

## Load Libraries and Set Seeds

```
In [1]: # !pip install mplsoccer
# !pip install altair
# !pip install utils
# !pip install xgboost
# !pip install shap
# !brew install graphviz

from mplsoccer import Sbopen, Pitch
from statsbombpy import sb

import pandas as pd
import numpy as np
import warnings
import statsmodels.api as sm
import statsmodels.formula.api as smf
import os
import random as rn
import tensorflow as tf
import time
from multiprocessing import Pool

import matplotlib.patheffects as path_effects
import matplotlib.pyplot as plt
import graphviz

pd.options.display.max_columns = None
# pd.options.display.max_rows = None

import tensorflow as tf
import tensorflow.keras as keras
from tensorflow.keras import Sequential
from tensorflow.keras import backend as K
from tensorflow.keras.layers import Dense, Dropout, BatchNormalization
from tensorflow.keras.optimizers import Adam
from tensorflow.keras.callbacks import EarlyStopping
from tensorflow.keras.models import Sequential
```

```
from sklearn.metrics import roc_curve, roc_auc_score, brier_score_loss, log_loss, accuracy_score, precision_score, recall_score, f1_score, fbeta_score, average_precision_score, classification_report, confusion_matrix
from sklearn.calibration import calibration_curve, CalibratedClassifierCV
from sklearn.model_selection import train_test_split, StratifiedShuffleSplit, GridSearchCV, StratifiedKFold, cross_val_score
from sklearn.preprocessing import StandardScaler
from sklearn.ensemble import RandomForestClassifier
from sklearn.feature_selection import RFE, SelectKBest, mutual_info_classif, chi2
from sklearn import tree

from xgboost import XGBClassifier
from pathlib import Path
```

```
In [2]: # For reproducibility, setting seeds
os.environ['PYTHONHASHSEED'] = '42'
np.random.seed(42)
rn.seed(42)
tf.random.set_seed(42)
```

## Helper Methods: Gather, Clean Data; Add New Metrics; Standardise Features, Targets

```
In [3]: competitions_df = sb.competitions()
def gather_data(ids_list):
    start_time = time.time()

    parser = Sbopen()

    event_df = pd.DataFrame()
    related_df = pd.DataFrame()
    frames_df = pd.DataFrame()

    for comp_id, seas_id in ids_list:
        # Get all matches and store their ids
        df_match = parser.match(competition_id=comp_id, season_id=seas_id)
        matches = df_match.match_id.unique()
        print(f"Matches : {len(matches)}")

        # Get tracking 360 data for the particular season
        comp_row = competitions_df[(competitions_df["season_id"] == seas_id) & (competitions_df["competition_id"] == comp_id)]
        df_frames = sb.competition_frames(country=comp_row["country_name"], division=comp_row["competition"])
        frames_df = pd.concat([frames_df, df_frames], ignore_index=True)

    return event_df, related_df, frames_df
```

```

for match in matches:

    # Open events
    df_event, df_related, _, _ = parser.event(match)
    df_event["comp_id"] = comp_id
    df_event["seas_id"] = seas_id

    # Append event and trackings to a dataframe
    event_df = pd.concat([event_df, df_event], ignore_index=True)
    related_df = pd.concat([related_df, df_related], ignore_index=True)

#reset indices
event_df.reset_index(drop=True, inplace=True)
event_df.dropna(axis=1, how='all', inplace=True)

pass_df = event_df.loc[event_df['type_name'] == 'Pass'].reset_index(drop=True).copy(deep=True)
pass_df.dropna(axis=1, how='all', inplace=True)

related_df.reset_index(drop=True, inplace=True)
related_df.dropna(axis=1, how='all', inplace=True)

frames_df.reset_index(drop=True, inplace=True)
frames_df.dropna(axis=1, how='all', inplace=True)
frames_df[['x', 'y']] = pd.DataFrame(frames_df['location'].tolist(), index=frames_df.index)
frames_df.drop(columns=['location'], inplace=True)

print(f'Data Gathering completed in: {round(time.time() - start_time, 2)}s')
return pass_df, event_df, related_df, frames_df

```

In [4]:

```

def clean_passes(pass_df, frames_df):
    clean_pass_df = pass_df[pass_df["id"].isin(set(frames_df["event_uuid"]))]
    return clean_pass_df

```

In [5]:

```

def player_within_distances(df, frames_df):
    start_time = time.time()
    results = []

    # Group frames_df by event_uuid and match_id
    grouped_frames = frames_df[frames_df['teammate'] == False].groupby(['event_uuid', 'match_id'])

    for _, pass_row in df.iterrows():

```

```

row_pass_id = pass_row["id"]
row_match_id = pass_row["match_id"]

try:
    player_positions = grouped_frames.get_group((row_pass_id, row_match_id))
    y_diff = pass_row["y"] - player_positions["y"].values
    x_diff = pass_row["x"] - player_positions["x"].values
    distances = np.sqrt(x_diff**2 + y_diff**2)

    counts = [np.sum(distances < d) for d in [1, 2, 3]]
    results.append(tuple(counts))

except KeyError:
    results.append((0, 0, 0))

return results

```

```

In [6]: def vectorized_distance_from_point_to_line(line_starts, line_ends, points):
    x1, y1 = line_starts[:, 0], line_starts[:, 1]
    x2, y2 = line_ends[:, 0], line_ends[:, 1]
    A = y2 - y1
    B = x1 - x2
    C = x2 * y1 - x1 * y2

    # Reshape A, B, C to allow broadcasting
    A = A[:, np.newaxis]
    B = B[:, np.newaxis]
    C = C[:, np.newaxis]

    # Ensure points is a 3D array
    if points.ndim == 2:
        points = points[:, np.newaxis, :]

    distances = np.abs(A * points[..., 0] + B * points[..., 1] + C) / np.sqrt(A**2 + B**2)
    return distances

def vectorized_avg_defender_distance(df, opposition_positions):
    pass_starts = df[['x', 'y']].values
    pass_ends = df[['end_x', 'end_y']].values
    pass_ids = df['id'].values

```

```

# Create an array to store the minimum distances
avg_distances = np.full(len(df), 72.0)

# Get opposition positions for each pass
opp_positions = [np.array(opposition_positions.get(pid, [])) for pid in pass_ids]

# Filter out passes with no opposition players
valid_indices = [i for i, pos in enumerate(opp_positions) if pos.size > 0]

if valid_indices:
    valid_starts = pass_starts[valid_indices]
    valid_ends = pass_ends[valid_indices]
    valid_positions = [opp_positions[i] for i in valid_indices]

    # Calculate distances
    distances = [vectorized_distance_from_point_to_line(start[np.newaxis], end[np.newaxis], pos)
                 for start, end, pos in zip(valid_starts, valid_ends, valid_positions)]

    # Get average distances
    avg_distances[valid_indices] = [np.average(d) for d in distances]

return avg_distances

```

```

In [7]: def create_new_metrics(clean_pass_df, frames_df):
    start_time = time.time()
    model_vars = pd.DataFrame()
    results = player_within_distances(clean_pass_df, frames_df)
    model_vars[['num_1_away', 'num_2_away', 'num_3_away']] = pd.DataFrame(results, index=clean_pass_df.index)
    print(f"Player_within_distances completed in {round(time.time() - start_time, 2)}s")

    start_time = time.time()
    opposition_positions = frames_df[frames_df['teammate'] == False].groupby('event_uuid').apply(lambda g:
        model_vars['avg_defender_distance'] = vectorized_avg_defender_distance(clean_pass_df, opposition_positions)
    )
    model_vars = model_vars.dropna(subset=["avg_defender_distance"])
    clean_pass_df = clean_pass_df.loc[model_vars.index]
    print(f"Closest_defender_passing_line completed in {round(time.time() - start_time, 2)}s")

    return model_vars, clean_pass_df

```

```

In [8]: def standardise_features(df):
    try:

```

```
df["is_under_pressure"] = np.where(df["under_pressure"].isnull(), 0, 1)
df.drop(columns=["under_pressure"], axis=1, inplace=True)
df.rename(columns={"is_under_pressure":"under_pressure"}, inplace=True)
except:
    print("no under pressure")
df.fillna(0, inplace=True)
object_columns = df.select_dtypes(include=['object']).columns
df[object_columns] = df[object_columns].astype(int)
assert list(df.select_dtypes(include=['object']).columns) == []
return df
```

```
In [9]: def standardise_target(df):
    df["pass_outcome"] = np.where(df["outcome_id"].isnull(), 1, 0)
    df.drop(columns=["outcome_id"], axis=1, inplace=True)
    df.rename(columns={"pass_outcome":"outcome_id"}, inplace=True)
    return df
```

## Gather Training Data

```
In [193...]: # Women's world cup ((72, 107)) + Euros 2020 and 2024 + Bayer Leverkusen 23/24
train_ids = [(55,43), (9,281), (72, 107)]
test_ids = [(55,282)]

# Get the data
pass_df, event_df, related_df, frames_df = gather_data(train_ids)
```

Matches : 51

Matches : 34

Matches : 64

```
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
Data Gathering completed in: 475.45s
```

## Clean Training Data

In [194..]

```
# Only store those rows that have corresponding 360 entry in frames_df
clean_pass_df = clean_passes(pass_df, frames_df)
print(f"Data lost from cleaning pass_df: {round((1 - len(clean_pass_df)) / len(pass_df))*100.0, 2}%)"

new_metrics_df, clean_pass_df = create_new_metrics(clean_pass_df, frames_df)
# Add new metrics to our main_df
clean_pass_df = pd.concat([clean_pass_df, new_metrics_df], axis=1)
```

```
Data lost from cleaning pass_df: 14.87%
Player_within_distances completed in 58.46s
```

```
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/4125588332.py:9: DeprecationWarning: DataFrameGroupBy.apply operated on the grouping columns. This behavior is deprecated, and in a future version of pandas the grouping columns will be excluded from the operation. Either pass `include_groups=False` to exclude the groupings or explicitly select the grouping columns after groupby to silence this warning.
    opposition_positions = frames_df[frames_df['teammate'] == False].groupby('event_uuid').apply(lambda g: g[['x', 'y']].values).to_dict()
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2822652700.py:17: RuntimeWarning: invalid
value encountered in divide
    distances = np.abs(A * points[..., 0] + B * points[..., 1] + C) / np.sqrt(A**2 + B**2)
```

```
Closest_defender_passing_line completed in 108.08s
```

## Create Training Variables and Features

In [195...]

```
# What I think are the basic features that should be included to predict pass completion
basic_features = ['play_pattern_id', 'pass_length', 'pass_angle', 'pass_height_id',
                  'end_x', 'end_y', 'body_part_id', 'sub_type_id', 'x', 'y', 'under_pressure']

# All features in the model (only excludes target variable, *_name counterparts of *_id, and match time)
all_features = ['duration', 'pass_length', 'pass_angle', 'pass_height_id', 'end_x', 'end_y', 'body_part_id',
                 'under_pressure', 'technique_id', 'off_camera', 'counterpress', 'out', 'num_1_away', 'num_2_away',
                 'num_3_away', 'avg_defender_distance', 'aerial_won', 'pass_cross', 'pass_switch', 'pass_shots',
                 'pass_goal_assist', 'pass_cut_back', 'pass_deflected', 'pass_no_touch', 'pass_miscommunicated']

# Features that were manually created
created_features = ['num_3_away', 'num_2_away', 'num_1_away', 'avg_defender_distance']

# Features that were considered statistically important by RF, Permutation Importance, Chi2, and Mutual Information
imp_features = ['pass_height_id', 'pass_length', 'pass_angle', 'duration', 'x', 'y', 'end_x', 'end_y', 'body_part_id',
                 'sub_type_id', 'aerial_won', 'avg_defender_distance', 'num_1_away']

features = {"basic" : (basic_features + created_features),
            "imp" : imp_features,
            "all" : all_features
          }
```

In [196...]

```
#store dependent variable
y = clean_pass_df["outcome_id"].to_frame()
y = standardise_target(y)

#store independent variables
X_basic = clean_pass_df[features["basic"]]
X_basic = standardise_features(X_basic)

X_imp = clean_pass_df[features["imp"]]
X_imp = standardise_features(X_imp)

X_all = clean_pass_df[features["all"]]
X_all = standardise_features(X_all)
```

```
X_dict = {"basic":X_basic, "imp":X_imp, "all":X_all}
```

```
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:3: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame.  
Try using .loc[row_indexer,col_indexer] = value instead
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df["is_under_pressure"] = np.where(df["under_pressure"].isnull(), 0, 1)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:4: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df.drop(columns=["under_pressure"], axis=1, inplace=True)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:5: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df.rename(columns={"is_under_pressure": "under_pressure"}, inplace=True)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:8: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df.fillna(0, inplace=True)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:8: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df.fillna(0, inplace=True)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:10: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame.  
Try using .loc[row_indexer,col_indexer] = value instead
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df[object_columns] = df[object_columns].astype(int)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:3: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame.  
Try using .loc[row_indexer,col_indexer] = value instead
```

