 | 0.000000 |
| 55 | LoginCategory_High | 0.000000 |
| 42 | Rolling_7D_Groceries_bined_Rolling_7D_Grocerie... | 0.000000 |
| 41 | Rolling_7D_Books_bined_Rolling_7D_Books_80 | 0.000000 |
| 40 | Rolling_7D_Books_bined_Rolling_7D_Books_220+ | 0.000000 |
| 50 | DaysSinceLastLogin | 0.000000 |
| 38 | Rolling_7D_Electronics_bined_Rolling_7D_Electr... | 0.000000 |
| 45 | Rolling_7D_Groceries_bined_Rolling_7D_Grocerie... | 0.000000 |
| 28 | Rolling_7D_600+ | 0.000000 |
| 35 | Rolling_7D_Furniture_bined_Rolling_7D_Furnitur... | 0.000000 |
| 19 | Complaint | 0.000000 |

In [19]:
```
correlation_matrix[abs(correlation_matrix["ChurnStatus"]) > 0.001].index
```

Out[19]:
```
Index(['ServiceUsage_Website', 'Rolling_7D_Clothing', 'LoginCategory_Mediu
m',
       'Zscore_MaritalStatusdiff', 'MaritalStatus_Married', 'Rolling_7D_Boo
ks',
       'LoginFrequency', 'Age_range_30-40', 'Age_range_20-30',
       'Rolling_7D_200-400',
       'Rolling_7D_Groceries_bined_Rolling_7D_Groceries_80',
       'Rolling_7D_Electronics_bined_Rolling_7D_Electronics_310',
       'Rolling_7D_Electronics_bined_Rolling_7D_Electronics_360',
       'LoginFrequency_Ratio', 'Age_range_50-60',
       'ServiceUsage_Online Banking', 'Rolling_7D_400-600', 'Unresolved',
       'MaritalStatus_Widowed', 'Age_range_40-50', 'Age_range_60+',
       'CustomerID', 'Zscore_Genderdiff', 'ChurnStatus'],
      dtype='object')
```

In [48]:
```
from ctgan import CTGAN
import pandas as pd
from tqdm import tqdm
import time

os.environ["OMP_NUM_THREADS"] = "1"
os.environ["MKL_NUM_THREADS"] = "1"

data = enhanced_Interaction_Customer_Transaction_Login.copy()



data_to_augment = data[data['ChurnStatus'] == 1]
num_samples = len(data_to_augment) * 5


epochs = 500


ctgan = CTGAN(epochs=epochs, batch_size=500, verbose=False)


print("Training CTGAN...")
for epoch in tqdm(range(epochs), desc="CTGAN Training Progress"):

    ctgan.fit(data_to_augment)

print("CTGAN Training Complete!")


print("Generating synthetic data...")
new_data = ctgan.sample(num_samples)


for col in data_to_augment.columns:
    if col in new_data.columns:
        new_data[col] = new_data[col].astype(data_to_augment[col].dtype)

print("Synthetic Data Generated!")
```

