



CDW Documentation

Github ML Pipeline

Github ML Pipeline

Github repository structure

[screenshot_2025-08-08_at_10.37.34 am](#)

mlops-pipeline.yml

```
name: MLOps CI/CD Pipeline

on:
  push:
    branches: [ main ]
  pull_request:
    branches: [ main ]

env:
  AZURE_ML_WORKSPACE: ${ secrets.AZURE_ML_WORKSPACE }
  AZURE_RESOURCE_GROUP: ${ secrets.AZURE_RESOURCE_GROUP }
  AZURE_SUBSCRIPTION_ID: ${ secrets.AZURE_SUBSCRIPTION_ID }
  MODEL_NAME: "customer-churn-model"
  ENDPOINT_NAME: "churn-prediction-endpoint"

permissions:
  id-token: write
  contents: read

jobs:
  unit-tests:
    runs-on: ubuntu-latest
    steps:
      - name: Checkout code
        uses: actions/checkout@v4

      - name: Set up Python
        uses: actions/setup-python@v4
        with:
          python-version: '3.9'

      - name: Install dependencies
        run: |
          python -m pip install --upgrade pip
          pip install -r requirements.txt
          pip install pytest pytest-cov flake8

      - name: Run linting
```

```
    run: |
      flake8 src/ --count --select=E9,F63,F7,F82 --show-source --
statistics
      flake8 src/ --count --exit-zero --max-complexity=10 --max-line-
length=127 --statistics

- name: Run unit tests
  run: |
    pytest tests/ -v --cov=src --cov-report=xml --cov-report=term-
missing

- name: Upload coverage reports
  uses: codecov/codecov-action@v3
  with:
    file: ./coverage.xml
    flags: unittests

build-and-train:
  needs: unit-tests
  runs-on: ubuntu-latest
  if: github.event_name == 'push' && github.ref == 'refs/heads/main'
  steps:
    - name: Checkout code
      uses: actions/checkout@v4

    - name: Set up Python
      uses: actions/setup-python@v4
      with:
        python-version: '3.9'

    - name: Install Azure CLI and ML extension
      run: |
        curl -sL https://aka.ms/InstallAzureCLIDeb | sudo bash
        az extension add -n ml

    - name: Azure Login
      uses: azure/login@v2
      with:
        client-id: ${ secrets.AZURE_CLIENT_ID }
        tenant-id: ${ secrets.AZURE_TENANT_ID }
        subscription-id: ${ secrets.AZURE_SUBSCRIPTION_ID }
# auth-type: OIDC is implied in v2 when no client-secret is provided

    - name: Install dependencies
      run: |
        python -m pip install --upgrade pip
        pip install -r requirements.txt

    - name: Set Azure ML workspace
      run: |
        az configure --defaults group=$AZURE_RESOURCE_GROUP
workspace=$AZURE_ML_WORKSPACE
```

```

- name: Create compute cluster if not exists
  run: |
    az ml compute create --name cpu-cluster --type amlcompute --min-
instances 0 --max-instances 4 --size Standard_DS3_v2 || true

- name: Submit training job
  id: training
  run: |
    RUN_ID=$(az ml job create --file ml/training-job.yml --query name -o
tsv)
    echo "run_id=$RUN_ID" >> $GITHUB_OUTPUT
    echo "Training job submitted with ID: $RUN_ID"
    # Wait for job completion with timeout
    timeout 1800 az ml job stream --name $RUN_ID || {
      echo "Training job timed out or failed"
      az ml job show --name $RUN_ID --query status
      exit 1
    }

- name: Get training metrics
  run: |
    az ml job show --name ${ steps.training.outputs.run_id } --query
tags

- name: Debug job outputs
  run: |
    echo "Checking job outputs..."
    az ml job show --name ${ steps.training.outputs.run_id } --query
outputs
    echo "Listing job artifacts..."
    az ml job download --name ${ steps.training.outputs.run_id } --
output-name model_output --download-path ./debug_model --all || echo
"Download failed, checking alternative paths"

- name: Debug job outputs and register model
  id: register
  run: |
    echo "=== Debugging Job Outputs ==="
    JOB_ID=${ steps.training.outputs.run_id }
    echo "Job ID: $JOB_ID"
    # Check job details
    echo "Job details:"
    az ml job show --name $JOB_ID --query "{status: status, outputs:
outputs}" -o json
    # List all outputs
    echo "Available outputs:"
    az ml job show --name $JOB_ID --query "outputs" -o json
    # Check if there's a model_output
    echo "Checking model_output specifically:"
    az ml job show --name $JOB_ID --query "outputs.model_output" -o json
|| echo "model_output not found"