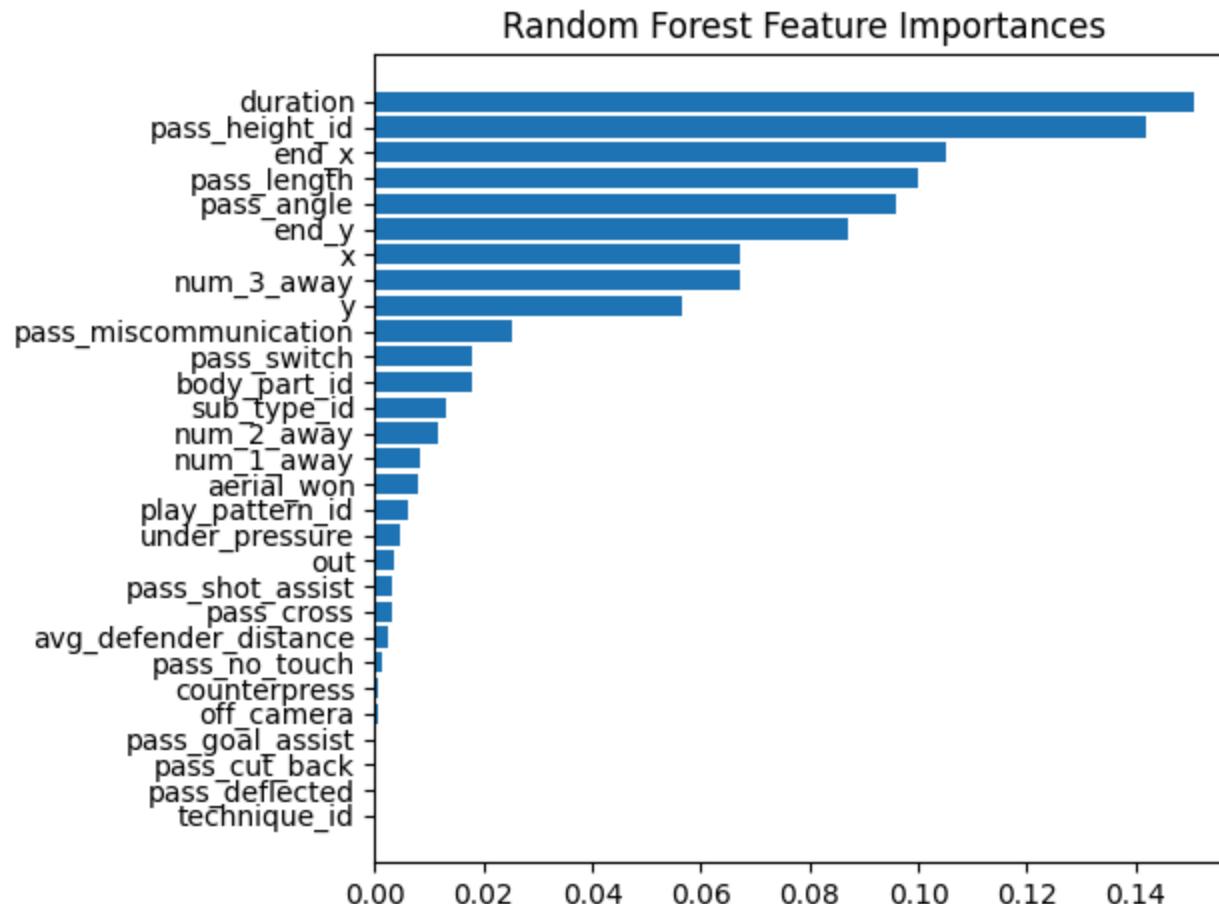
```
See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html  
#returning-a-view-versus-a-copy  
    df["is_under_pressure"] = np.where(df["under_pressure"].isnull(), 0, 1)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:4: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame  
  
See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html  
#returning-a-view-versus-a-copy  
    df.drop(columns=["under_pressure"], axis=1, inplace=True)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:5: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame  
  
See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html  
#returning-a-view-versus-a-copy  
    df.rename(columns={"is_under_pressure":"under_pressure"}, inplace=True)  
no under pressure  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:8: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame  
  
See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html  
#returning-a-view-versus-a-copy  
    df.fillna(0, inplace=True)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:10: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame.  
Try using .loc[row_indexer,col_indexer] = value instead  
  
See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html  
#returning-a-view-versus-a-copy  
    df[object_columns] = df[object_columns].astype(int)
```

## Feature Selection and Importance

```
In [198]: # Feature Importance  
X_train, X_test, y_train, y_test = train_test_split(X_all, y, train_size = 0.7, random_state = 123, stratify=y)  
start_time = time.time()  
rf = RandomForestClassifier(n_estimators=100)  
rf.fit(X_train, y_train)  
print(f"RandomForest fitted in: {time.time() - start_time}s")  
  
importances = rf.feature_importances_  
rf_importances = pd.Series(importances, index=all_features).sort_values(ascending=False)
```

```
print("#####\nRandom Forest Inate Importances", rf_importances, "\n#####\n"
# std = np.std([rf.feature_importances_ for tree in rf.estimators_], axis=0)
# fig, ax = plt.subplots()
# rf_importances.plot.bar(yerr=std, ax=ax)
# ax.set_title("Feature importances using Random Forest")
# ax.set_ylabel("Mean decrease in impurity")
# fig.tight_layout()
# plt.show()
print("#####")
scores = rf_importances.sort_values()
width = np.arange(len(scores))
ticks = list(scores.index)
fig, ax = plt.subplots()
plt.barh(width, scores)
plt.yticks(width, ticks)
plt.title("Random Forest Feature Importances")
fig.tight_layout()
plt.show()
```

```
RandomForest fitted in: 27.68886971473694s
#####
Random Forest Inate Importances duration          0.150566
pass_height_id        0.142077
end_x                 0.105206
pass_length           0.099925
pass_angle             0.095827
end_y                 0.087145
x                      0.067167
num_3_away            0.067088
y                      0.056414
pass_miscommunication 0.025219
pass_switch            0.018071
body_part_id           0.017904
sub_type_id            0.012944
num_2_away             0.011467
num_1_away              0.008199
aerial_won              0.007872
play_pattern_id         0.006307
under_pressure          0.004660
out                     0.003684
pass_shot_assist       0.003193
pass_cross              0.003128
avg_defender_distance  0.002385
pass_no_touch           0.001485
counterpress             0.000591
off_camera               0.000512
pass_goal_assist        0.000285
pass_cut_back            0.000278
pass_deflected           0.000249
technique_id             0.000149
dtype: float64
#####
#####
```



In [191]:

```

from sklearn.inspection import permutation_importance
start_time = time.time()
result = permutation_importance(rf, X_test, y_test, n_repeats=10, random_state=42, n_jobs=2)
print(f"Permutation Importances completed in: {(time.time() - start_time):.3f}s")

rf_perm_importances = pd.Series(result.importances_mean, index=all_features).sort_values(ascending=False)
# print("#####\nPermutation Importances", rf_perm_importances, "\n#####\n")
# fig, ax = plt.subplots()
# rf_perm_importances.plot.bar(yerr=result.importances_std, ax=ax)
# ax.set_title("Permutation Importance")
# ax.set_ylabel("Mean accuracy decrease")
# fig.tight_layout()
# plt.show()

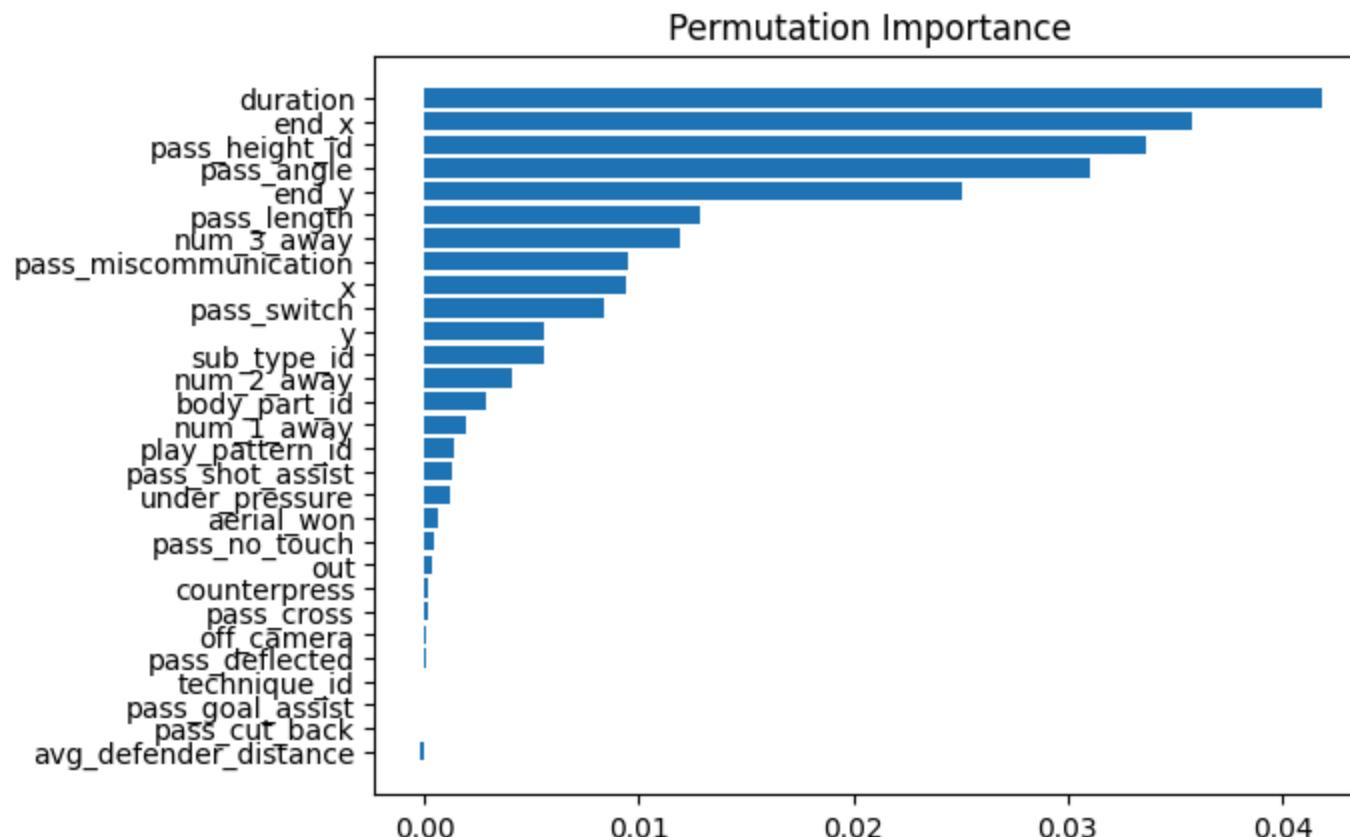
```

```

scores = rf_perm_importances.sort_values()
width = np.arange(len(scores))
ticks = list(scores.index)
plt.barh(width, scores)
plt.yticks(width, ticks)
ax.set_ylabel("Mean accuracy decrease")
plt.title("Permutation Importance")
plt.show()

