```python
import pandas as pd
from sklearn.preprocessing import LabelEncoder
from sklearn.model_selection import train_test_split
from sklearn.metrics import accuracy_score, classification_report, roc_curve, auc
import matplotlib.pyplot as plt
import seaborn as sns
import numpy as np
import tensorflow as tf
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, LSTM, Conv1D, MaxPooling1D, Flatten, Embedding
```

```python
from tensorflow.keras.preprocessing.text import Tokenizer
from tensorflow.keras.preprocessing.sequence import pad_sequences
from tensorflow.keras.utils import to_categorical
from tensorflow.keras.callbacks import EarlyStopping
```

```python
# Load the data from the file
file_path = 'breach_report_archive.txt'
data = pd.read_csv(file_path, delimiter='\t', encoding='latin1')
```

```python
# Convert 'Breach Submission Date' to datetime
data['Breach Submission Date'] = pd.to_datetime(data['Breach Submission Date'])
```

```python
# Encode categorical variables
label_encoders = {}
for column in ['State', 'Covered Entity Type', 'Type of Breach', 'Location of Breached Information', 'Business Associate Present']:
    le = LabelEncoder()
    data[column] = le.fit_transform(data[column])
    label_encoders[column] = le
```

```python
# Define categorical features and target variable
categorical_features = ['State', 'Covered Entity Type', 'Type of Breach', 'Location of Breached Information', 'Business Associate Present
textual_feature = 'Web Description'
target = 'Individuals Affected'
```

```python
# Binarize the target variable for classification
data['High Risk'] = data[target] > data[target].median()
y = data['High Risk'].astype(int)
```

```python
# Tokenize and pad sequences for RNN and CNN models
max_words = 5000  # Maximum number of words to consider in the vocabulary
max_len = 512     # Maximum length of sequences
```

```python
# Ensure the textual_feature column contains only strings
data[textual_feature] = data[textual_feature].astype(str)
```

```python