```

```

# Get MLflow run ID if available
echo "Getting MLflow run ID:"
MLFLOW_RUN_ID=$(az ml job show --name $JOB_ID --query
"properties.mlflow.runId" -o tsv 2>/dev/null || echo "not_found")
echo "MLflow Run ID: $MLFLOW_RUN_ID"
# Try to register model with correct path
echo "=== Attempting Model Registration ==="
if [ "$MLFLOW_RUN_ID" != "not_found" ] && [ ! -z "$MLFLOW_RUN_ID" ];
then
    echo "Trying MLflow run path..."
    MODEL_VERSION=$(az ml model create \
        --name $MODEL_NAME \
        --path "runs:$MLFLOW_RUN_ID/model" \
        --type mlflow_model \
        --description "Customer churn prediction model trained via
GitHub Actions" \
        --query version -o tsv 2>/dev/null || echo "mlflow_failed")
    else
        MODEL_VERSION="mlflow_failed"
    fi
    if [ "$MODEL_VERSION" = "mlflow_failed" ] || [ -z "$MODEL_VERSION"
]; then
        echo "MLflow path failed, trying job output path..."
        MODEL_VERSION=$(az ml model create \
            --name $MODEL_NAME \
            --path "azureml://jobs/$JOB_ID/outputs/model_output" \
            --type mlflow_model \
            --description "Customer churn prediction model trained via
GitHub Actions" \
            --query version -o tsv 2>/dev/null || echo "job_output_failed")
        fi
        if [ "$MODEL_VERSION" = "job_output_failed" ] || [ -z
"$MODEL_VERSION" ]; then
            echo "Job output path failed, checking what files actually
exist..."
            # Try to download and check the structure
            mkdir -p ./debug_download
            az ml job download --name $JOB_ID --download-path ./debug_download
--all || echo "Download failed"
            echo "Downloaded structure:"
            find ./debug_download -type f -name "*.pkl" -o -name "MLmodel" -o
-name "*.json" | head -20
            # Look for any MLmodel files which indicate MLflow model format
            MLMODEL_PATH=$(find ./debug_download -name "MLmodel" | head -1)
            if [ ! -z "$MLMODEL_PATH" ]; then
                MODEL_DIR=$(dirname "$MLMODEL_PATH")
                RELATIVE_PATH=${MODEL_DIR#./debug_download/}
                echo "Found MLmodel at: $MLMODEL_PATH"
                echo "Relative path: $RELATIVE_PATH"
                # Try registering with the discovered path
                MODEL_VERSION=$(az ml model create \

```

```

        --name $MODEL_NAME \
        --path "azureml://jobs/$JOB_ID/outputs/$RELATIVE_PATH" \
        --type mlflow_model \
        --description "Customer churn prediction model trained via
GitHub Actions" \
        --query version -o tsv)
    else
        echo "No MLmodel file found. Available files:"
        find ./debug_download -type f | head -20
        exit 1
    fi
fi
if [ ! -z "$MODEL_VERSION" ] && [ "$MODEL_VERSION" !=
"mlflow_failed" ] && [ "$MODEL_VERSION" != "job_output_failed" ]; then
    echo "model_version=$MODEL_VERSION" >> $GITHUB_OUTPUT
    echo "Model successfully registered with version: $MODEL_VERSION"
else
    echo "Failed to register model after all attempts"
    exit 1
fi
- name: Create/Update Online Endpoint
run: |
    # Check if endpoint exists
    if az ml online-endpoint show --name $ENDPOINT_NAME &>/dev/null;
then
        echo "Endpoint $ENDPOINT_NAME already exists"
    else
        echo "Creating new endpoint $ENDPOINT_NAME"
        az ml online-endpoint create --file ml/endpoint.yml --name
$ENDPOINT_NAME
    fi

- name: Deploy model to endpoint
run: |
    # Create deployment configuration
    cat > deployment.yml << EOF
    \${schema:
https://azuremlschemas.azureedge.net/latest/managedOnlineDeployment.schema.j
son
    name: blue
    endpoint_name: $ENDPOINT_NAME
    model: azureml:$MODEL_NAME:${{ steps.register.outputs.model_version
}}
    instance_type: Standard_DS3_v2
    instance_count: 1
    environment_variables:
        MLFLOW_MODEL_DIRECTORY: /var/azureml-app/azureml-models/model/1
    request_settings:
        request_timeout_ms: 90000
        max_concurrent_requests_per_instance: 1
    liveness_probe:

```

```
    initial_delay: 10
    period: 10
    timeout: 2
    success_threshold: 1
    failure_threshold: 30
  readiness_probe:
    initial_delay: 10
    period: 10
    timeout: 2
    success_threshold: 1
    failure_threshold: 3
  EOF
  az ml online-deployment create --file deployment.yml --all-traffic

- name: Test endpoint
  run: |
    az ml online-endpoint invoke --name $ENDPOINT_NAME --request-file
ml/sample-request.json

- name: Send custom metrics to Azure Monitor
  run: |
    # Send custom metrics about the deployment
    az monitor metrics send \
      --resource
"/subscriptions/$AZURE_SUBSCRIPTION_ID/resourceGroups/$AZURE_RESOURCE_GROUP/
providers/Microsoft.MachineLearningServices/workspaces/$AZURE_ML_WORKSPACE"
\
      --metric-name "ModelDeploymentSuccess" \
      --metric-value 1 \
      --metric-timestamp $(date -u +"%Y-%m-%dT%H:%M:%SZ") || true

- name: Create Application Insights alert
  run: |
    # Create alert rule for endpoint failures
    az monitor metrics alert create \
      --name "MLEndpointFailureAlert" \
      --resource-group $AZURE_RESOURCE_GROUP \
      --condition "avg requests/failed > 5" \
      --window-size 5m \
      --evaluation-frequency 1m \
      --severity 2 \
      --description "Alert when ML endpoint has more than 5 failed
requests" \
      --scopes
"/subscriptions/$AZURE_SUBSCRIPTION_ID/resourceGroups/$AZURE_RESOURCE_GROUP/
providers/Microsoft.MachineLearningServices/workspaces/$AZURE_ML_WORKSPACE/o
nlineEndpoints/$ENDPOINT_NAME" || true

  notify-on-failure:
    runs-on: ubuntu-latest
    needs: [unit-tests, build-and-train]
```

```
  if: failure()
  steps:
  - name: Notify on pipeline failure
    uses: 8398a7/action-slack@v3
    with:
      status: failure
      channel: '#mlops-alerts'
      webhook_url: ${ secrets.SLACK_WEBHOOK }
    env:
      SLACK_WEBHOOK_URL: ${ secrets.SLACK_WEBHOOK }

  - name: Create GitHub issue on failure
    if: github.event_name == 'push'
    uses: actions/github-script@v6
    with:
      script: |
        github.rest.issues.create({
          owner: context.repo.owner,
          repo: context.repo.repo,
          title: `MLOps Pipeline Failed - ${context.sha.substring(0, 7)}`,
          body: `The MLOps pipeline failed for commit
        ${context.sha}.\n\nWorkflow: ${context.workflow}\nRun:
        ${context.runNumber}\n\nPlease investigate the failure.`
          labels: ['mlops', 'pipeline-failure', 'bug']
        })

security-scan:
  runs-on: ubuntu-latest
  steps:
  - name: Checkout code
    uses: actions/checkout@v4

  - name: Run Trivy vulnerability scanner
    uses: aquasecurity/trivy-action@master
    with:
      scan-type: 'fs'
      scan-ref: '.'
      format: 'sarif'
      output: 'trivy-results.sarif'

  - name: Upload Trivy scan results
    uses: github/codeql-action/upload-sarif@v2
    with:
      sarif_file: 'trivy-results.sarif'
```

endpoint.yml

```
$schema:
  https://azuremlschemas.azureedge.net/latest/managedOnlineEndpoint.schema.json
```

```
n
name: churn-prediction-endpoint
description: Endpoint for customer churn prediction
auth_mode: key

tags:
  model: customer-churn-model
  environment: production
```

environment.yml

```
# ml/environment.yml
name: ml-environment
dependencies:
  - python=3.9
  - pip
  - pip:
    - scikit-learn==1.3.0
    - pandas==2.0.3
    - numpy==1.24.3
    - mlflow==2.5.0
    - azure-ai-ml==1.8.0
    - joblib==1.3.1
```

sample-request.json

```
{
  "input_data": {
    "columns": [
      "Account Length", "Area Code", "VMail Message", "Day Mins", "Day
Calls",
      "Day Charge", "Eve Mins", "Eve Calls", "Eve Charge", "Night Mins",
      "Night Calls", "Night Charge", "Intl Mins", "Intl Calls", "Intl
Charge",
      "CustServ Calls", "State", "Int'l Plan", "VMail Plan",
      "Avg_Day_Call_Duration", "Avg_Eve_Call_Duration",
      "Avg_Night_Call_Duration",
      "Total_Charges", "Total_Usage_Mins"
    ],
    "index": [0],
    "data": [
      [142, 408, 28, 180.5, 95, 30.69, 210.2, 88, 17.87, 201.9, 82, 9.09,
      8.5, 4, 2.30, 2, 5, 0, 1, 1.9, 2.4, 2.5, 59.95, 601.1]
    ]
  }
}
```

== training-job.yml ==

```
# ml/training-job.yml
$schema: https://azuremlschemas.azureedge.net/latest/commandJob.schema.json
type: command

display_name: Customer Churn Model Training
description: Training job for customer churn prediction model

experiment_name: customer-churn-experiment

compute: azureml:cpu-cluster

environment: azureml:AzureML-sklearn-1.0-ubuntu20.04-py38-cpu@latest

code: ../src

command: >
  python train.py
  --data_path ${inputs.training_data}
  --model_output ${outputs.model_output}
  --test_size 0.2
  --random_state 42

inputs:
  training_data:
    type: uri_file
    path:
https://raw.githubusercontent.com/albayraktaroglu/Datasets/master/churn.csv

outputs:
  model_output:
    type: uri_folder
    mode: rw_mount

environment_variables:
  MLFLOW_TRACKING_URI: "azureml://experiments/customer-churn-experiment"

tags:
  model_type: "classification"
  framework: "scikit-learn"
  training_method: "automated"
```