```

Permutation Importances completed in: 93.958s



In [16]:

```

# mutual_info_classif, chi2
X_kchi = SelectKBest(chi2, k='all').fit(X_all.loc[:, X_all.columns != 'pass_angle'], y)
X_kmut = SelectKBest(mutual_info_classif, k='all').fit(X_all, y)

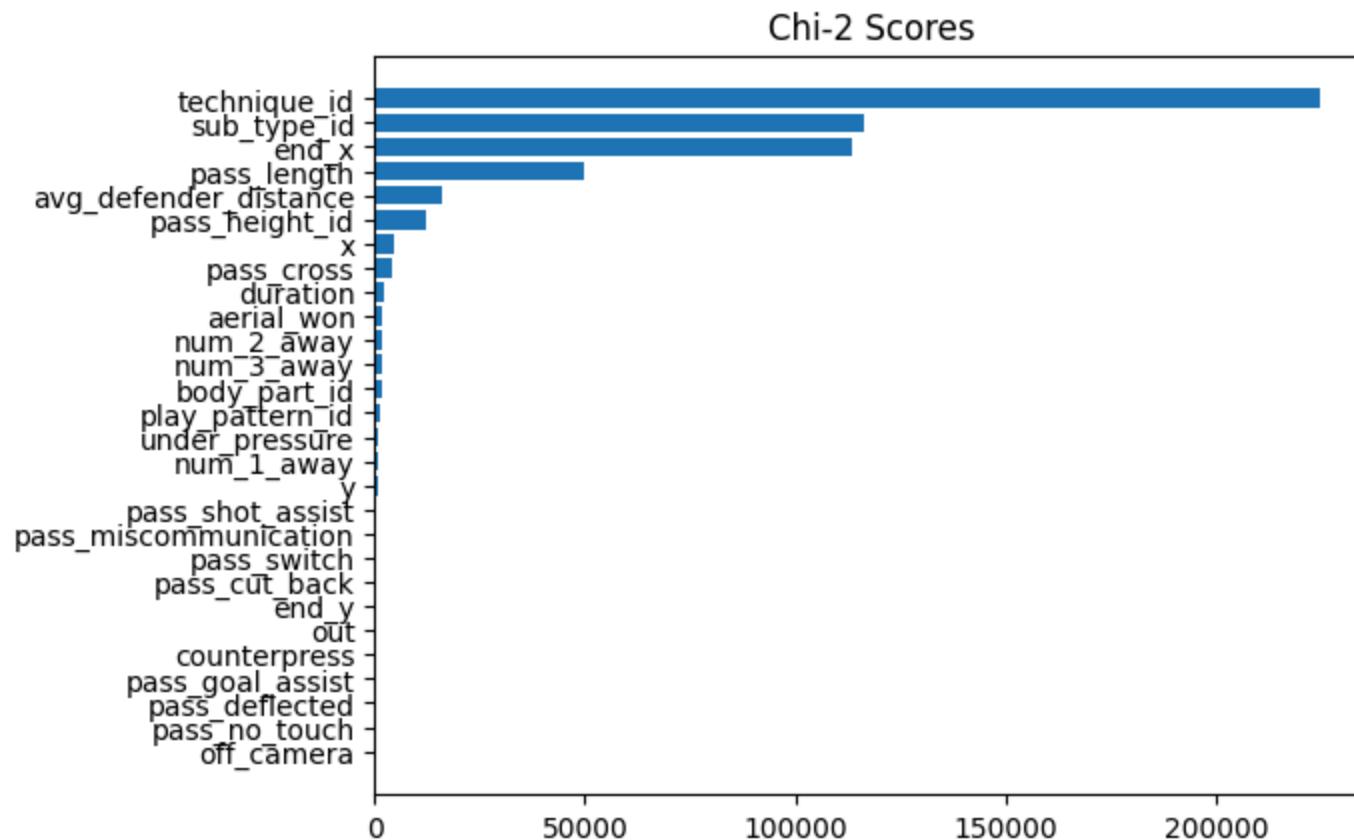
chi_scores = pd.Series(X_kchi.scores_, index=X_all.columns[X_all.columns != 'pass_angle']).sort_values(ascending=True)

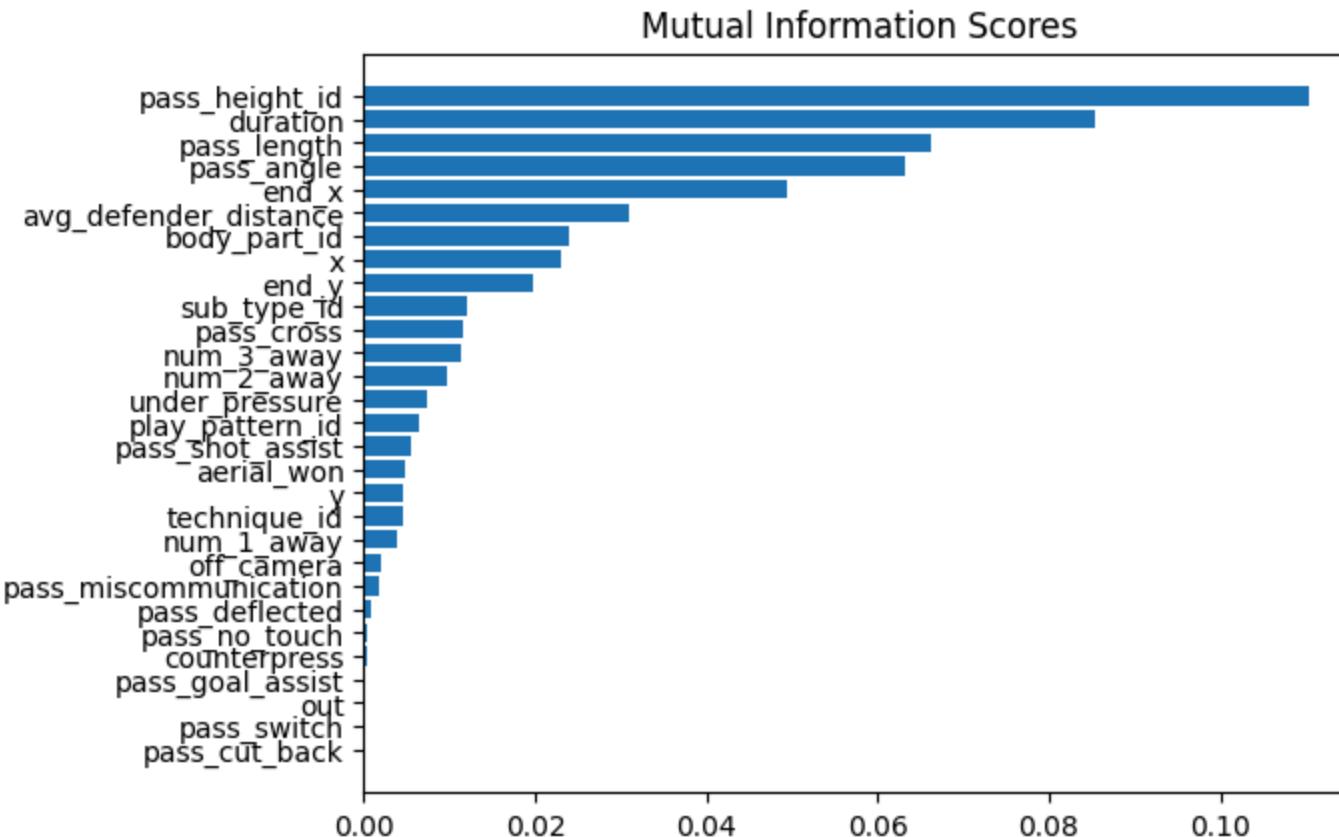
```

```
chi_pvalues = pd.Series(X_kchi.pvalues_, index=X_all.columns[X_all.columns != 'pass_angle']).sort_values(ascending=False)
minfo_scores = pd.Series(X_kmut.scores_, index=X_all.columns).sort_values(ascending=False)

scores = chi_scores.sort_values()
width = np.arange(len(scores))
ticks = list(scores.index)
plt.barh(width, scores)
plt.yticks(width, ticks)
plt.title("Chi-2 Scores")
plt.show()

scores = minfo_scores.sort_values()
width = np.arange(len(scores))
ticks = list(scores.index)
plt.barh(width, scores)
plt.yticks(width, ticks)
plt.title("Mutual Information Scores")
plt.show()
```





```
In [17]: print("In Minfo and not in Chi2: ", set(minfo_scores[minfo_scores > 0].index).difference(chi_pvalues[chi_pvalues < 0.005].index))
print("In Chi2 and not in Minfo: ", set(chi_pvalues[chi_pvalues < 0.005].index).difference(minfo_scores[minfo_scores > 0].index))
print("In Imp but not in Minfo: ", set(imp_features).difference(minfo_scores[minfo_scores > 0].index))
print("In MInfo but not in Imp: ", set(minfo_scores[minfo_scores > 0].index).difference(imp_features))
print("In All but not in Minfo: ", set(all_features).difference(minfo_scores[minfo_scores > 0].index))
print("In MInfo but not in All: ", set(minfo_scores[minfo_scores > 0].index).difference(all_features))
```

In Minfo and not in Chi2: {'pass\_angle', 'pass\_no\_touch', 'off\_camera'}

In Chi2 and not in Minfo: {'pass\_switch', 'pass\_cut\_back', 'out', 'pass\_goal\_assist'}

In Imp but not in Minfo: set()

In MInfo but not in Imp: {'play\_pattern\_id', 'num\_2-away', 'pass\_miscommunication', 'pass\_cross', 'under\_pressure', 'pass\_deflected', 'technique\_id', 'off\_camera', 'pass\_no\_touch', 'counterpress', 'pass\_shot\_assist', 'num\_3-away'}

In All but not in Minfo: {'pass\_switch', 'pass\_cut\_back', 'out', 'pass\_goal\_assist'}

In MInfo but not in All: set()

```
In [18]: # Excluding all but "under_pressure" due to huge imbalance in value_counts
print(X_all["pass_no_touch"].value_counts(normalize=True), "\n")
print(X_all["pass_miscommunication"].value_counts(normalize=True), "\n")
print(X_all["counterpress"].value_counts(normalize=True), "\n")
print(X_all["out"].value_counts(normalize=True), "\n")
print(X_all["off_camera"].value_counts(normalize=True), "\n")
print(X_all["under_pressure"].value_counts(normalize=True), "\n")
print(X_all["pass_shot_assist"].value_counts(normalize=True), "\n")
```

```
pass_no_touch
0    0.999015
1    0.000985
Name: proportion, dtype: float64

pass_miscommunication
0    0.999488
1    0.000512
Name: proportion, dtype: float64

counterpress
0.0    0.996534
1.0    0.003466
Name: proportion, dtype: float64

out
0.0    0.999656
1.0    0.000344
Name: proportion, dtype: float64

off_camera
0.0    0.998717
1.0    0.001283
Name: proportion, dtype: float64

under_pressure
0    0.832394
1    0.167606
Name: proportion, dtype: float64

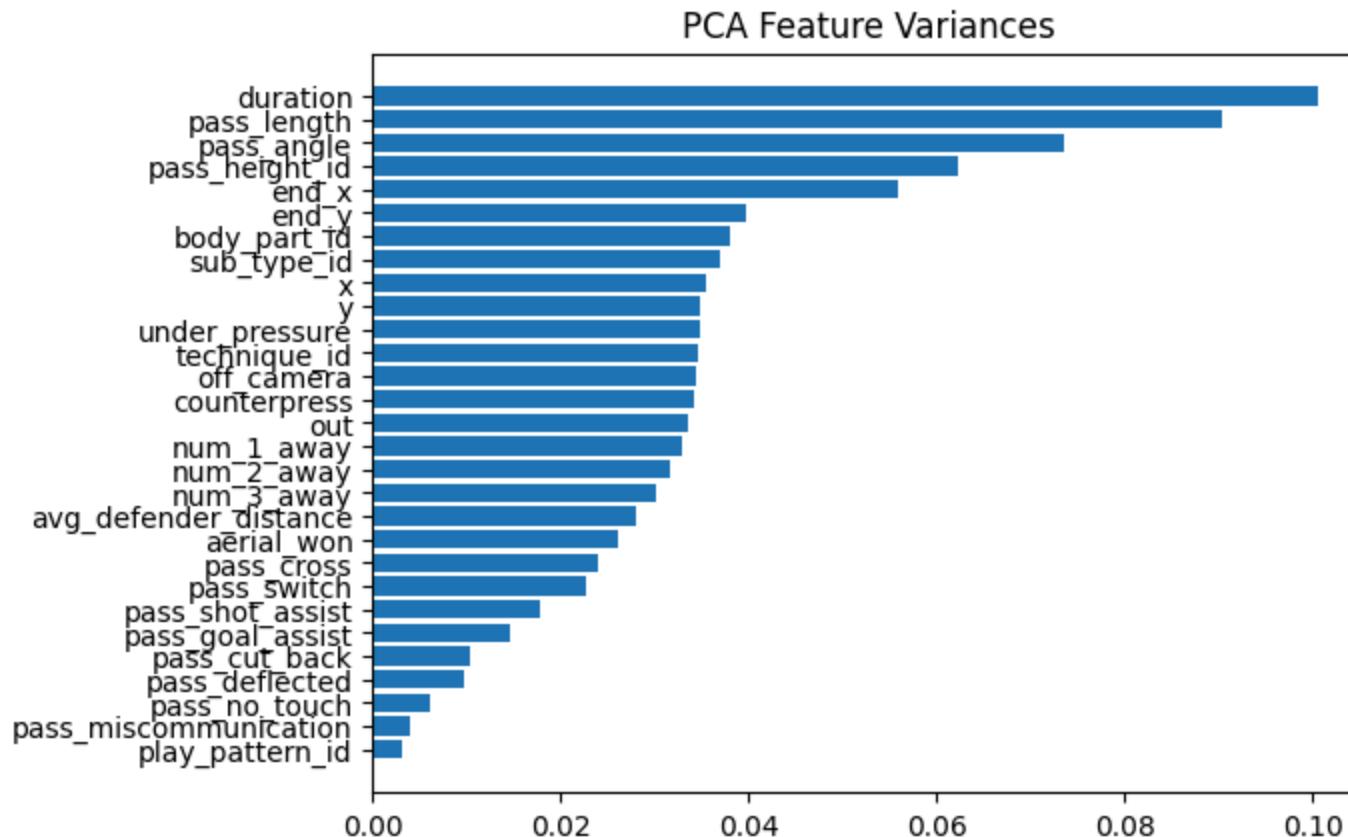
pass_shot_assist
0    0.983607
1    0.016393
Name: proportion, dtype: float64
```

```
In [19]: from sklearn.decomposition import PCA
pca = PCA()
scaler = StandardScaler()
X_all = scaler.fit_transform(X_all)
pca.fit(X_all)
pca_var = pd.Series(pca.explained_variance_ratio_, index=all_features).sort_values(ascending=False)
```

```
pca_sing = pd.Series(pca.singular_values_, index=all_features).sort_values(ascending=False)
print(pca_sing)
```

```
duration           617.895358
pass_length        585.928287
pass_angle         528.212880
pass_height_id    486.529975
end_x              460.943717
end_y              388.509738
body_part_id       379.532358
sub_type_id        374.185332
x                  367.452956
y                  363.800989
under_pressure     363.607254
technique_id       362.303352
off_camera          361.383971
counterpress        359.949412
out                 356.764123
num_1_away          352.981397
num_2_away          346.066183
num_3_away          338.948183
avg_defender_distance 325.837098
aerial_won          314.307292
pass_cross          302.323020
pass_switch         294.034626
pass_shot_assist    260.522124
pass_goal_assist    235.040774
pass_cut_back        197.317969
pass_deflected       192.726943
pass_no_touch        152.810802
pass_miscommunication 123.494560
play_pattern_id      108.661305
dtype: float64
```

```
In [190]: scores = pca_var.sort_values()
width = np.arange(len(scores))
ticks = list(scores.index)
plt.barh(width, scores)
plt.yticks(width, ticks)
plt.title("PCA Feature Variances")
plt.show()
```