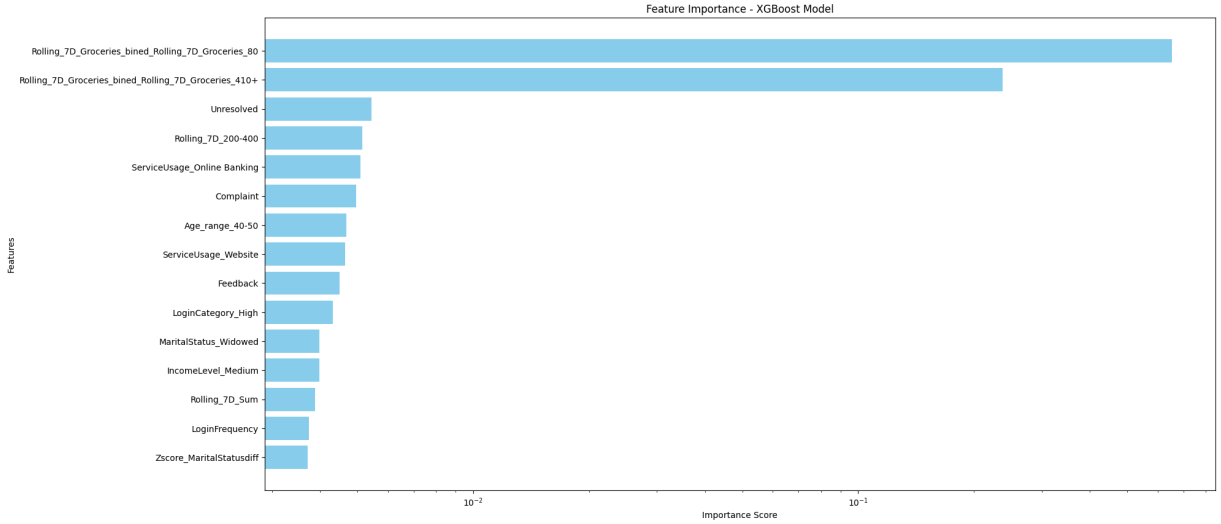
```
augmented_data = pd.concat([data, new_data], ignore_index=True)
```

```
Training CTGAN...
CTGAN Training Progress: 100%|██████████| 50/50 [02:14<00:00,  2.69
s/it]
CTGAN Training Complete!
🔄 Generating synthetic data...
✅ Synthetic Data Generated!
🎯 Training XGBoost Model...
✅ XGBoost Training Complete!
📊 Classification Report:
              precision    recall  f1-score   support

           0       0.76      0.92      0.83       159
           1       0.94      0.81      0.87       245

    accuracy                           0.85       404
   macro avg       0.85      0.86      0.85       404
weighted avg       0.87      0.85      0.85       404
```

In [70]:
```
X = augmented_data.drop(columns=["ChurnStatus"])
y = augmented_data["ChurnStatus"]


from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, rar


from xgboost import XGBClassifier
print("🎯 Training XGBoost Model...")
model_enhanced = XGBClassifier(n_estimators=30, max_depth=10, learning_rate=
model_enhanced.fit(X_train, y_train)
print("✅ XGBoost Training Complete!")


y_pred = model_enhanced.predict(X_test)


from sklearn.metrics import classification_report
print(" Classification Report:")
print(classification_report(y_test, y_pred))
```

```
🎯 Training XGBoost Model...
✅ XGBoost Training Complete!
📊 Classification Report:
              precision    recall  f1-score   support

           0       0.76      0.95      0.85       159
           1       0.96      0.81      0.88       245

    accuracy                           0.86       404
   macro avg       0.86      0.88      0.86       404
weighted avg       0.88      0.86      0.87       404
```

In [78]:
```
feature_importances = model_enhanced.feature_importances_
feature_names = X_train.columns

importance_df = pd.DataFrame({'Feature': feature_names, 'Importance': featur
importance_df = importance_df.sort_values(by='Importance', ascending=False).

plt.figure(figsize=(20, 10))
plt.barh(importance_df['Feature'], importance_df['Importance'], color='skybl
plt.xlabel("Importance Score")
plt.ylabel("Features")

plt.title("Feature Importance - XGBoost Model")
plt.xscale("log")
plt.gca().invert_yaxis()
plt.savefig("Plots/importance_rank.png", dpi=300, bbox_inches='tight')
plt.show()
```




In [76]:
```
importance_df
```

Out[76]:

| | Feature | Importance |
|---|---|---|
| **46** | Rolling_7D_Groceries_bined_Rolling_7D_Grocerie... | 0.654101 |
| **45** | Rolling_7D_Groceries_bined_Rolling_7D_Grocerie... | 0.237621 |
| **23** | Unresolved | 0.005438 |
| **26** | Rolling_7D_200-400 | 0.005156 |
| **52** | ServiceUsage_Online Banking | 0.005088 |
| **19** | Complaint | 0.004958 |
| **9** | Age_range_40-50 | 0.004691 |
| **53** | ServiceUsage_Website | 0.004653 |
| **20** | Feedback | 0.004492 |
| **55** | LoginCategory_High | 0.004325 |
| **14** | MaritalStatus_Widowed | 0.003990 |
| **16** | IncomeLevel_Medium | 0.003987 |
| **24** | Rolling_7D_Sum | 0.003883 |
| **49** | LoginFrequency | 0.003739 |
| **4** | Zscore_MaritalStatusdiff | 0.003722 |
| **1** | Age | 0.003688 |
| **0** | CustomerID | 0.003681 |
| **18** | Markov_Churn_prob | 0.003673 |
| **54** | LoginCategory_Medium | 0.003600 |
| **2** | Zscore_Genderdiff | 0.003585 |
| **17** | Duration_Interation | 0.003534 |
| **50** | DaysSinceLastLogin | 0.003356 |
| **22** | Resolved | 0.003296 |
| **5** | Zscore_IncomeLeveldiff | 0.003220 |
| **13** | MaritalStatus_Single | 0.003203 |
| **32** | Rolling_7D_Furniture | 0.002988 |
| **21** | Inquiry | 0.002813 |
| **33** | Rolling_7D_Groceries | 0.002531 |
| **30** | Rolling_7D_Clothing | 0.002237 |
| **31** | Rolling_7D_Electronics | 0.002114 |
| **7** | Age_range_20-30 | 0.001662 |
| **3** | Zscore_Age_rangediff | 0.000976 |
| **51** | LoginFrequency_Ratio | 0.000000 |