train.py

```
# src/train.py
import argparse
import os
import pandas as pd
import numpy as np
import mlflow
```

```
import mlflow.sklearn
import joblib
from sklearn.model_selection import train_test_split
from sklearn.ensemble import RandomForestClassifier
from sklearn.preprocessing import LabelEncoder, StandardScaler
from sklearn.metrics import accuracy_score, precision_score, recall_score,
f1_score, roc_auc_score
from sklearn.pipeline import Pipeline
import logging

# Configure logging
logging.basicConfig(level=logging.INFO)
logger = logging.getLogger(__name__)

def parse_args():
    parser = argparse.ArgumentParser(description="Train customer churn
model")
    parser.add_argument("--data_path", type=str, required=True, help="Path
to training data")
    parser.add_argument("--model_output", type=str, required=True,
help="Path to save model")
    parser.add_argument("--test_size", type=float, default=0.2, help="Test
set size")
    parser.add_argument("--random_state", type=int, default=42, help="Random
state")
    parser.add_argument("--n_estimators", type=int, default=100,
help="Number of trees")
    parser.add_argument("--max_depth", type=int, default=10, help="Maximum
depth")
    return parser.parse_args()

def load_and_preprocess_data(data_path):
    """Load and preprocess the customer churn data"""
    logger.info(f"Loading data from {data_path}")
    # For demo purposes, creating sample data if file doesn't exist
    if not os.path.exists(data_path):
        logger.info("Creating sample data for demonstration")
        np.random.seed(42)
        n_samples = 10000
        data = {
            'CreditScore': np.random.randint(350, 850, n_samples),
            'Geography': np.random.choice(['France', 'Spain', 'Germany'],
n_samples),
            'Gender': np.random.choice(['Male', 'Female'], n_samples),
            'Age': np.random.randint(18, 92, n_samples),
            'Tenure': np.random.randint(0, 10, n_samples),
            'Balance': np.random.uniform(0, 250000, n_samples),
            'NumOfProducts': np.random.randint(1, 4, n_samples),
            'HasCrCard': np.random.choice([0, 1], n_samples),
            'IsActiveMember': np.random.choice([0, 1], n_samples),
            'EstimatedSalary': np.random.uniform(0, 200000, n_samples),
```

```
    }
    # Create target with some logic
    df = pd.DataFrame(data)
    churn_prob = (
        0.1 +
        0.3 * (df['Age'] > 50).astype(int) +
        0.2 * (df['NumOfProducts'] == 1).astype(int) +
        0.15 * (df['IsActiveMember'] == 0).astype(int) +
        0.1 * (df['Balance'] == 0).astype(int)
    )
    df['Exited'] = np.random.binomial(1, churn_prob)
else:
    df = pd.read_csv(data_path)
    logger.info(f"Data shape: {df.shape}")
    logger.info(f"Column names: {list(df.columns)}")
    # Handle different target column names
    if 'Churn?' in df.columns:
        # Convert Churn? to binary Exited column
        df['Exited'] = (df['Churn?'] == 'True.').astype(int)
        logger.info(f"Churn rate: {df['Exited'].mean():.3f}")
        # Drop the original column
        df = df.drop('Churn?', axis=1)
    elif 'Exited' in df.columns:
        logger.info(f"Churn rate: {df['Exited'].mean():.3f}")
    else:
        logger.error("No target column found. Expected 'Exited' or
'Churn?'")
        raise ValueError("Target column not found")
    return df

def preprocess_features(df):
    """Preprocess features for training"""
    df_processed = df.copy()
    label_encoders = {}
    # Handle different dataset structures
    if 'Geography' in df.columns and 'Gender' in df.columns:
        # Bank churn dataset structure
        le_geography = LabelEncoder()
        le_gender = LabelEncoder()
        df_processed['Geography'] =
le_geography.fit_transform(df['Geography'])
        df_processed['Gender'] = le_gender.fit_transform(df['Gender'])
        label_encoders['Geography'] = le_geography
        label_encoders['Gender'] = le_gender
    # Feature engineering for bank dataset
    if 'CreditScore' in df.columns and 'Age' in df.columns:
        df_processed['CreditScore_Age_Ratio'] =
df_processed['CreditScore'] / df_processed['Age']
        if 'Balance' in df.columns and 'EstimatedSalary' in df.columns:
            df_processed['Balance_Salary_Ratio'] = df_processed['Balance'] /
(df_processed['EstimatedSalary'] + 1)
```

```
df_processed['Balance_Log'] = np.log1p(df_processed['Balance'])
df_processed['EstimatedSalary_Log'] =
np.log1p(df_processed['EstimatedSalary'])
else:
    # Telecom churn dataset structure
    logger.info("Processing telecom churn dataset")
    # Handle categorical columns
    categorical_columns = []
    for col in df_processed.columns:
        if df_processed[col].dtype == 'object' and col != 'Exited':
            categorical_columns.append(col)
    logger.info(f"Categorical columns found: {categorical_columns}")
    # Encode categorical variables
    for col in categorical_columns:
        if col not in ['Phone']: # Skip phone numbers
            le = LabelEncoder()
            df_processed[col] =
le.fit_transform(df_processed[col].astype(str))
            label_encoders[col] = le
    # Drop non-predictive columns
    columns_to_drop = ['Phone']
    df_processed = df_processed.drop(columns=[col for col in
columns_to_drop if col in df_processed.columns])
    # Feature engineering for telecom dataset
    if 'Day Mins' in df_processed.columns and 'Day Calls' in
df_processed.columns:
        df_processed['Avg_Day_Call_Duration'] = df_processed['Day Mins']
/ (df_processed['Day Calls'] + 1)
        if 'Eve Mins' in df_processed.columns and 'Eve Calls' in
df_processed.columns:
            df_processed['Avg_Eve_Call_Duration'] = df_processed['Eve Mins']
/ (df_processed['Eve Calls'] + 1)
            if 'Night Mins' in df_processed.columns and 'Night Calls' in
df_processed.columns:
                df_processed['Avg_Night_Call_Duration'] = df_processed['Night
Mins'] / (df_processed['Night Calls'] + 1)
    # Total usage features
    usage_cols = [col for col in df_processed.columns if 'Mins' in col]
    if usage_cols:
        df_processed['Total_Usage_Mins'] =
df_processed[usage_cols].sum(axis=1)
        charge_cols = [col for col in df_processed.columns if 'Charge' in
col]
        if charge_cols:
            df_processed['Total_Charges'] =
df_processed[charge_cols].sum(axis=1)
    # Handle boolean columns
    for col in df_processed.columns:
        if df_processed[col].dtype == 'bool':
            df_processed[col] = df_processed[col].astype(int)
    return df_processed, label_encoders
```

```
def train_model(X_train, y_train, n_estimators, max_depth, random_state):
    """Train the random forest model"""
    logger.info("Training Random Forest model")
    # Create pipeline with scaling
    pipeline = Pipeline([
        ('scaler', StandardScaler()),
        ('classifier', RandomForestClassifier(
            n_estimators=n_estimators,
            max_depth=max_depth,
            random_state=random_state,
            n_jobs=-1
        ))
    ])
    pipeline.fit(X_train, y_train)
    return pipeline

def evaluate_model(model, X_test, y_test):
    """Evaluate model performance"""
    y_pred = model.predict(X_test)
    y_pred_proba = model.predict_proba(X_test)[:, 1]
    metrics = {
        'accuracy': accuracy_score(y_test, y_pred),
        'precision': precision_score(y_test, y_pred),
        'recall': recall_score(y_test, y_pred),
        'f1_score': f1_score(y_test, y_pred),
        'roc_auc': roc_auc_score(y_test, y_pred_proba)
    }
    logger.info("Model Performance:")
    for metric, value in metrics.items():
        logger.info(f"{metric}: {value:.4f}")
    return metrics

def main():
    args = parse_args()
    # Start MLflow run
    with mlflow.start_run():
        # Log parameters
        mlflow.log_param("test_size", args.test_size)
        mlflow.log_param("random_state", args.random_state)
        mlflow.log_param("n_estimators", args.n_estimators)
        mlflow.log_param("max_depth", args.max_depth)
        # Load and preprocess data
        df = load_and_preprocess_data(args.data_path)
        df_processed, label_encoders = preprocess_features(df)
        # Prepare features and target
        feature_columns = [col for col in df_processed.columns if col !=
'Exited']
        X = df_processed[feature_columns]
        y = df_processed['Exited']
        logger.info(f"Feature columns: {feature_columns}")
        logger.info(f"Features shape: {X.shape}")
```

```
    logger.info(f"Target shape: {y.shape}")
    # Split data
    X_train, X_test, y_train, y_test = train_test_split(
        X, y, test_size=args.test_size, random_state=args.random_state,
stratify=y
    )
    logger.info(f"Training set size: {X_train.shape[0]}")
    logger.info(f"Test set size: {X_test.shape[0]}")
    # Train model
    model = train_model(X_train, y_train, args.n_estimators,
args.max_depth, args.random_state)
    # Evaluate model
    metrics = evaluate_model(model, X_test, y_test)
    # Log metrics
    for metric, value in metrics.items():
        mlflow.log_metric(metric, value)
    # Log feature importance
    feature_importance =
model.named_steps['classifier'].feature_importances_
    for i, (feature, importance) in enumerate(zip(feature_columns,
feature_importance)):
        # Sanitize feature name for MLflow (remove invalid characters)
        sanitized_feature = feature.replace("'", "").replace(" ",
"_").replace("-", "_")
        mlflow.log_metric(f"feature_importance_{sanitized_feature}",
importance)
    # Log additional info
    mlflow.log_metric("training_samples", len(X_train))
    mlflow.log_metric("test_samples", len(X_test))
    mlflow.log_metric("n_features", X_train.shape[1])
    # Save model artifacts
    os.makedirs(args.model_output, exist_ok=True)
    # Save the model using MLflow
    model_path = os.path.join(args.model_output, "model")
    mlflow.sklearn.save_model(model, model_path)
    # Log the model path for debugging
    logger.info(f"Model saved to: {model_path}")
    logger.info(f"Contents of model output directory:
{os.listdir(args.model_output)}")
    # Save preprocessing objects
    joblib.dump(label_encoders, os.path.join(args.model_output,
"label_encoders.pkl"))
    joblib.dump(feature_columns, os.path.join(args.model_output,
"feature_columns.pkl"))
    # Log model with MLflow
    mlflow.sklearn.log_model(
        model,
        "model",
        registered_model_name="customer-churn-model"
    )
    logger.info(f"Model saved to {args.model_output}")
```

```
        logger.info("Training completed successfully!")

if __name__ == "__main__":
    main()
```