## Model Selection

### DT Selection

```
In [21]: # Decision Trees
f = open("DT_params.txt", "w")
for type_, X in X_dict.items():
    # Split the data to train, validation and test
    X_train, X_test, y_train, y_test = train_test_split(X, y, train_size = 0.7, random_state = 123, stratify = y)

    param_grid = {
        'criterion': ['gini', 'entropy', "log_loss"],
        'max_depth': list(np.arange(3, 8)) + [None]
    }
```

```
start_time = time.time()
tree_model = tree.DecisionTreeClassifier(random_state=1234)
tree_gs_cv = GridSearchCV(tree_model, param_grid, scoring='balanced_accuracy',
                         cv=StratifiedKFold(n_splits=10, random_state=1234, shuffle=True))
tree_gs_cv.fit(X_train, y_train)

duration_ = time.time() - start_time

# Get accuracies
train_acc = accuracy_score(tree_gs_cv.predict(X_train), y_train)
test_acc = accuracy_score(tree_gs_cv.predict(X_test), y_test)
# Print Time and Params
print(f"DT Training completing in: {duration_:.3f}s")
print(f"Best Params, Score: {tree_gs_cv.best_params_, tree_gs_cv.best_score_}")

# Show Training and Testing Accuracy
print(f"Training Accuracy: {train_acc}")
print(f"Testing Accuracy: {test_acc}")
print("#####\n")

f.write(f"\nModel {type_}\nTraining completing in: {duration_:.3f}s\nBest Params: {tree_gs_cv.best_params_}\n"
       f"Training Accuracy: {train_acc}\nTesting Accuracy: {test_acc}\n")
f.close()
```

```

DT Training completing in: 98.483s
Best Params, Score: ({'criterion': 'gini', 'max_depth': 5}, 0.7618943977073764)
Training Accuracy: 0.8518231694680468
Testing Accuracy: 0.8497442292520296
#####
DT Training completing in: 114.472s
Best Params, Score: ({'criterion': 'gini', 'max_depth': 6}, 0.7827146987173829)
Training Accuracy: 0.8630795911911956
Testing Accuracy: 0.859033415621103
#####
DT Training completing in: 420.348s
Best Params, Score: ({'criterion': 'gini', 'max_depth': 5}, 0.7945406497087782)
Training Accuracy: 0.8592729136898594
Testing Accuracy: 0.8576336752093248
#####

```

## XGB Selection

```

In [23]: # XGB
f = open("XGB_params.txt", "w")
for type_, X in X_dict.items():
    #split the data to train, validation and test
    X_train, X_test, y_train, y_test = train_test_split(X, y, train_size = 0.7, random_state = 123, stratify=y)

    param_grid = {
        "learning_rate": [0.01, 0.001],
        "n_estimators": [2000],
        "max_depth": list(np.arange(3, 8)) + [None],
    }

    start_time = time.time()
    xgb_tree_model = XGBClassifier(random_state=1234)
    xgb_tree_gs_cv = RandomizedSearchCV(
        xgb_tree_model, param_distributions=param_grid, scoring='balanced_accuracy',
        cv=StratifiedKFold(n_splits=10, random_state=1234, shuffle=True), verbose=2)
    xgb_tree_gs_cv.fit(X_train, y_train)

    duration_ = time.time() - start_time
    f.write(f"Type: {type_} \n")
    f.write(f"Duration: {duration_} \n")
    f.write(f"Best Params, Score: {xgb_tree_gs_cv.best_params_, xgb_tree_gs_cv.best_score_} \n")
    f.write(f"Training Accuracy: {xgb_tree_gs_cv.score(X_train, y_train)} \n")
    f.write(f"Testing Accuracy: {xgb_tree_gs_cv.score(X_test, y_test)} \n")
    f.write("##### \n")

```

```
# Get accuracies
train_acc = accuracy_score(xgb_tree_gs_cv.predict(X_train), y_train)
test_acc = accuracy_score(xgb_tree_gs_cv.predict(X_test), y_test)
# Print Time and Params
print(f"XGB Training completing in: {duration_.3f}s")
print(f"Best Params, Score: {xgb_tree_gs_cv.best_params_, xgb_tree_gs_cv.best_score_}")

# Show Training and Testing Accuracy
print(f"Training Accuracy: {train_acc}")
print(f"Testing Accuracy: {test_acc}")
print("#####\n")

f.write(f"\nModel {type_}\nTraining completing in: {duration_.3f}s\nBest Params: {xgb_tree_gs_cv.best_
    \nTraining Accuracy: {train_acc}\nTesting Accuracy: {test_acc}\n")
f.close()
```

Fitting 10 folds for each of 10 candidates, totalling 100 fits



```
[CV] END .learning_rate=0.01, max_depth=3, n_estimators=2000; total time= 3.5s
[CV] END .learning_rate=0.01, max_depth=3, n_estimators=2000; total time= 3.9s
[CV] END .learning_rate=0.01, max_depth=3, n_estimators=2000; total time= 4.5s
[CV] END .learning_rate=0.01, max_depth=3, n_estimators=2000; total time= 3.8s
[CV] END .learning_rate=0.01, max_depth=3, n_estimators=2000; total time= 3.6s
[CV] END .learning_rate=0.01, max_depth=3, n_estimators=2000; total time= 3.4s
[CV] END .learning_rate=0.01, max_depth=3, n_estimators=2000; total time= 3.4s
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 8.5s
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 8.3s
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 9.6s
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 9.2s
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 9.0s
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 8.8s
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 8.5s
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 8.4s
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 9.1s
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 9.8s
XGB Training completing in: 590.230s
Best Params, Score: ({'n_estimators': 2000, 'max_depth': None, 'learning_rate': 0.01}, 0.798026488724982)
Training Accuracy: 0.8985722232523642
Testing Accuracy: 0.8810475148245235
#####

```

```
Fitting 10 folds for each of 10 candidates, totalling 100 fits
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 6.1s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 6.1s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 5.9s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 5.9s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 5.9s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 6.1s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 6.3s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 6.1s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 6.2s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 6.3s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 6.9s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 6.8s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 6.9s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 6.8s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 6.8s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 6.8s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 6.9s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 6.8s
```



XGB Training completing in: 1327.743s

Best Params, Score: ({'n\_estimators': 2000, 'max\_depth': 7, 'learning\_rate': 0.01}, 0.8034163426078182)

Training Accuracy: 0.9116174561795792

Testing Accuracy: 0.8864428778662866

#####

Fitting 10 folds for each of 10 candidates, totalling 100 fits

```
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 7.1s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 7.2s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 6.9s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 7.3s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 7.7s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 19.0s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 7.0s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 7.2s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 7.3s
[CV] END learning_rate=0.01, max_depth=None, n_estimators=2000; total time= 6.8s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 8.0s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 8.5s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 8.5s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 8.2s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 8.4s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 8.2s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 8.7s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 8.5s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 8.5s
[CV] END learning_rate=0.001, max_depth=None, n_estimators=2000; total time= 8.4s
[CV] END learning_rate=0.001, max_depth=3, n_estimators=2000; total time= 4.7s
[CV] END learning_rate=0.001, max_depth=3, n_estimators=2000; total time= 4.9s
[CV] END learning_rate=0.001, max_depth=3, n_estimators=2000; total time= 4.4s
[CV] END learning_rate=0.001, max_depth=3, n_estimators=2000; total time= 4.4s
[CV] END learning_rate=0.001, max_depth=3, n_estimators=2000; total time= 4.5s
[CV] END learning_rate=0.001, max_depth=3, n_estimators=2000; total time= 4.7s
[CV] END learning_rate=0.001, max_depth=3, n_estimators=2000; total time= 4.7s
[CV] END learning_rate=0.001, max_depth=3, n_estimators=2000; total time= 4.5s
[CV] END learning_rate=0.001, max_depth=3, n_estimators=2000; total time= 4.7s
[CV] END learning_rate=0.001, max_depth=3, n_estimators=2000; total time= 4.5s
[CV] END .learning_rate=0.01, max_depth=6, n_estimators=2000; total time= 7.4s
[CV] END .learning_rate=0.01, max_depth=6, n_estimators=2000; total time= 7.2s
[CV] END .learning_rate=0.01, max_depth=6, n_estimators=2000; total time= 7.2s
[CV] END .learning_rate=0.01, max_depth=6, n_estimators=2000; total time= 6.9s
[CV] END .learning_rate=0.01, max_depth=6, n_estimators=2000; total time= 7.4s
[CV] END .learning_rate=0.01, max_depth=6, n_estimators=2000; total time= 7.2s
```



```
[CV] END learning_rate=0.001, max_depth=7, n_estimators=2000; total time= 10.6s
[CV] END .learning_rate=0.01, max_depth=7, n_estimators=2000; total time= 8.7s
[CV] END .learning_rate=0.01, max_depth=7, n_estimators=2000; total time= 8.4s
[CV] END .learning_rate=0.01, max_depth=7, n_estimators=2000; total time= 9.0s
[CV] END .learning_rate=0.01, max_depth=7, n_estimators=2000; total time= 8.8s
[CV] END .learning_rate=0.01, max_depth=7, n_estimators=2000; total time= 9.0s
[CV] END .learning_rate=0.01, max_depth=7, n_estimators=2000; total time= 13.0s
[CV] END .learning_rate=0.01, max_depth=7, n_estimators=2000; total time= 9.7s
[CV] END .learning_rate=0.01, max_depth=7, n_estimators=2000; total time= 11.6s
[CV] END .learning_rate=0.01, max_depth=7, n_estimators=2000; total time= 12.4s
[CV] END .learning_rate=0.01, max_depth=7, n_estimators=2000; total time= 9.7s
[CV] END learning_rate=0.001, max_depth=5, n_estimators=2000; total time= 7.8s
[CV] END learning_rate=0.001, max_depth=5, n_estimators=2000; total time= 7.9s
[CV] END learning_rate=0.001, max_depth=5, n_estimators=2000; total time= 7.8s
[CV] END learning_rate=0.001, max_depth=5, n_estimators=2000; total time= 7.2s
[CV] END learning_rate=0.001, max_depth=5, n_estimators=2000; total time= 7.8s
[CV] END learning_rate=0.001, max_depth=5, n_estimators=2000; total time= 7.5s
[CV] END learning_rate=0.001, max_depth=5, n_estimators=2000; total time= 7.1s
[CV] END learning_rate=0.001, max_depth=5, n_estimators=2000; total time= 6.9s
[CV] END learning_rate=0.001, max_depth=5, n_estimators=2000; total time= 6.8s
[CV] END learning_rate=0.001, max_depth=5, n_estimators=2000; total time= 7.5s
XGB Training completing in: 1266.401s
Best Params, Score: ({'n_estimators': 2000, 'max_depth': 7, 'learning_rate': 0.01}, 0.8234712270293073)
Training Accuracy: 0.9162203728144327
Testing Accuracy: 0.897895299417199
#####
```

