In [16]:

```
!pip install pyswarms
```

```
Collecting pyswarms
  Downloading pyswarms-1.3.0-py2.py3-none-any.whl.metadata (33 kB)
Requirement already satisfied: scipy in /usr/local/lib/python3.10/dist-packages
(from pyswarms) (1.13.1)
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages
(from pyswarms) (1.26.4)
Requirement already satisfied: matplotlib>=1.3.1 in /usr/local/lib/python3.10/d
ist-packages (from pyswarms) (3.7.5)
Requirement already satisfied: attrs in /usr/local/lib/python3.10/dist-packages
(from pyswarms) (24.3.0)
Requirement already satisfied: tqdm in /usr/local/lib/python3.10/dist-packages
(from pyswarms) (4.67.1)
Requirement already satisfied: future in /usr/local/lib/python3.10/dist-package
s (from pyswarms) (1.0.0)
Requirement already satisfied: pyyaml in /usr/local/lib/python3.10/dist-package
s (from pyswarms) (6.0.2)
Requirement already satisfied: contourpy>=1.0.1 in /usr/local/lib/python3.10/di
st-packages (from matplotlib>=1.3.1->pyswarms) (1.3.1)
Requirement already satisfied: cycler>=0.10 in /usr/local/lib/python3.10/dist-p
ackages (from matplotlib>=1.3.1->pyswarms) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in /usr/local/lib/python3.10/d
ist-packages (from matplotlib>=1.3.1->pyswarms) (4.55.3)
Requirement already satisfied: kiwisolver>=1.0.1 in /usr/local/lib/python3.10/d
ist-packages (from matplotlib>=1.3.1->pyswarms) (1.4.7)
Requirement already satisfied: packaging>=20.0 in /usr/local/lib/python3.10/dis
t-packages (from matplotlib>=1.3.1->pyswarms) (24.2)
Requirement already satisfied: pillow>=6.2.0 in /usr/local/lib/python3.10/dist-
packages (from matplotlib>=1.3.1->pyswarms) (11.0.0)
Requirement already satisfied: pyparsing>=2.3.1 in /usr/local/lib/python3.10/di
st-packages (from matplotlib>=1.3.1->pyswarms) (3.2.0)
Requirement already satisfied: python-dateutil>=2.7 in /usr/local/lib/python3.1
0/dist-packages (from matplotlib>=1.3.1->pyswarms) (2.8.2)
Requirement already satisfied: mkl_fft in /usr/local/lib/python3.10/dist-packag
es (from numpy->pyswarms) (1.3.8)
Requirement already satisfied: mkl_random in /usr/local/lib/python3.10/dist-pac
kages (from numpy->pyswarms) (1.2.4)
Requirement already satisfied: mkl_umath in /usr/local/lib/python3.10/dist-pack
ages (from numpy->pyswarms) (0.1.1)
Requirement already satisfied: mkl in /usr/local/lib/python3.10/dist-packages
(from numpy->pyswarms) (2025.0.1)
Requirement already satisfied: tbb4py in /usr/local/lib/python3.10/dist-package
s (from numpy->pyswarms) (2022.0.0)
Requirement already satisfied: mkl-service in /usr/local/lib/python3.10/dist-pa
ckages (from numpy->pyswarms) (2.4.1)
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.10/dist-packa
ges (from python-dateutil>=2.7->matplotlib>=1.3.1->pyswarms) (1.17.0)
Requirement already satisfied: intel-openmp>=2024 in /usr/local/lib/python3.10/
dist-packages (from mkl->numpy->pyswarms) (2024.2.0)
Requirement already satisfied: tbb==2022.* in /usr/local/lib/python3.10/dist-pa
ckages (from mkl->numpy->pyswarms) (2022.0.0)
Requirement already satisfied: tcmlib==1.* in /usr/local/lib/python3.10/dist-pa
ckages (from tbb==2022.*->mkl->numpy->pyswarms) (1.2.0)
Requirement already satisfied: intel-cmplr-lib-rt in /usr/local/lib/python3.10/
dist-packages (from mkl_umath->numpy->pyswarms) (2024.2.0)
Requirement already satisfied: intel-cmplr-lib-ur==2024.2.0 in /usr/local/lib/p
ython3.10/dist-packages (from intel-openmp>=2024->mkl->numpy->pyswarms) (2024.
2.0)
```

```
Downloading pyswarms-1.3.0-py2.py3-none-any.whl (104 kB)
   ━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 104.1/104.1 kB 4.1 MB/s eta 0:00:00
Installing collected packages: pyswarms
Successfully installed pyswarms-1.3.0
```