tokenizer_keras = tf.keras.preprocessing.text.Tokenizer(num_words=max_words)
tokenizer_keras.fit_on_texts(data[textual_feature])
sequences = tokenizer_keras.texts_to_sequences(data[textual_feature])
X_textual_padded = tf.keras.preprocessing.sequence.pad_sequences(sequences, maxlen=max_len)
```

```python
# Split the padded sequences into training and testing sets
X_train_textual, X_test_textual, y_train_textual, y_test_textual = train_test_split(X_textual_padded, y, test_size=0.2, random_state=42)
```

RNN Model (LSTM)

```python
from tensorflow.keras.layers import Dropout # Import Dropout
```

```python
# Define RNN model (LSTM) with increased complexity and regularization
rnn_model = Sequential()
rnn_model.add(Embedding(input_dim=max_words, output_dim=128, input_length=max_len))
rnn_model.add(LSTM(128, return_sequences=True))
rnn_model.add(LSTM(64))
rnn_model.add(Dropout(0.5))
rnn_model.add(Dense(1, activation='sigmoid'))
rnn_model.compile(optimizer='adam', loss='binary_crossentropy', metrics=['accuracy'])
```

```
/usr/local/lib/python3.10/dist-packages/keras/src/layers/core/embedding.py:90: UserWarning: Argument `input_length` is deprecated. Just
  warnings.warn(
```

```
# Train RNN model (LSTM) with early stopping
early_stopping = EarlyStopping(monitor='val_loss', patience=3, restore_best_weights=True)
rnn_model.fit(X_train_textual, y_train_textual, epochs=20, batch_size=32, validation_split=0.2, callbacks=[early_stopping])
```

```
Epoch 1/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 181s 1s/step - accuracy: 0.5365 - loss: 0.6882 - val_accuracy: 0.5895 - val_loss: 0.6729
Epoch 2/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 161s 1s/step - accuracy: 0.6310 - loss: 0.6506 - val_accuracy: 0.6970 - val_loss: 0.5947
Epoch 3/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 203s 1s/step - accuracy: 0.7805 - loss: 0.4866 - val_accuracy: 0.7387 - val_loss: 0.5430
Epoch 4/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 159s 1s/step - accuracy: 0.6587 - loss: 0.6060 - val_accuracy: 0.5609 - val_loss: 0.6858