## NN Selection

```
In [26]: neg, pos = np.bincount(np.where(clean_pass_df["outcome_id"].isnull(), 1, 0))
total = neg + pos
print('Total: {}\nPositive: {} ( {:.2f} % of total)\n'.format(
    total, pos, 100 * pos / total))
```

```
Total: 130974
Positive: 105004 (80.17% of total)
```

```
In [27]: colors = plt.rcParams['axes.prop_cycle'].by_key()['color']
def plot_loss(history, label, n):
    # Use a log scale on y-axis to show the wide range of values.
```

```
plt.semilogy(history.epoch, history.history['loss'],
             color=colors[n], label='Train ' + label)
plt.semilogy(history.epoch, history.history['val_loss'],
             color=colors[n], label='Val ' + label,
             linestyle="--")
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()
plt.show()
```

```
In [28]: METRICS = [
    keras.metrics.BinaryCrossentropy(name='cross entropy'),
    keras.metrics.MeanSquaredError(name='Brier score'),
    keras.metrics.TruePositives(name='tp'),
    keras.metrics.FalsePositives(name='fp'),
    keras.metrics.TrueNegatives(name='tn'),
    keras.metrics.FalseNegatives(name='fn'),
    keras.metrics.BinaryAccuracy(name='accuracy'),
    keras.metrics.Precision(name='precision'),
    keras.metrics.Recall(name='recall'),
    keras.metrics.AUC(name='auc'),
    keras.metrics.AUC(name='prc', curve='PR'),
]

def create_nn_model(input_dim, hidden_layers, neurons_per_layer, dropout_rate=0.2, output_bias=None):
    if output_bias is not None:
        output_bias = tf.keras.initializers.Constant(output_bias)
    model = Sequential()
    model.add(Dense(neurons_per_layer[0], activation='relu', input_dim=input_dim))
    model.add(BatchNormalization())

    for i in range(1, hidden_layers):
        model.add(Dense(neurons_per_layer[i], activation='relu'))
        model.add(BatchNormalization())

    model.add(Dropout(dropout_rate))
    model.add(Dense(1, activation='sigmoid', bias_initializer=output_bias))

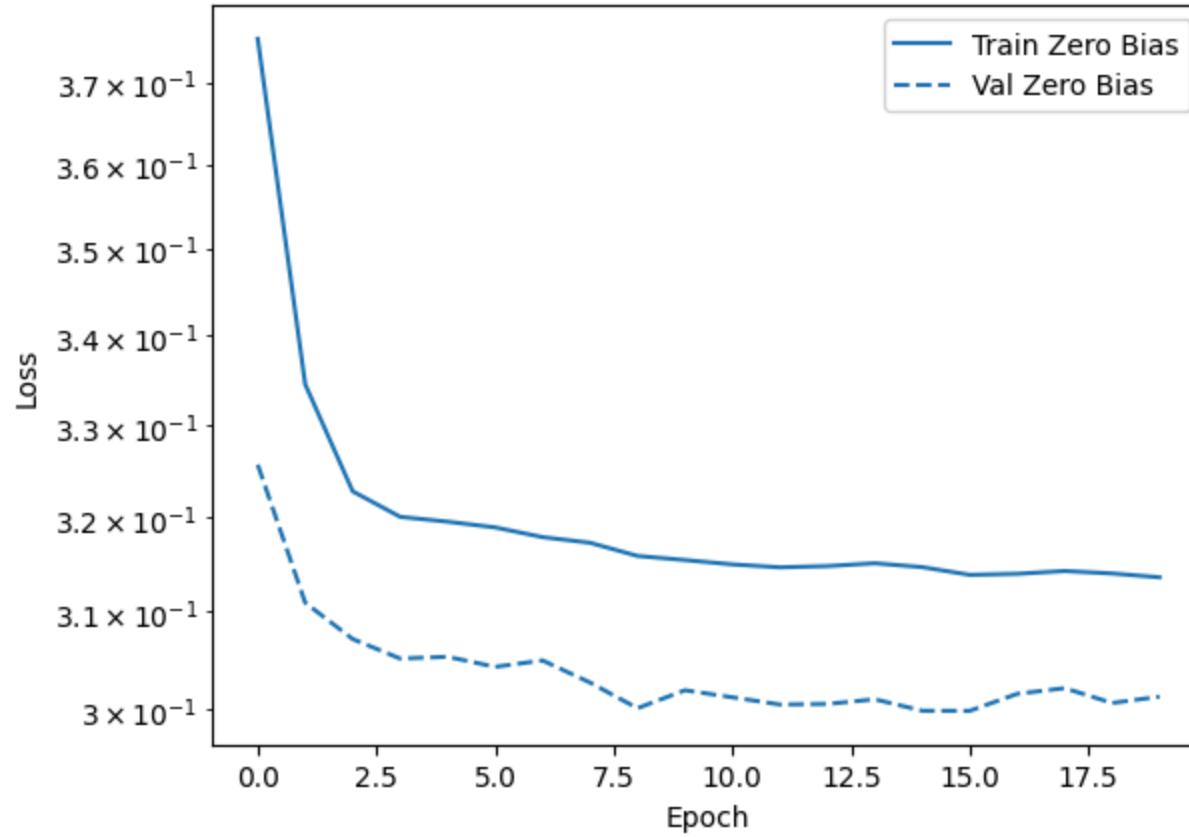
    model.compile(optimizer=Adam(), loss='binary_crossentropy', metrics=METRICS)
    return model
```

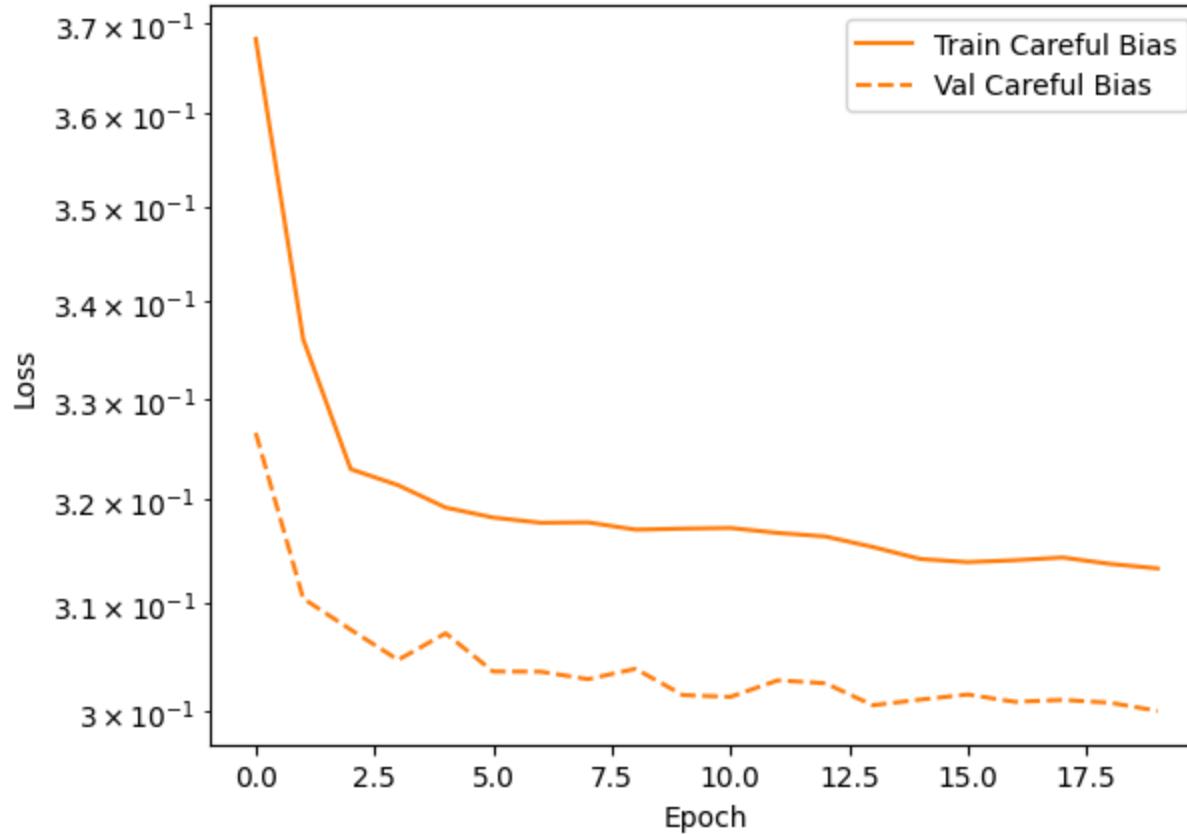
```
In [30]: # Split data
X_train, X_val, y_train, y_val = train_test_split(X_basic, y, train_size = 0.7, random_state = 123, stratify=y)

# Scale data
scaler = StandardScaler()
X_train = scaler.fit_transform(X_train)
X_val = scaler.transform(X_val)

model1 = create_nn_model(X_train.shape[1], 1, [32], output_bias=0.0)
zero_bias_history = model1.fit(
    X_train,
    y_train,
    batch_size=32,
    epochs=20,
    validation_data=(X_val, y_val),
    verbose=0)

model2 = create_nn_model(X_train.shape[1], 1, [32], output_bias=np.log([pos/neg]))
careful_bias_history = model2.fit(
    X_train,
    y_train,
    batch_size=32,
    epochs=20,
    validation_data=(X_val, y_val),
    verbose=0)
plot_loss(zero_bias_history, "Zero Bias", 0)
plot_loss(careful_bias_history, "Careful Bias", 1)
```





```
In [228]: def train_and_evaluate_model(model, X_train, y_train, X_val, y_val, X_cal, y_cal, epochs=100, batch_size=32):
    start_time = time.time()
    early_stopping = EarlyStopping(monitor='val_prc', patience=10, restore_best_weights=True)

    history = model.fit(
        X_train, y_train,
        validation_data=(X_val, y_val),
        epochs=epochs,
        batch_size=batch_size,
        callbacks=[early_stopping],
        verbose=0
    )

    # plot_loss(history, "History", 1)
```

```

## Metrics
y_pred = (model.predict(X_cal) > 0.5).astype(int)
accuracy = accuracy_score(y_cal, y_pred)
precision = precision_score(y_cal, y_pred)
recall = recall_score(y_cal, y_pred)
f1 = f1_score(y_cal, y_pred)
brier_score = brier_score_loss(y_cal, y_pred)
time_ = round(time.time() - start_time, 4)
print(f"Training completed in: {time_}s")

y_pred = model.predict(X_cal)

fig, axs = plt.subplots()
#ROC CURVE
fpr, tpr, _ = roc_curve(y_cal, y_pred)
auc = roc_auc_score(y_cal, y_pred)
axs.plot(fpr,tpr,label= "AUC = " + str(auc)[:4])
axs.plot([0, 1], [0, 1], color='black', ls = '--')
axs.legend()
axs.set_ylabel('True Positive Rate')
axs.set_xlabel('False Positive Rate')
axs.set_title('ROC curve')

return accuracy, precision, recall, f1, brier_score, time_, history

```

In [220...]

```

def model_selection(X, y):
    # Split data
    X_train, X_test, y_train, y_test = train_test_split(X, y, train_size = 0.6, random_state = 123, stratify=y)
    X_cal, X_val, y_cal, y_val = train_test_split(X_test, y_test, train_size = 0.5, random_state = 123, stratify=y)

    # Scale data
    scaler = StandardScaler()
    X_train = scaler.fit_transform(X_train)
    X_val = scaler.transform(X_val)
    X_cal = scaler.transform(X_cal)

    # Architectures to test
    architectures = [
        # (1, [64]),
        # (1, [32]),
        # (2, [64, 32]),
        # (2, [64, 16]),