test_integration.py

```
# tests/test_integration.py
import pytest
import tempfile
import os
import pandas as pd
import numpy as np
from src.train import main
import sys
from unittest.mock import patch

class TestIntegration:
    def test_end_to_end_training(self):
        """Test the complete training pipeline"""
        with tempfile.TemporaryDirectory() as temp_dir:
            # Create test arguments
            test_args = [
                'train.py',
                '--data_path', 'non_existent_path.csv', # Will trigger
sample data creation
                '--model_output', temp_dir,
                '--test_size', '0.2',
                '--random_state', '42',
                '--n_estimators', '10',
                '--max_depth', '5'
            ]
            # Mock sys.argv
            with patch.object(sys, 'argv', test_args):
                try:
                    main()
                    # Check that model files are created
                    assert os.path.exists(os.path.join(temp_dir, 'model'))
                    assert os.path.exists(os.path.join(temp_dir,
'label_encoders.pkl'))
                    assert os.path.exists(os.path.join(temp_dir,
'feature_columns.pkl'))
                except SystemExit as e:
                    # MLflow might cause a system exit, which is okay for
testing
                    if e.code != 0:
                        raise
```

```

def test_end_to_end_training_with_telecom_data(self):
    """Test the complete training pipeline with telecom-style data"""
    with tempfile.TemporaryDirectory() as temp_dir:
        # Create a temporary CSV file with telecom data structure
        test_data_path = os.path.join(temp_dir, 'test_churn.csv')
        # Create sample telecom data
        np.random.seed(42)
        n_samples = 100
        telecom_data = {
            'State': np.random.choice(['TX', 'CA', 'NY', 'FL'],
n_samples),
            'Account Length': np.random.randint(1, 243, n_samples),
            'Area Code': np.random.choice([408, 415, 510], n_samples),
            'Phone': [f"{np.random.randint(100,999)}-
{np.random.randint(1000,9999)}" for _ in range(n_samples)],
            'Int'l Plan': np.random.choice(['yes', 'no'], n_samples),
            'VMail Plan': np.random.choice(['yes', 'no'], n_samples),
            'VMail Message': np.random.randint(0, 51, n_samples),
            'Day Mins': np.random.uniform(0, 351, n_samples),
            'Day Calls': np.random.randint(0, 166, n_samples),
            'Day Charge': np.random.uniform(0, 60, n_samples),
            'Eve Mins': np.random.uniform(0, 364, n_samples),
            'Eve Calls': np.random.randint(0, 171, n_samples),
            'Eve Charge': np.random.uniform(0, 31, n_samples),
            'Night Mins': np.random.uniform(0, 396, n_samples),
            'Night Calls': np.random.randint(0, 176, n_samples),
            'Night Charge': np.random.uniform(0, 18, n_samples),
            'Intl Mins': np.random.uniform(0, 20, n_samples),
            'Intl Calls': np.random.randint(0, 21, n_samples),
            'Intl Charge': np.random.uniform(0, 6, n_samples),
            'CustServ Calls': np.random.randint(0, 10, n_samples),
            'Churn?': np.random.choice(['True.', 'False.'], n_samples)
        }
        df = pd.DataFrame(telecom_data)
        df.to_csv(test_data_path, index=False)
        # Create test arguments
        test_args = [
            'train.py',
            '--data_path', test_data_path,
            '--model_output', temp_dir,
            '--test_size', '0.2',
            '--random_state', '42',
            '--n_estimators', '10',
            '--max_depth', '5'
        ]
        # Mock sys.argv
        with patch.object(sys, 'argv', test_args):
            try:
                main()
                # Check that model files are created
                assert os.path.exists(os.path.join(temp_dir, 'model'))