Epoch 5/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 161s 1s/step - accuracy: 0.6585 - loss: 0.6108 - val_accuracy: 0.7530 - val_loss: 0.5349
Epoch 6/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 161s 1s/step - accuracy: 0.8179 - loss: 0.4194 - val_accuracy: 0.7596 - val_loss: 0.5320
Epoch 7/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 202s 1s/step - accuracy: 0.7595 - loss: 0.4787 - val_accuracy: 0.6158 - val_loss: 0.6121
Epoch 8/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 203s 1s/step - accuracy: 0.7015 - loss: 0.5539 - val_accuracy: 0.5335 - val_loss: 0.6893
Epoch 9/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 201s 1s/step - accuracy: 0.5083 - loss: 0.7002 - val_accuracy: 0.5357 - val_loss: 0.6896
<keras.src.callbacks.history.History at 0x7d56a4fbfdc0>
```

```
# Evaluate RNN model (LSTM)
y_pred_rnn_proba = rnn_model.predict(X_test_textual).flatten()
y_pred_rnn = (y_pred_rnn_proba > 0.5).astype(int)
accuracy_rnn = accuracy_score(y_test_textual, y_pred_rnn)
report_rnn = classification_report(y_test_textual, y_pred_rnn)
```

```
36/36 ━━━━━━━━━━━━━━━━━━━━ 14s 377ms/step
```

CNN Model

```
from tensorflow.keras.layers import GlobalMaxPooling1D  # Import GlobalMaxPooling1D
```

```
# Define CNN model with increased complexity and regularization
cnn_model = Sequential()
cnn_model.add(Embedding(input_dim=max_words, output_dim=128, input_length=max_len))
cnn_model.add(Conv1D(128, 5, activation='relu'))
cnn_model.add(MaxPooling1D(pool_size=4))
cnn_model.add(Conv1D(64, 5, activation='relu'))
cnn_model.add(GlobalMaxPooling1D())
cnn_model.add(Dropout(0.5))
cnn_model.add(Dense(1, activation='sigmoid'))
cnn_model.compile(optimizer='adam', loss='binary_crossentropy', metrics=['accuracy'])
```

```
/usr/local/lib/python3.10/dist-packages/keras/src/layers/core/embedding.py:90: UserWarning: Argument `input_length` is deprecated. Just
  warnings.warn(
```

```