```

```

        (2, [32, 16])
        # ,
        # (2, [32, 8]),
        # (3, [128, 64, 32]),
        # (3, [64, 32, 16]),
        # (3, [32, 16, 8]),
        # (4, [128, 64, 32, 16])
    ]

results = []

for hidden_layers, neurons_per_layer in architectures:
    model = create_nn_model(X_train.shape[1], hidden_layers, neurons_per_layer)

    print(f"\n#####\t{neurons_per_layer}\t#####")
    accuracy, precision, recall, f1, brier_score, time_, history = train_and_evaluate_model(
        model, X_train, y_train, X_val, y_val, X_cal, y_cal
    )

    results.append({
        'Hidden Layers': hidden_layers,
        'Neurons per Layer': neurons_per_layer,
        'Accuracy': accuracy,
        'Precision': precision,
        'Recall': recall,
        'F1 Score': f1,
        'Brier Score': brier_score,
        'Time': time_
    })

# Return results
results_df = pd.DataFrame(results)
return results_df

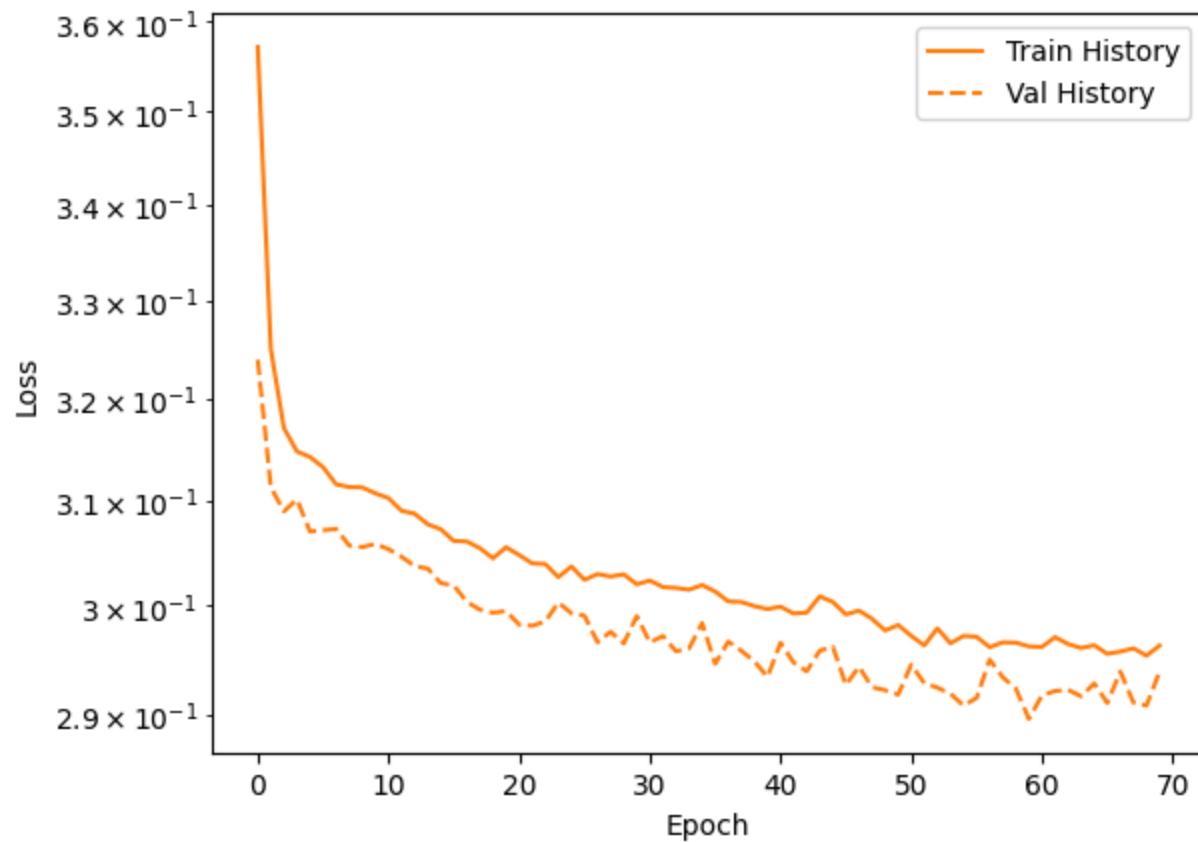
```

In [33]:

```

basic_models_results_df = model_selection(X_basic, y)
print(basic_models_results_df.to_string(index=False))
# Find the best model
best_model = basic_models_results_df.loc[basic_models_results_df['F1 Score'].idxmax()]
print("\nBest Model:")
print(best_model.to_string())
#####
([64]) #####