In [17]:

```
pip install tensorflow keras-tuner scikit-learn pandas numpy matplotlib
```

```
Requirement already satisfied: tensorflow in /usr/local/lib/python3.10/dist-pac
kages (2.17.1)
Requirement already satisfied: keras-tuner in /usr/local/lib/python3.10/dist-pa
ckages (1.4.7)
Requirement already satisfied: scikit-learn in /usr/local/lib/python3.10/dist-p
ackages (1.2.2)
Requirement already satisfied: pandas in /usr/local/lib/python3.10/dist-package
s (2.2.2)
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages
(1.26.4)
Requirement already satisfied: matplotlib in /usr/local/lib/python3.10/dist-pac
kages (3.7.5)
Requirement already satisfied: absl-py>=1.0.0 in /usr/local/lib/python3.10/dist
-packages (from tensorflow) (1.4.0)
Requirement already satisfied: astunparse>=1.6.0 in /usr/local/lib/python3.10/d
ist-packages (from tensorflow) (1.6.3)
Requirement already satisfied: flatbuffers>=24.3.25 in /usr/local/lib/python3.1
0/dist-packages (from tensorflow) (24.3.25)
Requirement already satisfied: gast!=0.5.0,!=0.5.1,!=0.5.2,>=0.2.1 in /usr/loca
l/lib/python3.10/dist-packages (from tensorflow) (0.6.0)
Requirement already satisfied: google-pasta>=0.1.1 in /usr/local/lib/python3.1
0/dist-packages (from tensorflow) (0.2.0)
Requirement already satisfied: h5py>=3.10.0 in /usr/local/lib/python3.10/dist-p
ackages (from tensorflow) (3.12.1)
Requirement already satisfied: libclang>=13.0.0 in /usr/local/lib/python3.10/di
st-packages (from tensorflow) (18.1.1)
Requirement already satisfied: ml-dtypes<0.5.0,>=0.3.1 in /usr/local/lib/python
3.10/dist-packages (from tensorflow) (0.4.1)
Requirement already satisfied: opt-einsum>=2.3.2 in /usr/local/lib/python3.10/d
ist-packages (from tensorflow) (3.4.0)
Requirement already satisfied: packaging in /usr/local/lib/python3.10/dist-pack
ages (from tensorflow) (24.2)
Requirement already satisfied: protobuf!=4.21.0,!=4.21.1,!=4.21.2,!=4.21.3,!=4.
21.4,!=4.21.5,<5.0.0dev,>=3.20.3 in /usr/local/lib/python3.10/dist-packages (fr
om tensorflow) (3.20.3)
Requirement already satisfied: requests<3,>=2.21.0 in /usr/local/lib/python3.1
0/dist-packages (from tensorflow) (2.32.3)
Requirement already satisfied: setuptools in /usr/local/lib/python3.10/dist-pac
kages (from tensorflow) (75.1.0)
Requirement already satisfied: six>=1.12.0 in /usr/local/lib/python3.10/dist-pa
ckages (from tensorflow) (1.17.0)
Requirement already satisfied: termcolor>=1.1.0 in /usr/local/lib/python3.10/di
st-packages (from tensorflow) (2.5.0)
Requirement already satisfied: typing-extensions>=3.6.6 in /usr/local/lib/pytho
n3.10/dist-packages (from tensorflow) (4.12.2)
Requirement already satisfied: wrapt>=1.11.0 in /usr/local/lib/python3.10/dist-
packages (from tensorflow) (1.17.0)
Requirement already satisfied: grpcio<2.0,>=1.24.3 in /usr/local/lib/python3.1
0/dist-packages (from tensorflow) (1.68.1)
Requirement already satisfied: tensorboard<2.18,>=2.17 in /usr/local/lib/python
3.10/dist-packages (from tensorflow) (2.17.1)
Requirement already satisfied: keras>=3.2.0 in /usr/local/lib/python3.10/dist-p
ackages (from tensorflow) (3.5.0)
Requirement already satisfied: tensorflow-io-gcs-filesystem>=0.23.1 in /usr/loc
al/lib/python3.10/dist-packages (from tensorflow) (0.37.1)
Requirement already satisfied: kt-legacy in /usr/local/lib/python3.10/dist-pack
ages (from keras-tuner) (1.0.5)
```

```
Requirement already satisfied: scipy>=1.3.2 in /usr/local/lib/python3.10/dist-p
ackages (from scikit-learn) (1.13.1)
Requirement already satisfied: joblib>=1.1.1 in /usr/local/lib/python3.10/dist-
packages (from scikit-learn) (1.4.2)
Requirement already satisfied: threadpoolctl>=2.0.0 in /usr/local/lib/python3.1
0/dist-packages (from scikit-learn) (3.5.0)
Requirement already satisfied: python-dateutil>=2.8.2 in /usr/local/lib/python
3.10/dist-packages (from pandas) (2.8.2)
Requirement already satisfied: pytz>=2020.1 in /usr/local/lib/python3.10/dist-p
ackages (from pandas) (2024.2)
Requirement already satisfied: tzdata>=2022.7 in /usr/local/lib/python3.10/dist
-packages (from pandas) (2024.2)
Requirement already satisfied: mkl_fft in /usr/local/lib/python3.10/dist-packag