```

```

        assert os.path.exists(os.path.join(temp_dir,
'label_encoders.pkl'))
        assert os.path.exists(os.path.join(temp_dir,
'feature_columns.pkl'))
        # Verify the saved files contain expected data
        import joblib
        label_encoders = joblib.load(os.path.join(temp_dir,
'label_encoders.pkl'))
        feature_columns = joblib.load(os.path.join(temp_dir,
'feature_columns.pkl'))
        # Should have label encoders for categorical columns
        assert isinstance(label_encoders, dict)
        assert len(label_encoders) > 0
        # Should have feature columns
        assert isinstance(feature_columns, list)
        assert len(feature_columns) > 0
        assert 'Exited' not in feature_columns # Target should
not be in features
    except SystemExit as e:
        # MLflow might cause a system exit, which is okay for
testing
        if e.code != 0:
            raise
def test_end_to_end_training_with_bank_data(self):
    """Test the complete training pipeline with bank-style data"""
    with tempfile.TemporaryDirectory() as temp_dir:
        # Create a temporary CSV file with bank data structure
        test_data_path = os.path.join(temp_dir, 'test_bank_churn.csv')
        # Create sample bank data
        np.random.seed(42)
        n_samples = 100
        bank_data = {
            'CreditScore': np.random.randint(350, 850, n_samples),
            'Geography': np.random.choice(['France', 'Spain',
'Germany'], n_samples),
            'Gender': np.random.choice(['Male', 'Female'], n_samples),
            'Age': np.random.randint(18, 92, n_samples),
            'Tenure': np.random.randint(0, 10, n_samples),
            'Balance': np.random.uniform(0, 250000, n_samples),
            'NumOfProducts': np.random.randint(1, 4, n_samples),
            'HasCrCard': np.random.choice([0, 1], n_samples),
            'IsActiveMember': np.random.choice([0, 1], n_samples),
            'EstimatedSalary': np.random.uniform(0, 200000, n_samples),
            'Exited': np.random.choice([0, 1], n_samples)
        }
        df = pd.DataFrame(bank_data)
        df.to_csv(test_data_path, index=False)
        # Create test arguments
        test_args = [
            'train.py',
            '--data_path', test_data_path,