```

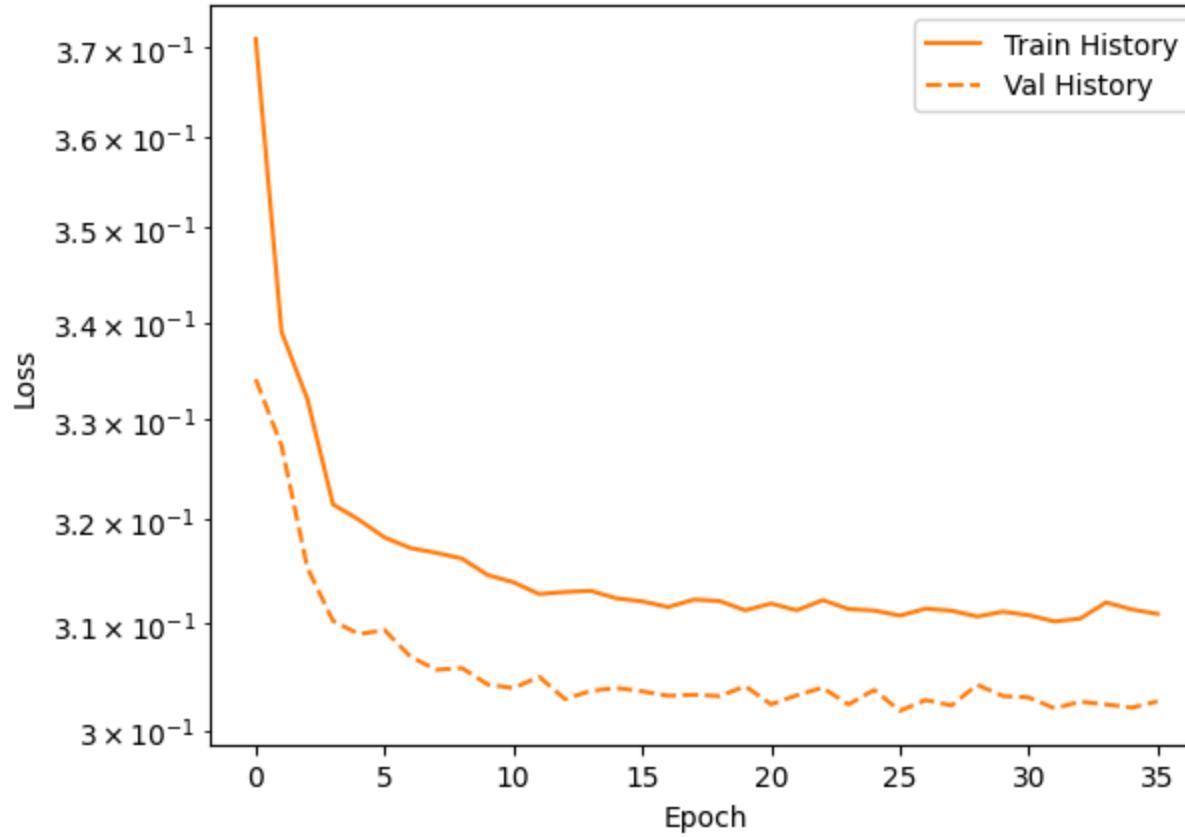


819/819 0s 408us/step

Training completed in: 141.8061s

819/819 0s 346us/step

##### ([32]) #####

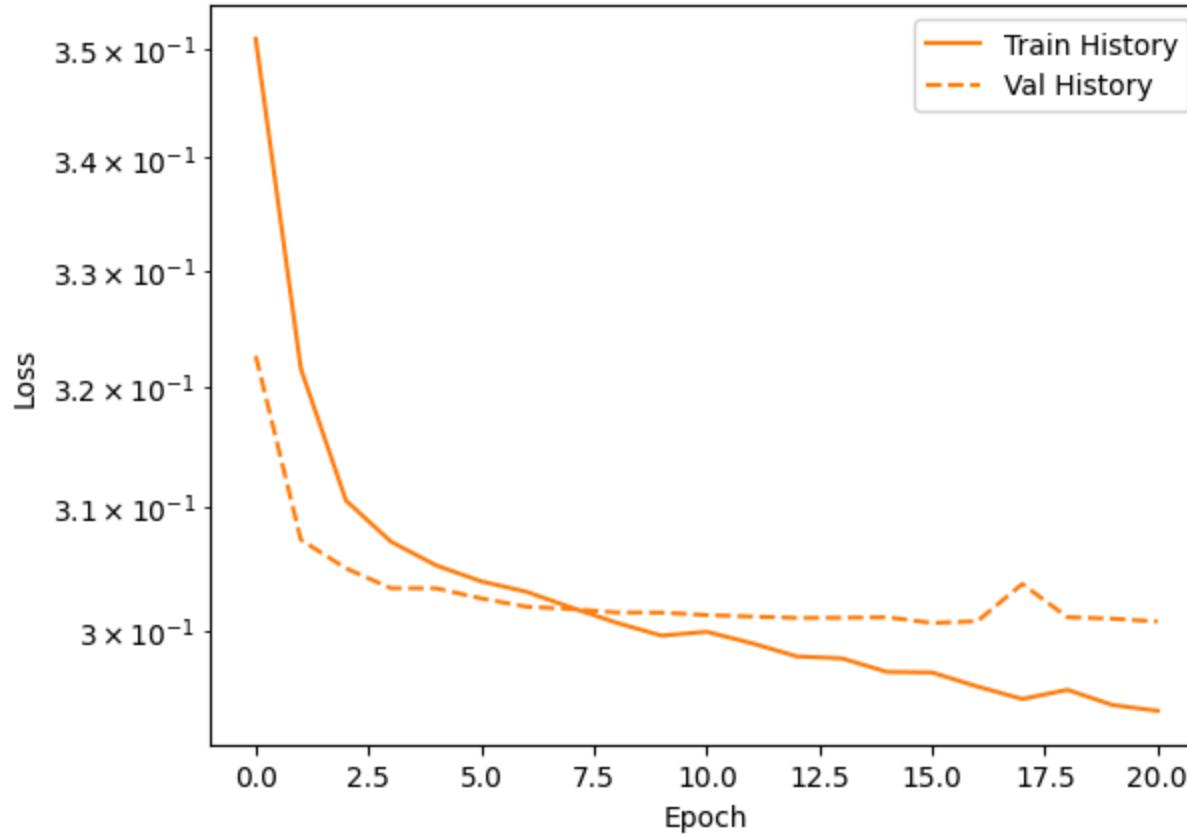


819/819 ————— 0s 559us/step

Training completed in: 71.399s

819/819 ————— 0s 348us/step

##### ([64, 32]) #####

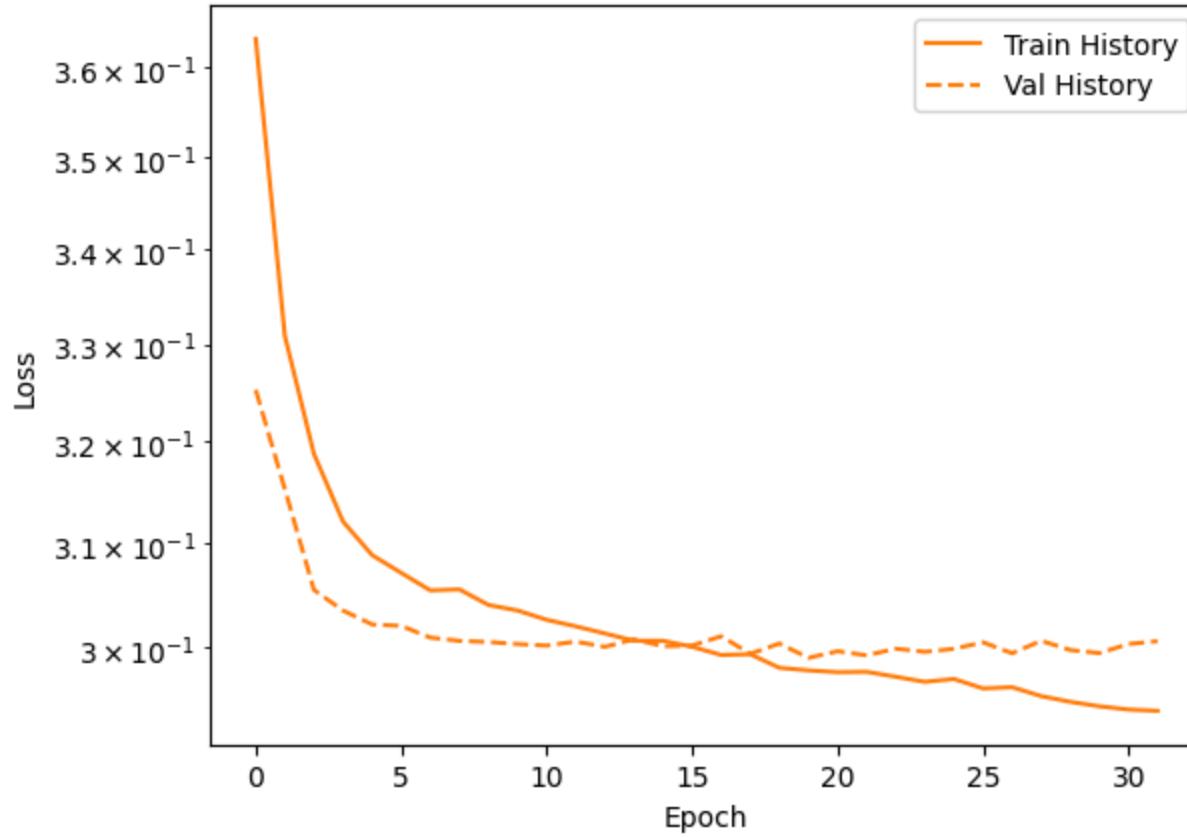


819/819 ————— 1s 551us/step

Training completed in: 49.8187s

819/819 ————— 0s 371us/step

##### ([64, 16]) #####

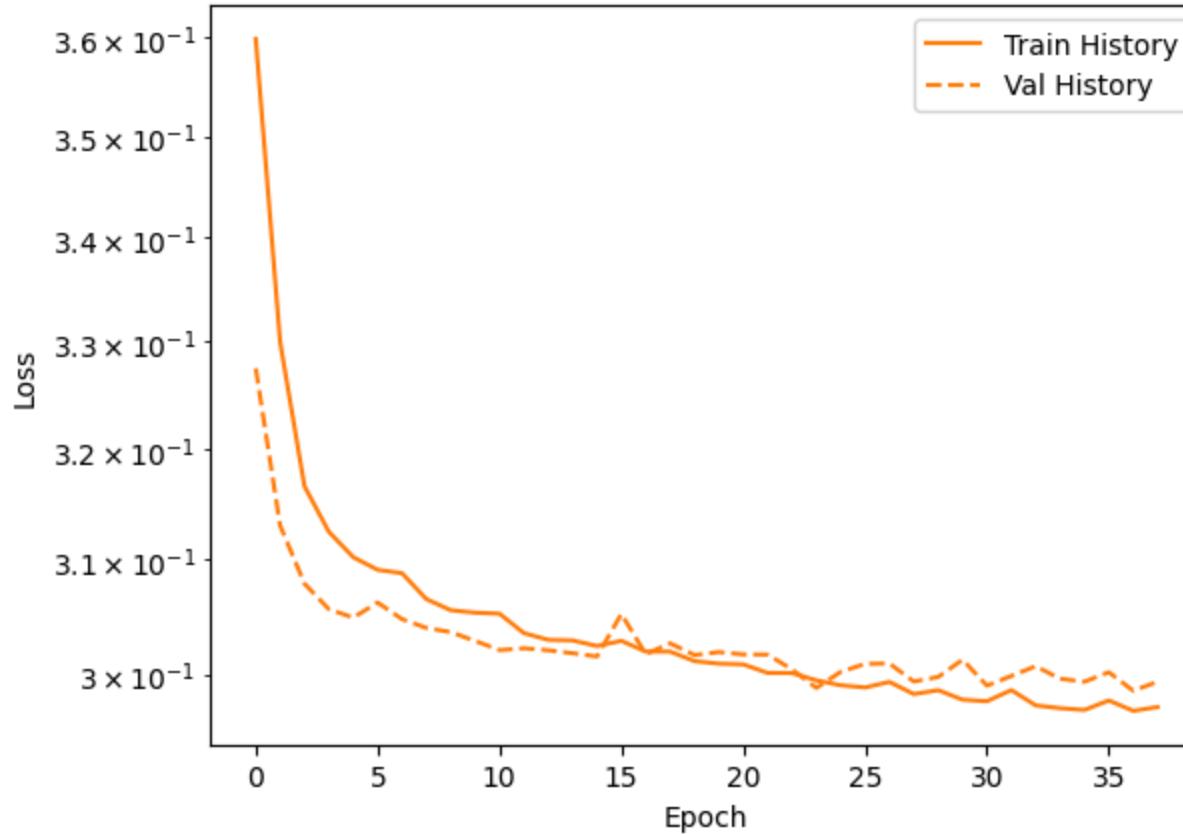


819/819 ————— 0s 432us/step

Training completed in: 335.4212s

819/819 ————— 0s 371us/step

##### ([32, 16]) #####

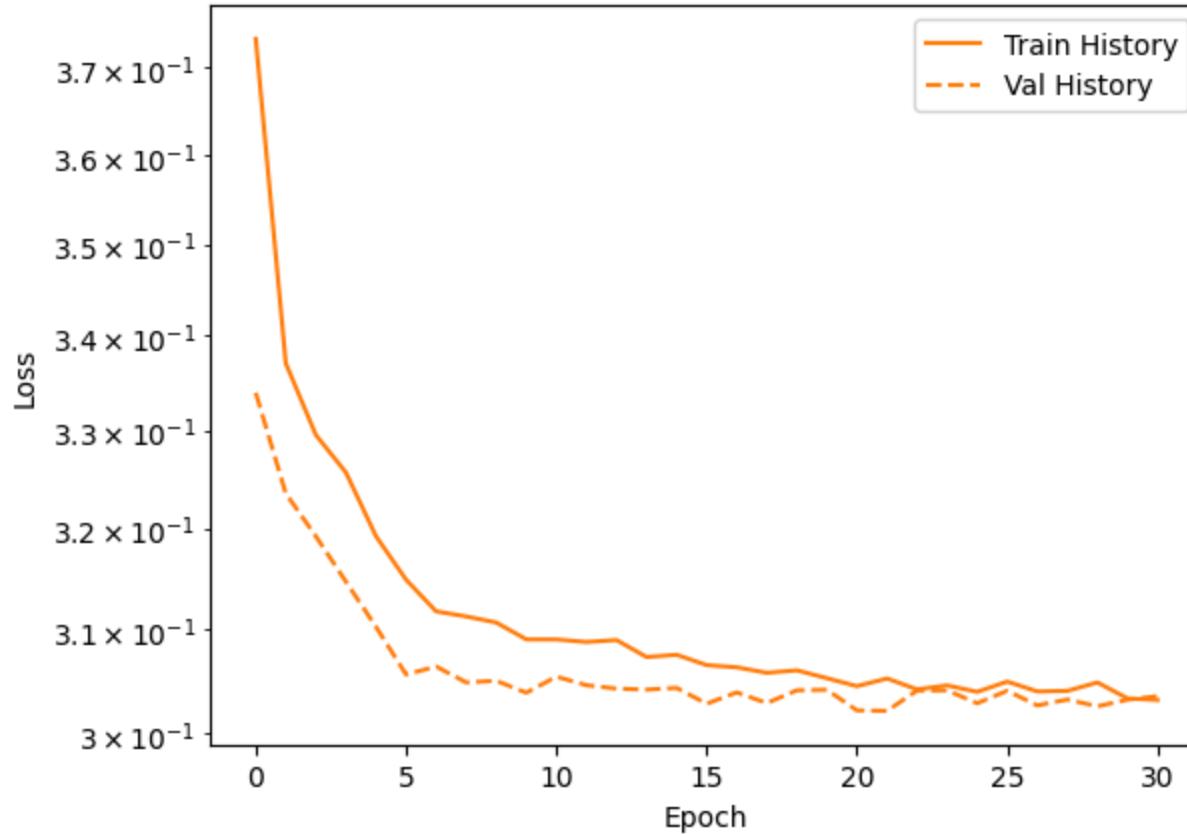


819/819 ————— 0s 464us/step

Training completed in: 87.2158s

819/819 ————— 0s 369us/step

##### ([32, 8]) #####

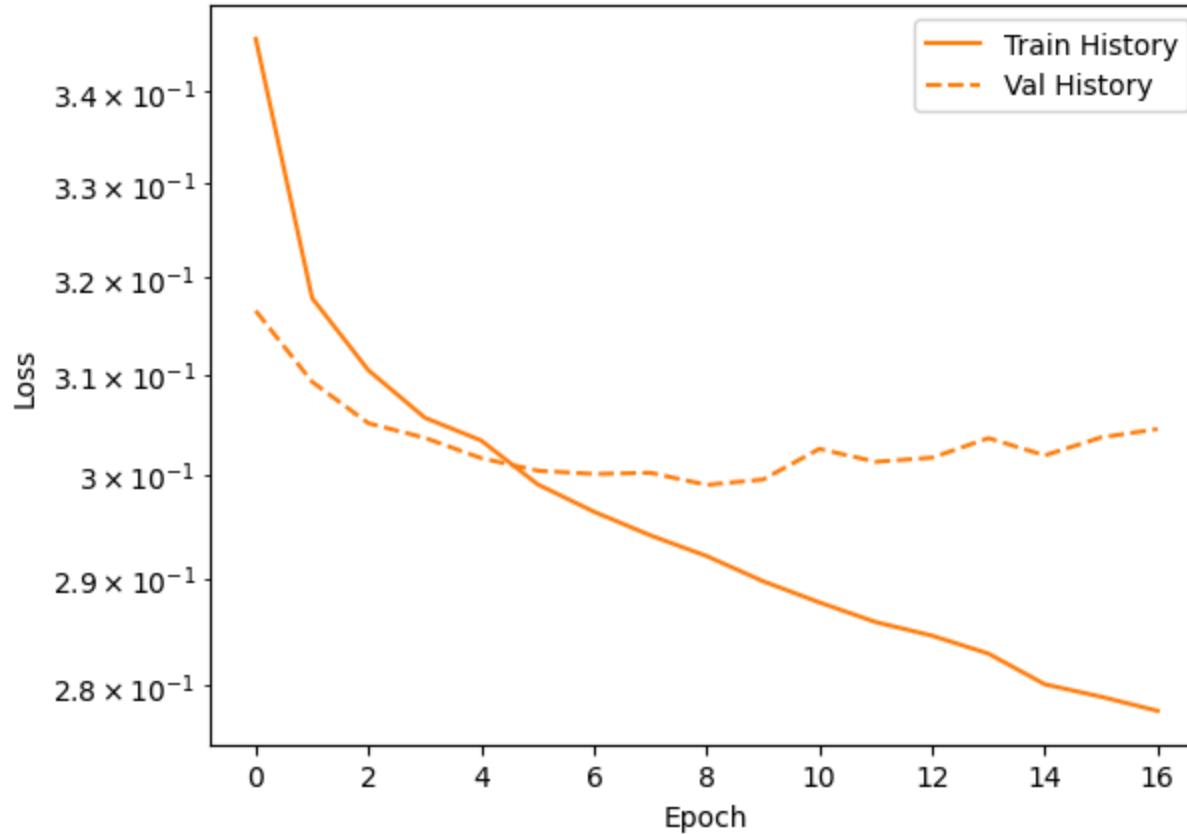


819/819 ————— 0s 525us/step

Training completed in: 70.3218s

819/819 ————— 0s 369us/step

##### ([128, 64, 32]) #####

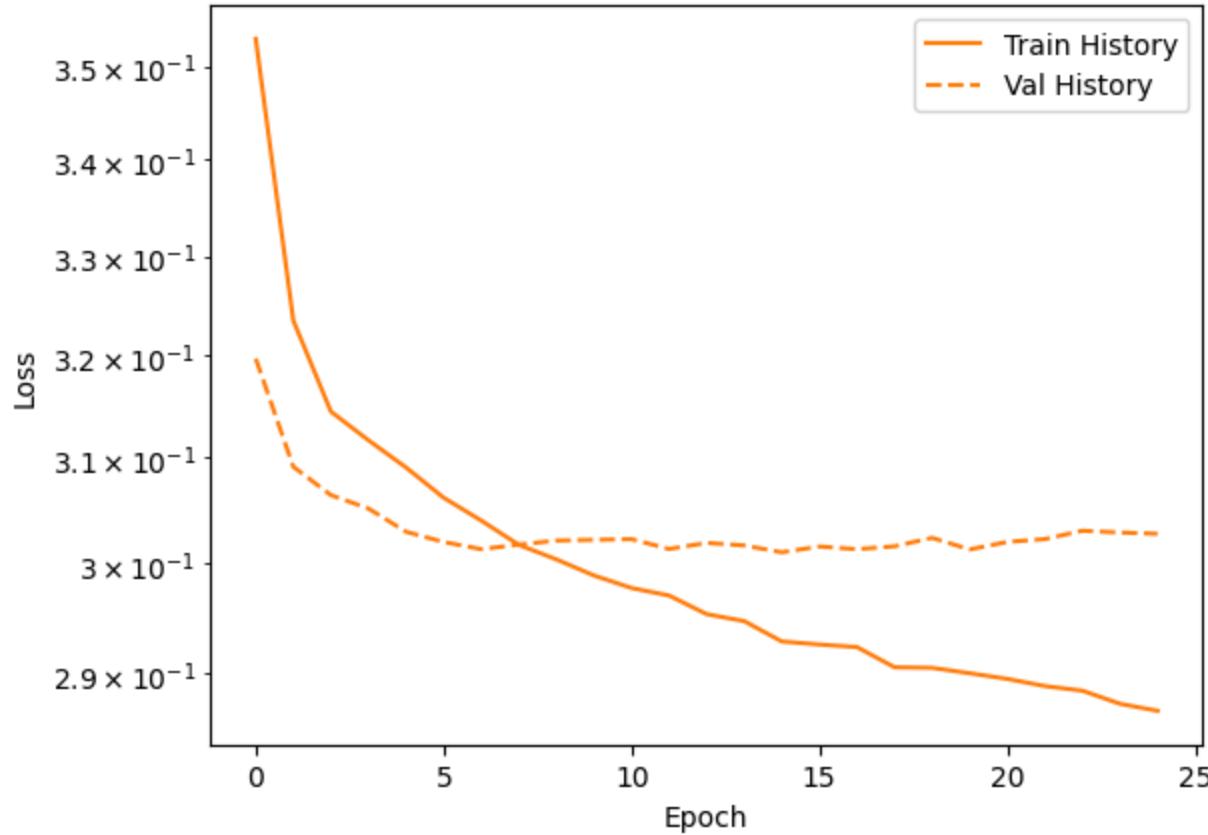


819/819  0s 522us/step

Training completed in: 49.2833s

819/819  0s 524us/step

##### ([64, 32, 16]) #####

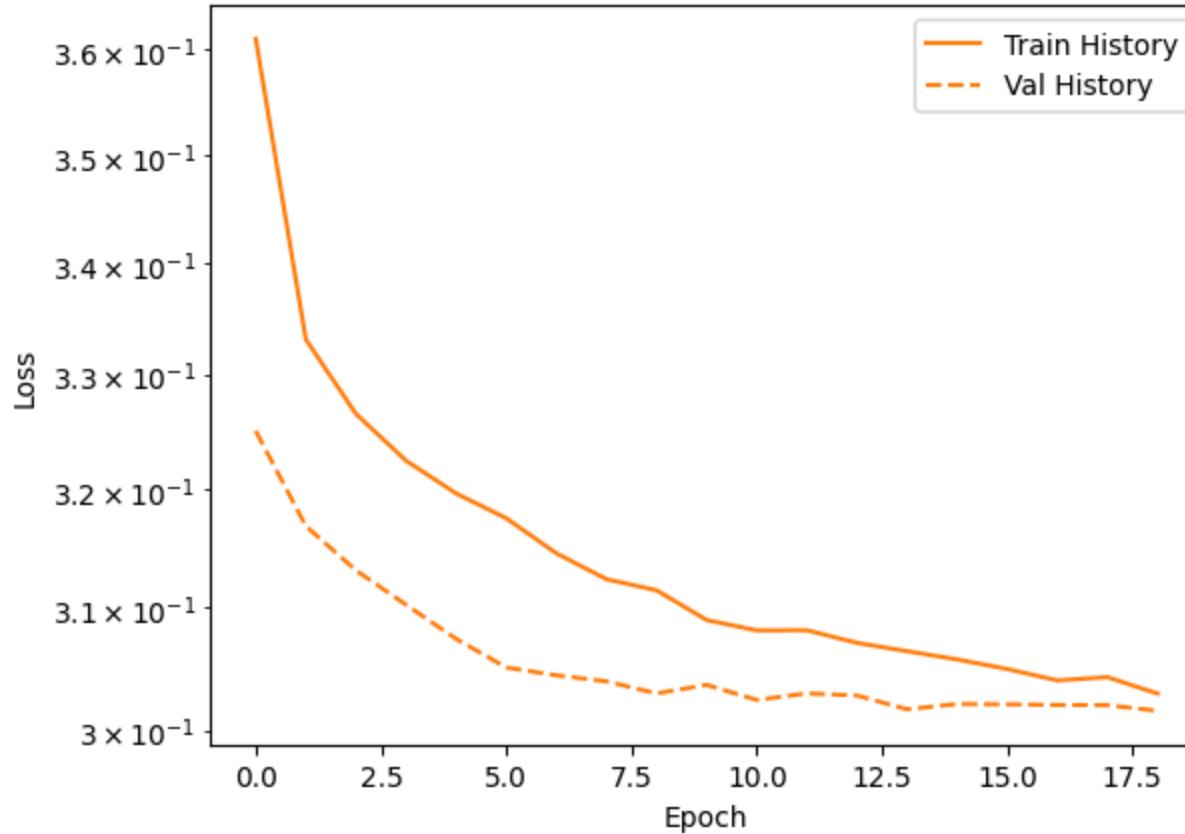


819/819 ————— 0s 494us/step

Training completed in: 64.6401s

819/819 ————— 0s 405us/step

##### ([32, 16, 8]) #####

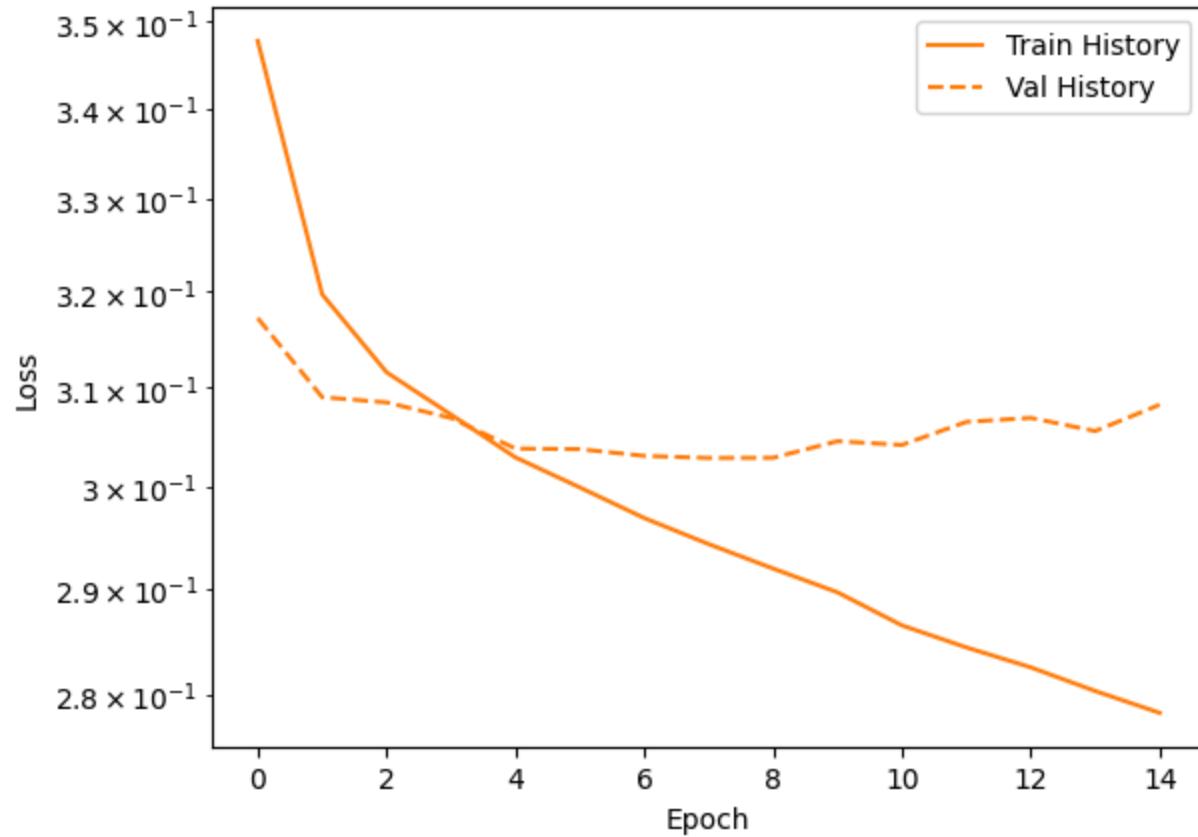


819/819 ————— 1s 660us/step

Training completed in: 48.9802s

819/819 ————— 0s 398us/step