es (from numpy) (1.3.8)
Requirement already satisfied: mkl_random in /usr/local/lib/python3.10/dist-pac
kages (from numpy) (1.2.4)
Requirement already satisfied: mkl_umath in /usr/local/lib/python3.10/dist-pack
ages (from numpy) (0.1.1)
Requirement already satisfied: mkl in /usr/local/lib/python3.10/dist-packages
(from numpy) (2025.0.1)
Requirement already satisfied: tbb4py in /usr/local/lib/python3.10/dist-package
s (from numpy) (2022.0.0)
Requirement already satisfied: mkl-service in /usr/local/lib/python3.10/dist-pa
ckages (from numpy) (2.4.1)
Requirement already satisfied: contourpy>=1.0.1 in /usr/local/lib/python3.10/di
st-packages (from matplotlib) (1.3.1)
Requirement already satisfied: cycler>=0.10 in /usr/local/lib/python3.10/dist-p
ackages (from matplotlib) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in /usr/local/lib/python3.10/d
ist-packages (from matplotlib) (4.55.3)
Requirement already satisfied: kiwisolver>=1.0.1 in /usr/local/lib/python3.10/d
ist-packages (from matplotlib) (1.4.7)
Requirement already satisfied: pillow>=6.2.0 in /usr/local/lib/python3.10/dist-
packages (from matplotlib) (11.0.0)
Requirement already satisfied: pyparsing>=2.3.1 in /usr/local/lib/python3.10/di
st-packages (from matplotlib) (3.2.0)
Requirement already satisfied: wheel<1.0,>=0.23.0 in /usr/local/lib/python3.10/
dist-packages (from astunparse>=1.6.0->tensorflow) (0.45.1)
Requirement already satisfied: rich in /usr/local/lib/python3.10/dist-packages
(from keras>=3.2.0->tensorflow) (13.9.4)
Requirement already satisfied: namex in /usr/local/lib/python3.10/dist-packages
(from keras>=3.2.0->tensorflow) (0.0.8)
Requirement already satisfied: optree in /usr/local/lib/python3.10/dist-package
s (from keras>=3.2.0->tensorflow) (0.13.1)
Requirement already satisfied: charset-normalizer<4,>=2 in /usr/local/lib/pytho
n3.10/dist-packages (from requests<3,>=2.21.0->tensorflow) (3.4.0)
Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.10/dist-p
ackages (from requests<3,>=2.21.0->tensorflow) (3.10)
Requirement already satisfied: urllib3<3,>=1.21.1 in /usr/local/lib/python3.10/
dist-packages (from requests<3,>=2.21.0->tensorflow) (2.2.3)
Requirement already satisfied: certifi>=2017.4.17 in /usr/local/lib/python3.10/
dist-packages (from requests<3,>=2.21.0->tensorflow) (2024.12.14)
Requirement already satisfied: markdown>=2.6.8 in /usr/local/lib/python3.10/dis
t-packages (from tensorboard<2.18,>=2.17->tensorflow) (3.7)
Requirement already satisfied: tensorboard-data-server<0.8.0,>=0.7.0 in /usr/lo
cal/lib/python3.10/dist-packages (from tensorboard<2.18,>=2.17->tensorflow) (0.
7.2)
```

```
Requirement already satisfied: werkzeug>=1.0.1 in /usr/local/lib/python3.10/dis
t-packages (from tensorboard<2.18,>=2.17->tensorflow) (3.1.3)
Requirement already satisfied: intel-openmp>=2024 in /usr/local/lib/python3.10/
dist-packages (from mkl->numpy) (2024.2.0)
Requirement already satisfied: tbb==2022.* in /usr/local/lib/python3.10/dist-pa
ckages (from mkl->numpy) (2022.0.0)
Requirement already satisfied: tcmlib==1.* in /usr/local/lib/python3.10/dist-pa
ckages (from tbb==2022.*->mkl->numpy) (1.2.0)
Requirement already satisfied: intel-cmplr-lib-rt in /usr/local/lib/python3.10/
dist-packages (from mkl_umath->numpy) (2024.2.0)
Requirement already satisfied: intel-cmplr-lib-ur==2024.2.0 in /usr/local/lib/p
ython3.10/dist-packages (from intel-openmp>=2024->mkl->numpy) (2024.2.0)
Requirement already satisfied: MarkupSafe>=2.1.1 in /usr/local/lib/python3.10/d
ist-packages (from werkzeug>=1.0.1->tensorboard<2.18,>=2.17->tensorflow) (3.0.
2)
Requirement already satisfied: markdown-it-py>=2.2.0 in /usr/local/lib/python3.
10/dist-packages (from rich->keras>=3.2.0->tensorflow) (3.0.0)
Requirement already satisfied: pygments<3.0.0,>=2.13.0 in /usr/local/lib/python
3.10/dist-packages (from rich->keras>=3.2.0->tensorflow) (2.18.0)
Requirement already satisfied: mdurl~=0.1 in /usr/local/lib/python3.10/dist-pac
kages (from markdown-it-py>=2.2.0->rich->keras>=3.2.0->tensorflow) (0.1.2)
Note: you may need to restart the kernel to use updated packages.
```