# Train CNN model with early stopping
cnn_model.fit(X_train_textual, y_train_textual, epochs=20, batch_size=32, validation_split=0.2, callbacks=[early_stopping])
```

```
Epoch 1/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 38s 311ms/step - accuracy: 0.5494 - loss: 0.6810 - val_accuracy: 0.8277 - val_loss: 0.4044
Epoch 2/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 29s 255ms/step - accuracy: 0.8314 - loss: 0.3461 - val_accuracy: 0.8869 - val_loss: 0.2647
Epoch 3/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 41s 252ms/step - accuracy: 0.8969 - loss: 0.2179 - val_accuracy: 0.8858 - val_loss: 0.2695
Epoch 4/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 41s 257ms/step - accuracy: 0.9163 - loss: 0.1792 - val_accuracy: 0.8683 - val_loss: 0.3156
Epoch 5/20
114/114 ━━━━━━━━━━━━━━━━━━━━ 41s 256ms/step - accuracy: 0.9261 - loss: 0.1398 - val_accuracy: 0.8705 - val_loss: 0.3186
<keras.src.callbacks.history.History at 0x7d569ae1c7c0>
```

```
# Evaluate CNN model
y_pred_cnn_proba = cnn_model.predict(X_test_textual).flatten()
y_pred_cnn = (y_pred_cnn_proba > 0.5).astype(int)
accuracy_cnn = accuracy_score(y_test_textual, y_pred_cnn)
report_cnn = classification_report(y_test_textual, y_pred_cnn)
```

```
36/36 ━━━━━━━━━━━━━━━━━━━━ 2s 62ms/step
```

Evaluate and Compare Models

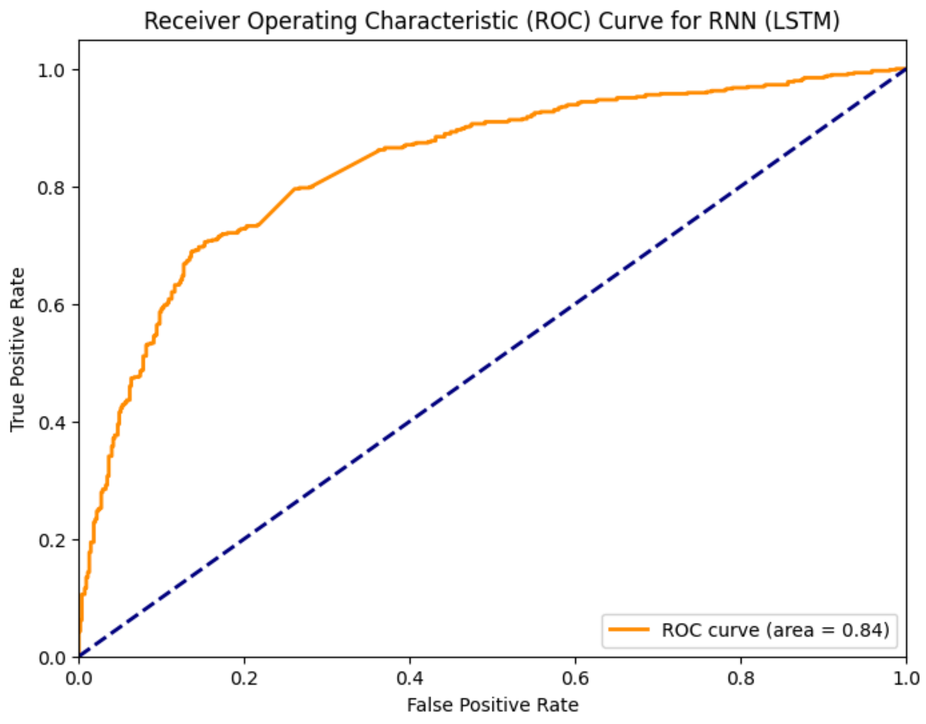
Plot ROC Curves and Confusion Matrices

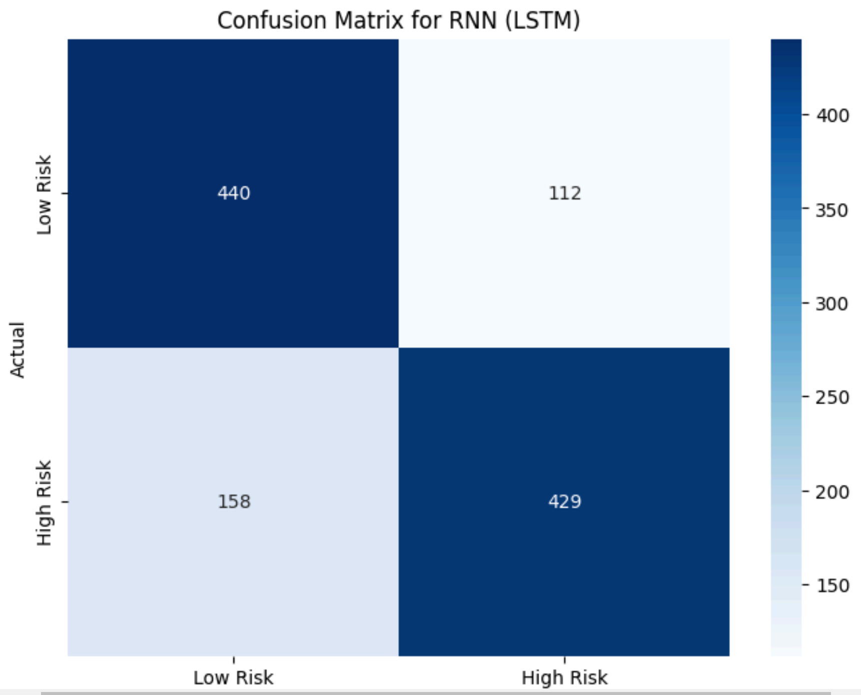
```
# Function to plot ROC curve
def plot_roc_curve(y_true, y_pred_proba, model_name):
    fpr, tpr, _ = roc_curve(y_true, y_pred_proba)
    roc_auc = auc(fpr, tpr)
    plt.figure(figsize=(8, 6))
    plt.plot(fpr, tpr, color='darkorange', lw=2, label=f'ROC curve (area = {roc_auc:.2f})')
    plt.plot([0, 1], [0, 1], color='navy', lw=2, linestyle='--')
    plt.xlim([0.0, 1.0])
    plt.ylim([0.0, 1.05])
    plt.xlabel('False Positive Rate')
    plt.ylabel('True Positive Rate')
    plt.title(f'Receiver Operating Characteristic (ROC) Curve for {model_name}')
    plt.legend(loc="lower right")
    plt.show()
```

```
# Import the necessary libraries
from sklearn.metrics import roc_curve, auc