```

```
        '--model_output', temp_dir,
        '--test_size', '0.2',
        '--random_state', '42',
        '--n_estimators', '10',
        '--max_depth', '5'
    ]
    # Mock sys.argv
    with patch.object(sys, 'argv', test_args):
        try:
            main()
            # Check that model files are created
            assert os.path.exists(os.path.join(temp_dir, 'model'))
            assert os.path.exists(os.path.join(temp_dir,
'label_encoders.pkl'))
            assert os.path.exists(os.path.join(temp_dir,
'feature_columns.pkl'))
            # Verify the saved files contain expected data
            import joblib
            label_encoders = joblib.load(os.path.join(temp_dir,
'label_encoders.pkl'))
            feature_columns = joblib.load(os.path.join(temp_dir,
'feature_columns.pkl'))
            # Should have label encoders for Geography and Gender
            assert isinstance(label_encoders, dict)
            assert 'Geography' in label_encoders
            assert 'Gender' in label_encoders
            # Should have feature columns including engineered
features
            assert isinstance(feature_columns, list)
            assert len(feature_columns) > 10 # Should have original
+ engineered features
            assert 'Exited' not in feature_columns # Target should
not be in features
            # Check for engineered features
            assert 'CreditScore_Age_Ratio' in feature_columns
            assert 'Balance_Salary_Ratio' in feature_columns
        except SystemExit as e:
            # MLflow might cause a system exit, which is okay for
testing
            if e.code != 0:
                raise
```

test_train.py

```
# tests/test_train.py
import pytest
import pandas as pd
```

```

import numpy as np
from sklearn.model_selection import train_test_split
from src.train import load_and_preprocess_data, preprocess_features,
train_model, evaluate_model

class TestTrainingPipeline:
    @pytest.fixture
    def sample_bank_data(self):
        """Create sample bank churn data for testing"""
        np.random.seed(42)
        n_samples = 100
        data = {
            'CreditScore': np.random.randint(350, 850, n_samples),
            'Geography': np.random.choice(['France', 'Spain', 'Germany'],
n_samples),
            'Gender': np.random.choice(['Male', 'Female'], n_samples),
            'Age': np.random.randint(18, 92, n_samples),
            'Tenure': np.random.randint(0, 10, n_samples),
            'Balance': np.random.uniform(0, 250000, n_samples),
            'NumOfProducts': np.random.randint(1, 4, n_samples),
            'HasCrCard': np.random.choice([0, 1], n_samples),
            'IsActiveMember': np.random.choice([0, 1], n_samples),
            'EstimatedSalary': np.random.uniform(0, 200000, n_samples),
            'Exited': np.random.choice([0, 1], n_samples)
        }
        return pd.DataFrame(data)
    @pytest.fixture
    def sample_telecom_data(self):
        """Create sample telecom churn data for testing"""
        np.random.seed(42)
        n_samples = 100
        data = {
            'State': np.random.choice(['TX', 'CA', 'NY', 'FL'], n_samples),
            'Account Length': np.random.randint(1, 243, n_samples),
            'Area Code': np.random.choice([408, 415, 510], n_samples),
            'Phone': [f"{np.random.randint(100,999)}-
{np.random.randint(1000,9999)}" for _ in range(n_samples)],
            'Int'l Plan': np.random.choice(['yes', 'no'], n_samples),
            'VMail Plan': np.random.choice(['yes', 'no'], n_samples),
            'VMail Message': np.random.randint(0, 51, n_samples),
            'Day Mins': np.random.uniform(0, 351, n_samples),
            'Day Calls': np.random.randint(0, 166, n_samples),
            'Day Charge': np.random.uniform(0, 60, n_samples),
            'Eve Mins': np.random.uniform(0, 364, n_samples),
            'Eve Calls': np.random.randint(0, 171, n_samples),
            'Eve Charge': np.random.uniform(0, 31, n_samples),
            'Night Mins': np.random.uniform(0, 396, n_samples),
            'Night Calls': np.random.randint(0, 176, n_samples),
            'Night Charge': np.random.uniform(0, 18, n_samples),
            'Intl Mins': np.random.uniform(0, 20, n_samples),
            'Intl Calls': np.random.randint(0, 21, n_samples),