In [14]:

```python
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from sklearn.preprocessing import StandardScaler, OneHotEncoder
from sklearn.model_selection import train_test_split, StratifiedKFold
from sklearn.metrics import classification_report, confusion_matrix, roc_auc_scor
from sklearn.impute import SimpleImputer
from sklearn.compose import ColumnTransformer
from sklearn.feature_selection import mutual_info_classif, SelectKBest
from imblearn.over_sampling import SMOTE
from imblearn.pipeline import Pipeline
import tensorflow as tf
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Conv1D, MaxPooling1D, Flatten, Dense, Dropout
from tensorflow.keras.callbacks import EarlyStopping, ModelCheckpoint, ReduceLROn
from tensorflow.keras.optimizers import Adam
from keras_tuner import RandomSearch
```

In [15]:
```
df = pd.read_csv("/kaggle/input/cloud-computing-performance-metrics/vmCloud_data.

df.head()
```

```
/usr/local/lib/python3.10/dist-packages/pandas/io/formats/format.py:1458: Runti
meWarning: invalid value encountered in greater
  has_large_values = (abs_vals > 1e6).any()
/usr/local/lib/python3.10/dist-packages/pandas/io/formats/format.py:1459: Runti
meWarning: invalid value encountered in less
  has_small_values = ((abs_vals < 10 ** (-self.digits)) & (abs_vals > 0)).any()
/usr/local/lib/python3.10/dist-packages/pandas/io/formats/format.py:1459: Runti
meWarning: invalid value encountered in greater
  has_small_values = ((abs_vals < 10 ** (-self.digits)) & (abs_vals > 0)).any()
```