| | Feature | Importance |
|---|---|---|
| **48** | Rolling_7D_Clothing_bined_Rolling_7D_Clothing_40 | 0.000000 |
| **47** | Rolling_7D_Clothing_bined_Rolling_7D_Clothing_... | 0.000000 |
| **40** | Rolling_7D_Books_bined_Rolling_7D_Books_220+ | 0.000000 |
| **44** | Rolling_7D_Groceries_bined_Rolling_7D_Grocerie... | 0.000000 |
| **43** | Rolling_7D_Groceries_bined_Rolling_7D_Grocerie... | 0.000000 |
| **42** | Rolling_7D_Groceries_bined_Rolling_7D_Grocerie... | 0.000000 |
| **41** | Rolling_7D_Books_bined_Rolling_7D_Books_80 | 0.000000 |
| **28** | Rolling_7D_600+ | 0.000000 |
| **39** | Rolling_7D_Electronics_bined_Rolling_7D_Electr... | 0.000000 |
| **38** | Rolling_7D_Electronics_bined_Rolling_7D_Electr... | 0.000000 |
| **37** | Rolling_7D_Electronics_bined_Rolling_7D_Electr... | 0.000000 |
| **36** | Rolling_7D_Electronics_bined_Rolling_7D_Electr... | 0.000000 |
| **35** | Rolling_7D_Furniture_bined_Rolling_7D_Furnitur... | 0.000000 |
| **34** | Rolling_7D_Furniture_bined_Rolling_7D_Furnitur... | 0.000000 |
| **29** | Rolling_7D_Books | 0.000000 |
| **27** | Rolling_7D_400-600 | 0.000000 |
| **25** | Rolling_7D_0-200 | 0.000000 |
| **15** | IncomeLevel_Low | 0.000000 |
| **12** | MaritalStatus_Married | 0.000000 |
| **11** | Age_range_60+ | 0.000000 |
| **10** | Age_range_50-60 | 0.000000 |
| **8** | Age_range_30-40 | 0.000000 |
| **6** | Gender_M | 0.000000 |
| **56** | LoginCategory_VeryHigh | 0.000000 |

In [58]:
```
import matplotlib.pyplot as plt
from sklearn.metrics import roc_curve, auc


y_pred_proba = model_enhanced.predict_proba(X_test)[:, 1]
y_pred_proba_baseline = xgb_model_baseline.predict_proba(X_test_baseline)[:,


fpr, tpr, _ = roc_curve(y_test, y_pred_proba)
fpr_baseline, tpr_baseline, _1 = roc_curve(y_test_baseline, y_pred_proba_bas

roc_auc = auc(fpr, tpr)
roc_auc_baseline = auc(fpr_baseline, tpr_baseline)
```

```
plt.figure(figsize=(8, 6))
plt.plot(fpr, tpr, color="blue", lw=2, label=f"AUC with enhanced features= {
plt.plot(fpr_baseline, tpr_baseline, color="red", lw=2, label=f"AUC without 
plt.plot([0, 1], [0, 1], color="grey", linestyle="--")  # 参考线
plt.xlim([0.0, 1.0])
plt.ylim([0.0, 1.05])
plt.xlabel("False Positive Rate (FPR)")
plt.ylabel("True Positive Rate (TPR)")
plt.title("AUC-ROC Curve")
plt.legend(loc="lower right")
plt.grid()
plt.savefig("Plots/AUCs.png", dpi=300, bbox_inches='tight')
plt.show()
```