```

```
        'Intl Charge': np.random.uniform(0, 6, n_samples),
        'CustServ Calls': np.random.randint(0, 10, n_samples),
        'Churn?': np.random.choice(['True.', 'False.'], n_samples)
    }
    return pd.DataFrame(data)
def test_preprocess_bank_features(self, sample_bank_data):
    """Test feature preprocessing for bank data"""
    df_processed, label_encoders = preprocess_features(sample_bank_data)
    # Check that categorical variables are encoded
    assert df_processed['Geography'].dtype in ['int64', 'int32']
    assert df_processed['Gender'].dtype in ['int64', 'int32']
    # Check that new features are created
    assert 'CreditScore_Age_Ratio' in df_processed.columns
    assert 'Balance_Salary_Ratio' in df_processed.columns
    assert 'Balance_Log' in df_processed.columns
    assert 'EstimatedSalary_Log' in df_processed.columns
    # Check that encoders work
    assert 'Geography' in label_encoders
    assert 'Gender' in label_encoders
    assert len(label_encoders['Geography'].classes_) <= 3
    assert len(label_encoders['Gender'].classes_) <= 2
def test_preprocess_telecom_features(self, sample_telecom_data):
    """Test feature preprocessing for telecom data"""
    # First convert Churn? to Exited
    sample_telecom_data['Exited'] = (sample_telecom_data['Churn?'] ==
'True.').astype(int)
    sample_telecom_data = sample_telecom_data.drop('Churn?', axis=1)
    df_processed, label_encoders =
preprocess_features(sample_telecom_data)
    # Check that categorical variables are encoded
    categorical_cols = ['State', "Int'l Plan", 'VMail Plan']
    for col in categorical_cols:
        if col in df_processed.columns:
            assert df_processed[col].dtype in ['int64', 'int32']
            assert col in label_encoders
    # Check that phone numbers are dropped
    assert 'Phone' not in df_processed.columns
    # Check that new telecom features are created
    assert 'Avg_Day_Call_Duration' in df_processed.columns
    assert 'Avg_Eve_Call_Duration' in df_processed.columns
    assert 'Avg_Night_Call_Duration' in df_processed.columns
    assert 'Total_Usage_Mins' in df_processed.columns
    assert 'Total_Charges' in df_processed.columns
def test_train_model_bank_data(self, sample_bank_data):
    """Test model training with bank data"""
    df_processed, _ = preprocess_features(sample_bank_data)
    feature_columns = [col for col in df_processed.columns if col !=
'Exited']
    X = df_processed[feature_columns]
    y = df_processed['Exited']
    X_train, X_test, y_train, y_test = train_test_split(
```

```
        X, y, test_size=0.2, random_state=42
    )
    model = train_model(X_train, y_train, n_estimators=10, max_depth=5,
random_state=42)
    # Check that model is trained
    assert hasattr(model, 'predict')
    assert hasattr(model, 'predict_proba')
    # Check predictions
    predictions = model.predict(X_test)
    assert len(predictions) == len(X_test)
    assert all(pred in [0, 1] for pred in predictions)
def test_train_model_telecom_data(self, sample_telecom_data):
    """Test model training with telecom data"""
    # First convert Churn? to Exited
    sample_telecom_data['Exited'] = (sample_telecom_data['Churn?'] ==
'True.').astype(int)
    sample_telecom_data = sample_telecom_data.drop('Churn?', axis=1)
    df_processed, _ = preprocess_features(sample_telecom_data)
    feature_columns = [col for col in df_processed.columns if col !=
'Exited']
    X = df_processed[feature_columns]
    y = df_processed['Exited']
    X_train, X_test, y_train, y_test = train_test_split(
        X, y, test_size=0.2, random_state=42
    )
    model = train_model(X_train, y_train, n_estimators=10, max_depth=5,
random_state=42)
    # Check that model is trained
    assert hasattr(model, 'predict')
    assert hasattr(model, 'predict_proba')
    # Check predictions
    predictions = model.predict(X_test)
    assert len(predictions) == len(X_test)
    assert all(pred in [0, 1] for pred in predictions)
def test_evaluate_model(self, sample_bank_data):
    """Test model evaluation"""
    df_processed, _ = preprocess_features(sample_bank_data)
    feature_columns = [col for col in df_processed.columns if col !=
'Exited']
    X = df_processed[feature_columns]
    y = df_processed['Exited']
    X_train, X_test, y_train, y_test = train_test_split(
        X, y, test_size=0.2, random_state=42
    )
    model = train_model(X_train, y_train, n_estimators=10, max_depth=5,
random_state=42)
    metrics = evaluate_model(model, X_test, y_test)
    # Check that all metrics are present
    expected_metrics = ['accuracy', 'precision', 'recall', 'f1_score',
'roc_auc']
    for metric in expected_metrics:
```

```
        assert metric in metrics
        assert 0 <= metrics[metric] <= 1
def test_data_shapes_bank(self, sample_bank_data):
    """Test data shapes after preprocessing bank data"""
    df_processed, _ = preprocess_features(sample_bank_data)
    # Should have more columns after feature engineering
    assert df_processed.shape[1] > sample_bank_data.shape[1]
    # Should have same number of rows
    assert df_processed.shape[0] == sample_bank_data.shape[0]
def test_data_shapes_telecom(self, sample_telecom_data):
    """Test data shapes after preprocessing telecom data"""
    # First convert Churn? to Exited
    original_cols = sample_telecom_data.shape[1]
    sample_telecom_data['Exited'] = (sample_telecom_data['Churn?'] ==
'True.').astype(int)
    sample_telecom_data = sample_telecom_data.drop('Churn?', axis=1)
    df_processed, _ = preprocess_features(sample_telecom_data)
    # Should have more columns after feature engineering (considering
Phone is dropped)
    assert df_processed.shape[1] > original_cols - 2 # -1 for Phone
drop, -1 for Churn? -> Exited
    # Should have same number of rows
    assert df_processed.shape[0] == sample_telecom_data.shape[0]
def test_load_and_preprocess_data_nonexistent_file(self):
    """Test load_and_preprocess_data with non-existent file (should
create sample data)"""
    df = load_and_preprocess_data('nonexistent_file.csv')
    # Should create sample data
    assert isinstance(df, pd.DataFrame)
    assert 'Exited' in df.columns
    assert df.shape[0] > 0
    # Should have bank data structure when creating sample data
    expected_bank_cols = ['CreditScore', 'Geography', 'Gender', 'Age',
'Tenure',
                        'Balance', 'NumOfProducts', 'HasCrCard',
'IsActiveMember',
                        'EstimatedSalary', 'Exited']
    for col in expected_bank_cols:
        assert col in df.columns
```

requirements.txt

```
# requirements.txt
scikit-learn==1.3.0
pandas==2.0.3
numpy==1.24.3
mlflow==2.5.0
```

```
azure-ai-ml==1.8.0
azure-identity==1.13.0
azure-storage-blob==12.17.0
joblib==1.3.1
pytest==7.4.0
pytest-cov==4.1.0
flake8==6.0.0
```