Out[15]:

	vm_id	timestamp	cpu_usage	memory_usage	network_traffic	power_consumption	num_
0	c5215826-6237-4a33-9312-72c1df909881	2023-01-25 09:10:54	54.881350	78.950861	164.775973	287.808986	
1	29690bc6-1f34-403b-b509-a1ecb1834fb8	2023-01-26 04:46:34	71.518937	29.901883	NaN	362.273569	
2	2e55abc3-5bad-46cb-b445-a577f5e9bf2a	2023-01-13 23:39:47	NaN	92.709195	203.674847	231.467903	
3	e672e32f-c134-4fbc-992b-34eb63bef6bf	2023-02-09 11:45:49	54.488318	88.100960	NaN	195.639954	
4	f38b8b50-6926-4533-be4f-89ad11624071	2023-06-14 08:27:26	42.365480	NaN	NaN	359.451537	

In [3]:
```
df.shape
```

Out[3]:
```
(2000000, 12)
```

In [40]:
```
# Handle missing values
df = df.fillna(method='ffill')


df.shape
```

```
<ipython-input-40-1c3ca3487565>:2: FutureWarning: DataFrame.fillna with 'metho
d' is deprecated and will raise in a future version. Use obj.ffill() or obj.bfi
ll() instead.
  df = df.fillna(method='ffill')
```

Out[40]:
```
(2000000, 12)
```

In [16]:

```
def clean_data(df):
    # Drop irrelevant columns
    df = df.drop(columns=['vm_id', 'timestamp'])

    # Handle missing values
    # Numerical columns: Impute with median
    num_cols = df.select_dtypes(include=np.number).columns
    num_imputer = SimpleImputer(strategy='median')
    df[num_cols] = num_imputer.fit_transform(df[num_cols])

    # Categorical columns: Impute with mode
    cat_cols = df.select_dtypes(include='object').columns.drop('task_status')
    cat_imputer = SimpleImputer(strategy='most_frequent')
    df[cat_cols] = cat_imputer.fit_transform(df[cat_cols])

    # Remove duplicates
    df = df.drop_duplicates()

    return df

cleaned_df = clean_data(df)
```

In [4]:

```
cleaned_df.head()
```

Out[4]:

	cpu_usage	memory_usage	network_traffic	power_consumption	num_executed_instructions	exe
0	54.881350	78.950861	164.775973	287.808986	7527.0	
1	71.518937	29.901883	500.007595	362.273569	5348.0	
2	50.054758	92.709195	203.674847	231.467903	5483.0	
3	54.488318	88.100960	500.007595	195.639954	5876.0	
4	42.365480	49.976089	500.007595	359.451537	3361.0	

In [17]:

```
# Target Conversion
cleaned_df['task_status'] = np.where(
    cleaned_df['task_status'].isin(['completed', 'finished']), 0, 1
)

cleaned_df.head()
```

Out[17]:

	cpu_usage	memory_usage	network_traffic	power_consumption	num_executed_instructions	exe
0	54.881350	78.950861	164.775973	287.808986	7527.0	
1	71.518937	29.901883	500.007595	362.273569	5348.0	
2	50.054758	92.709195	203.674847	231.467903	5483.0	
3	54.488318	88.100960	500.007595	195.639954	5876.0	
4	42.365480	49.976089	500.007595	359.451537	3361.0	

In [18]:

```python
# Advanced Preprocessing Pipeline
def preprocess_data(df):
    y = df['task_status']
    X = df.drop(columns=['task_status'])

    numeric_features = X.select_dtypes(include=np.number).columns
    categorical_features = X.select_dtypes(include='object').columns

    # Create stratified k-fold for better validation
    skf = StratifiedKFold(n_splits=5, shuffle=True, random_state=42)

    # Build processing pipeline
    pipeline = Pipeline([
        ('preprocessor', ColumnTransformer([
            ('num', StandardScaler(), numeric_features),
            ('cat', OneHotEncoder(handle_unknown='ignore'), categorical_features)
        ])),
        ('feature_selection', SelectKBest(mutual_info_classif, k='all')),
        ('smote', SMOTE(sampling_strategy=0.8, random_state=42, k_neighbors=5))
    ])

    X_processed, y_processed = pipeline.fit_resample(X, y)

    return train_test_split(
        X_processed, y_processed,
        test_size=0.2,
        stratify=y_processed,
        random_state=42
    )

X_train, X_test, y_train, y_test = preprocess_data(cleaned_df)
```