from sklearn.metrics import confusion_matrix
```

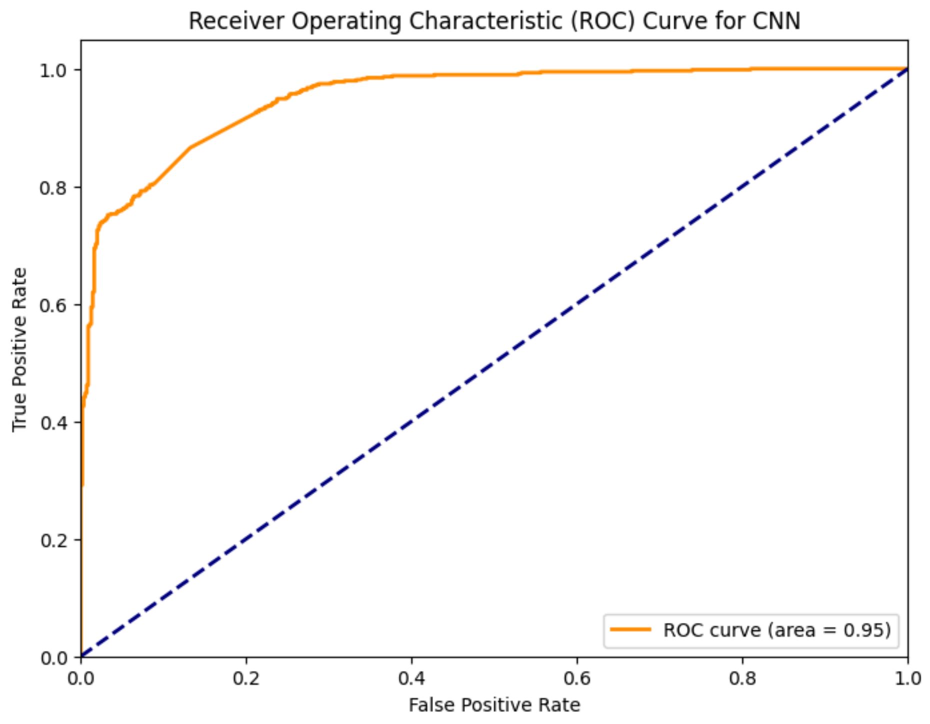
```
# Function to plot confusion matrix
def plot_confusion_matrix(y_true, y_pred, model_name):
    cm = confusion_matrix(y_true, y_pred)
    plt.figure(figsize=(8, 6))
    sns.heatmap(cm, annot=True, fmt='d', cmap='Blues', xticklabels=['Low Risk', 'High Risk'], yticklabels=['Low Risk', 'High Risk'])
    plt.xlabel('Predicted')
    plt.ylabel('Actual')
    plt.title(f'Confusion Matrix for {model_name}')
    plt.show()
```

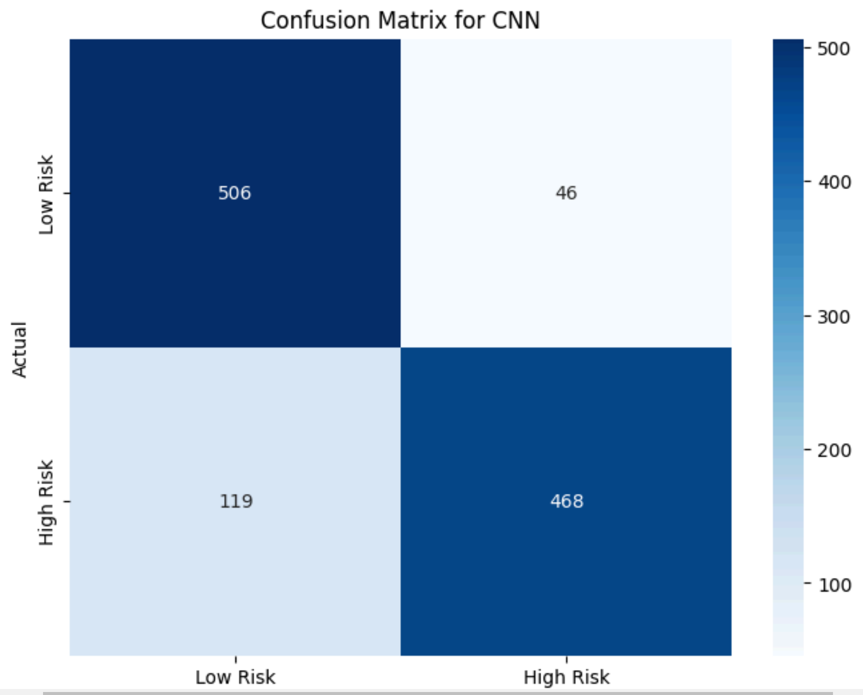
```
# Plot ROC curve and confusion matrix for RNN
plot_roc_curve(y_test_textual, y_pred_rnn_proba, 'RNN (LSTM)')
plot_confusion_matrix(y_test_textual, y_pred_rnn, 'RNN (LSTM)')
```





```
# Plot ROC curve and confusion matrix for CNN
plot_roc_curve(y_test_textual, y_pred_cnn_proba, 'CNN')
plot_confusion_matrix(y_test_textual, y_pred_cnn, 'CNN')
```





```
# Print results for RNN
print(f"Model: RNN (LSTM)")
print(f"Accuracy: {accuracy_rnn}")
print(f"Classification Report:\n{report_rnn}\n")
```

```
Model: RNN (LSTM)
Accuracy: 0.7629499561018437
Classification Report:
              precision    recall  f1-score   support

           0       0.74      0.80      0.77       552
           1       0.79      0.73      0.76       587

    accuracy                           0.76      1139
   macro avg       0.76      0.76      0.76      1139
weighted avg       0.77      0.76      0.76      1139
```

```
# Print results for CNN
print(f"Model: CNN")
print(f"Accuracy: {accuracy_cnn}")
print(f"Classification Report:\n{report_cnn}\n")
```

```
Model: CNN
Accuracy: 0.8551360842844601
Classification Report:
              precision    recall  f1-score   support

           0       0.81      0.92      0.86       552
           1       0.91      0.80      0.85       587

    accuracy                           0.86      1139
   macro avg       0.86      0.86      0.85      1139
weighted avg       0.86      0.86      0.85      1139
```