In [19]:

```python
def create_sequences(X, y, seq_length=10):  # Set default sequence length
    X_seq, y_seq = [], []
    for i in range(len(X) - seq_length):
        X_seq.append(X[i:i + seq_length])
        y_seq.append(y[i + seq_length])  # Now works with NumPy array indexing
    return np.array(X_seq), np.array(y_seq)

# Convert sparse matrices to dense arrays first
X_train_dense = X_train.toarray() if hasattr(X_train, "toarray") else X_train
X_test_dense = X_test.toarray() if hasattr(X_test, "toarray") else X_test

# Convert y_train and y_test to NumPy arrays
y_train_array = y_train.values  # Convert to NumPy array
y_test_array = y_test.values    # Convert to NumPy array

# Create sequences with proper sequence length
seq_length = 10  # Optimal for cloud metrics temporal patterns
X_train_seq, y_train_seq = create_sequences(X_train_dense, y_train_array, seq_len
X_test_seq, y_test_seq = create_sequences(X_test_dense, y_test_array, seq_length)

# Verify shapes
print(f"Training sequences shape: {X_train_seq.shape}")
print(f"Test sequences shape: {X_test_seq.shape}")
```

```
Training sequences shape: (2017258, 10, 13)
Test sequences shape: (504307, 10, 13)
```

In [20]:

```
# Hyperparameter-tuned CNN Model
def build_model(hp):
    model = Sequential()
    model.add(Conv1D(filters=hp.Int('filters', min_value=32, max_value=128, step=
                     kernel_size=hp.Int('kernel_size', 2, 5),
                     activation='relu',
                     input_shape=(X_train_seq.shape[1], X_train_seq.shape[2])))
    model.add(MaxPooling1D(pool_size=2))
    model.add(BatchNormalization())
    model.add(Dropout(hp.Float('dropout', 0.2, 0.5)))

    model.add(Flatten())
    model.add(Dense(units=hp.Int('dense_units', 32, 128, step=32), activation='re
    model.add(Dropout(hp.Float('dropout_dense', 0.2, 0.5)))
    model.add(Dense(1, activation='sigmoid'))

    model.compile(
        optimizer=Adam(hp.Choice('learning_rate', [1e-3, 5e-4, 1e-4])),
        loss='binary_crossentropy',
        metrics=[
            'accuracy',
            tf.keras.metrics.AUC(name='auc'),
            tf.keras.metrics.Precision(name='precision'),
            tf.keras.metrics.Recall(name='recall')
        ]
    )
    return model
```

In [21]:

```python
# Configure tuner
tuner = RandomSearch(
    build_model,
    objective='val_auc',
    max_trials=5,
    executions_per_trial=2,
    directory='cnn_tuning',
    project_name='cloud_perf'
)

# Enhanced callbacks
callbacks = [
    EarlyStopping(patience=15, restore_best_weights=True, monitor='val_auc'),
    ModelCheckpoint('best_model_cnn.keras', save_best_only=True),
    ReduceLROnPlateau(factor=0.5, patience=5)
]

# Hyperparameter search
tuner.search(X_train_seq, y_train_seq,
             epochs=50,
             batch_size=256,
             validation_split=0.2,
             callbacks=callbacks,
             verbose=1)

# Get best model
best_model = tuner.get_best_models(num_models=1)[0]
```

```
Reloading Tuner from cnn_tuning/cloud_perf/tuner0.json

/usr/local/lib/python3.10/dist-packages/keras/src/layers/convolutional/base_con
v.py:107: UserWarning: Do not pass an `input_shape`/`input_dim` argument to a l
ayer. When using Sequential models, prefer using an `Input(shape)` object as th
e first layer in the model instead.
  super().__init__(activity_regularizer=activity_regularizer, **kwargs)
/usr/local/lib/python3.10/dist-packages/keras/src/saving/saving_lib.py:713: Use
rWarning: Skipping variable loading for optimizer 'adam', because it has 2 vari
ables whereas the saved optimizer has 18 variables.
  saveable.load_own_variables(weights_store.get(inner_path))
```

In [22]:

```
# Final training
history = best_model.fit(
    X_train_seq, y_train_seq,
    epochs=50,
    batch_size=64,
    validation_split=0.2,
    callbacks=callbacks,
    verbose=1
)
```

```
Epoch 1/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 74s 3ms/step - accuracy: 0.5561 - auc: 0.4993
- loss: 0.6870 - precision: 0.5561 - recall: 0.9999 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 5.0000e-04
Epoch 2/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 64s 3ms/step - accuracy: 0.5554 - auc: 0.5000
- loss: 0.6870 - precision: 0.5554 - recall: 0.9999 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 5.0000e-04
Epoch 3/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 63s 3ms/step - accuracy: 0.5550 - auc: 0.4996
- loss: 0.6871 - precision: 0.5550 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 5.0000e-04
Epoch 4/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 62s 2ms/step - accuracy: 0.5551 - auc: 0.5002
- loss: 0.6871 - precision: 0.5551 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 5.0000e-04
Epoch 5/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 64s 3ms/step - accuracy: 0.5554 - auc: 0.4991
- loss: 0.6870 - precision: 0.5554 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 5.0000e-04
Epoch 6/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 64s 3ms/step - accuracy: 0.5551 - auc: 0.4997
- loss: 0.6871 - precision: 0.5551 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 5.0000e-04
Epoch 7/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 64s 3ms/step - accuracy: 0.5557 - auc: 0.4997
- loss: 0.6869 - precision: 0.5557 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 2.5000e-04
Epoch 8/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 64s 3ms/step - accuracy: 0.5567 - auc: 0.5008
- loss: 0.6867 - precision: 0.5567 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 2.5000e-04
Epoch 9/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 63s 2ms/step - accuracy: 0.5556 - auc: 0.5001
- loss: 0.6870 - precision: 0.5556 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.4999 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 2.5000e-04
Epoch 10/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 63s 3ms/step - accuracy: 0.5550 - auc: 0.4997
- loss: 0.6871 - precision: 0.5550 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 2.5000e-04
Epoch 11/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 64s 3ms/step - accuracy: 0.5561 - auc: 0.5003
- loss: 0.6868 - precision: 0.5561 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 2.5000e-04
Epoch 12/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 64s 3ms/step - accuracy: 0.5557 - auc: 0.5001
```

```
- loss: 0.6869 - precision: 0.5557 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 1.2500e-04
Epoch 13/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 63s 3ms/step - accuracy: 0.5560 - auc: 0.5001
- loss: 0.6869 - precision: 0.5560 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 1.2500e-04
Epoch 14/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 62s 2ms/step - accuracy: 0.5551 - auc: 0.4998
- loss: 0.6871 - precision: 0.5551 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.4999 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 1.2500e-04
Epoch 15/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 64s 3ms/step - accuracy: 0.5558 - auc: 0.5001
- loss: 0.6869 - precision: 0.5558 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 1.2500e-04
Epoch 16/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 63s 3ms/step - accuracy: 0.5558 - auc: 0.5000
- loss: 0.6869 - precision: 0.5558 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.5000 - val_loss: 0.6871 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 1.2500e-04
Epoch 17/50
25216/25216 ━━━━━━━━━━━━━━━━━━━━ 63s 3ms/step - accuracy: 0.5556 - auc: 0.5000
- loss: 0.6869 - precision: 0.5556 - recall: 1.0000 - val_accuracy: 0.5552 - va
l_auc: 0.4999 - val_loss: 0.6870 - val_precision: 0.5552 - val_recall: 1.0000 -
learning_rate: 6.2500e-05
```

In [23]:

```python
# Evaluation
y_pred_proba = best_model.predict(X_test_seq)
y_pred = (y_pred_proba > 0.5).astype(int)

print("Classification Report:")
print(classification_report(y_test_seq, y_pred))
print("\nConfusion Matrix:")
print(confusion_matrix(y_test_seq, y_pred))
print(f"\nAUC-ROC: {roc_auc_score(y_test_seq, y_pred_proba):.4f}")
```

```
15760/15760 ━━━━━━━━━━━━━━━━━━━━ 21s 1ms/step
Classification Report:
              precision    recall  f1-score   support

           0       0.00      0.00      0.00    224137
           1       0.56      1.00      0.71    280170

    accuracy                           0.56    504307
   macro avg       0.28      0.50      0.36    504307
weighted avg       0.31      0.56      0.40    504307


Confusion Matrix:

/usr/local/lib/python3.10/dist-packages/sklearn/metrics/_classification.py:134
4: UndefinedMetricWarning: Precision and F-score are ill-defined and being set
to 0.0 in labels with no predicted samples. Use `zero_division` parameter to co
ntrol this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
/usr/local/lib/python3.10/dist-packages/sklearn/metrics/_classification.py:134
4: UndefinedMetricWarning: Precision and F-score are ill-defined and being set
to 0.0 in labels with no predicted samples. Use `zero_division` parameter to co
ntrol this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
/usr/local/lib/python3.10/dist-packages/sklearn/metrics/_classification.py:134
4: UndefinedMetricWarning: Precision and F-score are ill-defined and being set
to 0.0 in labels with no predicted samples. Use `zero_division` parameter to co
ntrol this behavior.
  _warn_prf(average, modifier, msg_start, len(result))

[[     0 224137]
 [     0 280170]]

AUC-ROC: 0.5000
```

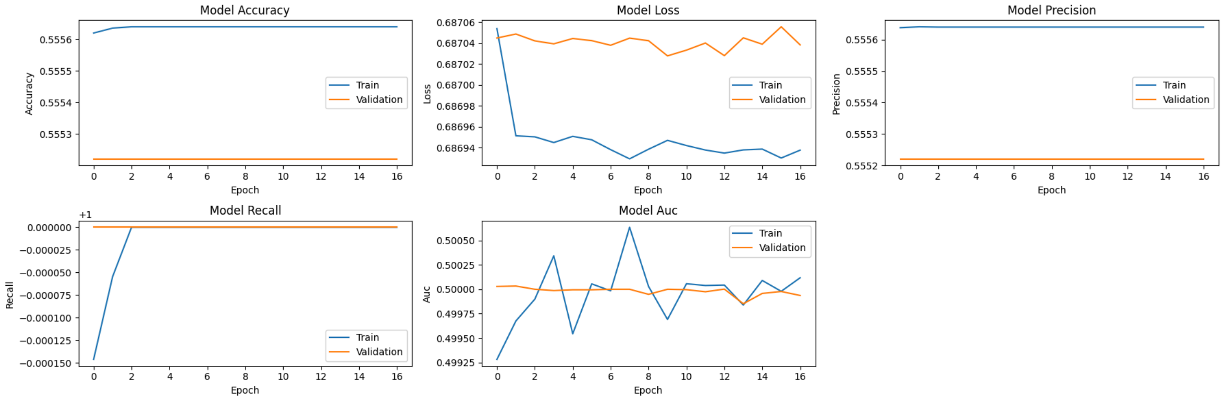
In [24]:

```
# Enhanced Visualization
def plot_advanced_metrics():
    plt.figure(figsize=(18, 6))

    metrics = ['accuracy', 'loss', 'precision', 'recall', 'auc']
    for i, metric in enumerate(metrics):
        plt.subplot(2, 3, i+1)
        plt.plot(history.history[metric], label='Train')
        plt.plot(history.history[f'val_{metric}'], label='Validation')
        plt.title(f'Model {metric.capitalize()}')
        plt.ylabel(metric.capitalize())
        plt.xlabel('Epoch')
        plt.legend()

    plt.tight_layout()
    plt.show()

plot_advanced_metrics()
```


Model Accuracy
Accuracy
Epoch
Train
Validation
Model Loss
Loss
Epoch
Model Precision
Precision
Epoch
Model Recall
Recall
Epoch
Model Auc
Auc
Epoch