##### ([128, 64, 32, 16]) #####



**819/819** ————— 1s 519us/step

Training completed in: 46.992s

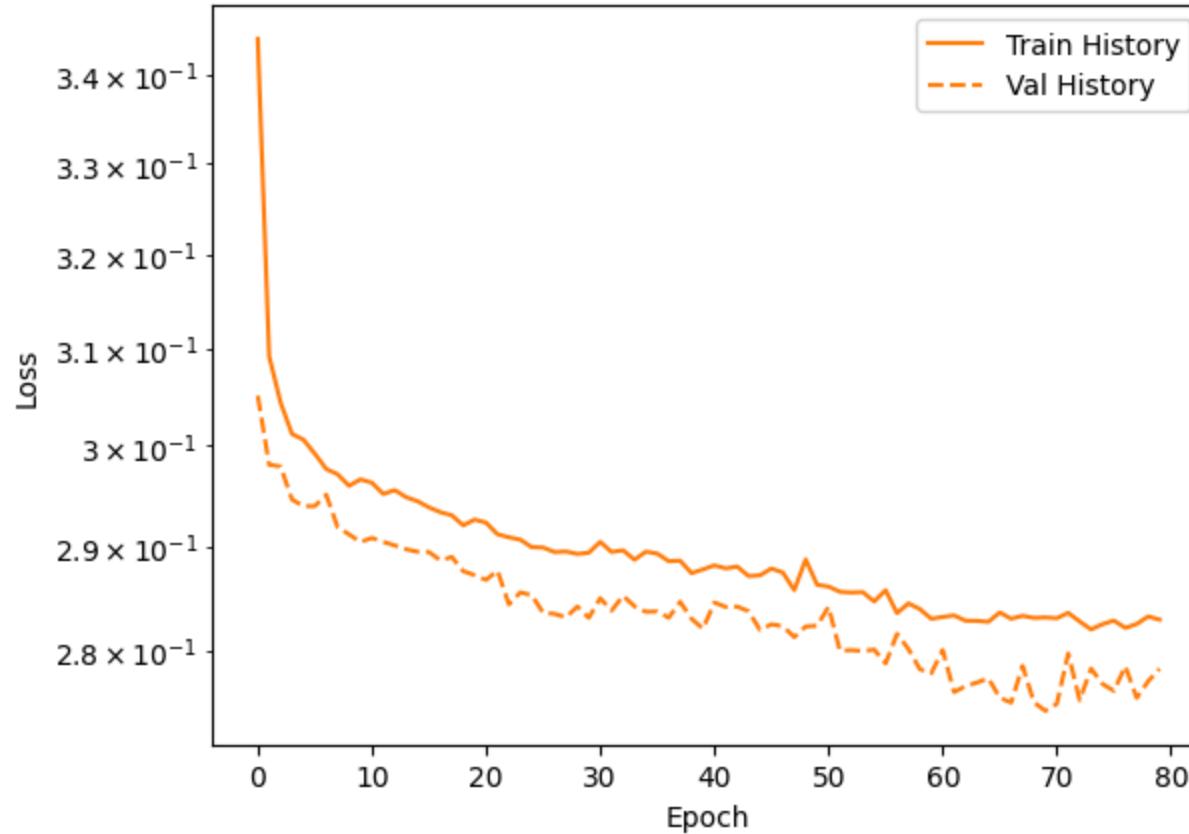
**819/819** ————— 0s 442us/step

Hidden Layers	Neurons per Layer	Accuracy	Precision	Recall	F1 Score	Brier Score	Time
1	[64]	0.874594	0.910131	0.936003	0.922886	0.125406	141.8061
1	[32]	0.869822	0.907936	0.932146	0.919882	0.130178	71.3990
2	[64, 32]	0.870510	0.911022	0.929241	0.920041	0.129490	49.8187
2	[64, 16]	0.870204	0.909078	0.931241	0.920026	0.129796	335.4212
2	[32, 16]	0.869822	0.909341	0.930384	0.919742	0.130178	87.2158
2	[32, 8]	0.869364	0.910859	0.927861	0.919281	0.130636	70.3218
3	[128, 64, 32]	0.870510	0.912138	0.927861	0.919932	0.129490	49.2833
3	[64, 32, 16]	0.870739	0.910243	0.930527	0.920273	0.129261	64.6401
3	[32, 16, 8]	0.868715	0.907093	0.931670	0.919217	0.131285	48.9802
4	[128, 64, 32, 16]	0.868525	0.905680	0.933194	0.919231	0.131475	46.9920

Best Model:

Hidden Layers 1  
Neurons per Layer [64]  
Accuracy 0.874594  
Precision 0.910131  
Recall 0.936003  
F1 Score 0.922886  
Brier Score 0.125406  
Time 141.8061

```
In [34]: imp_models_results_df = model_selection(X_imp, y)
print(imp_models_results_df.to_string(index=False))
# Find the best model
best_model = imp_models_results_df.loc[imp_models_results_df['F1 Score'].idxmax()]
print("\nBest Model:")
print(best_model.to_string())
#####
([64]) #####
#####
```

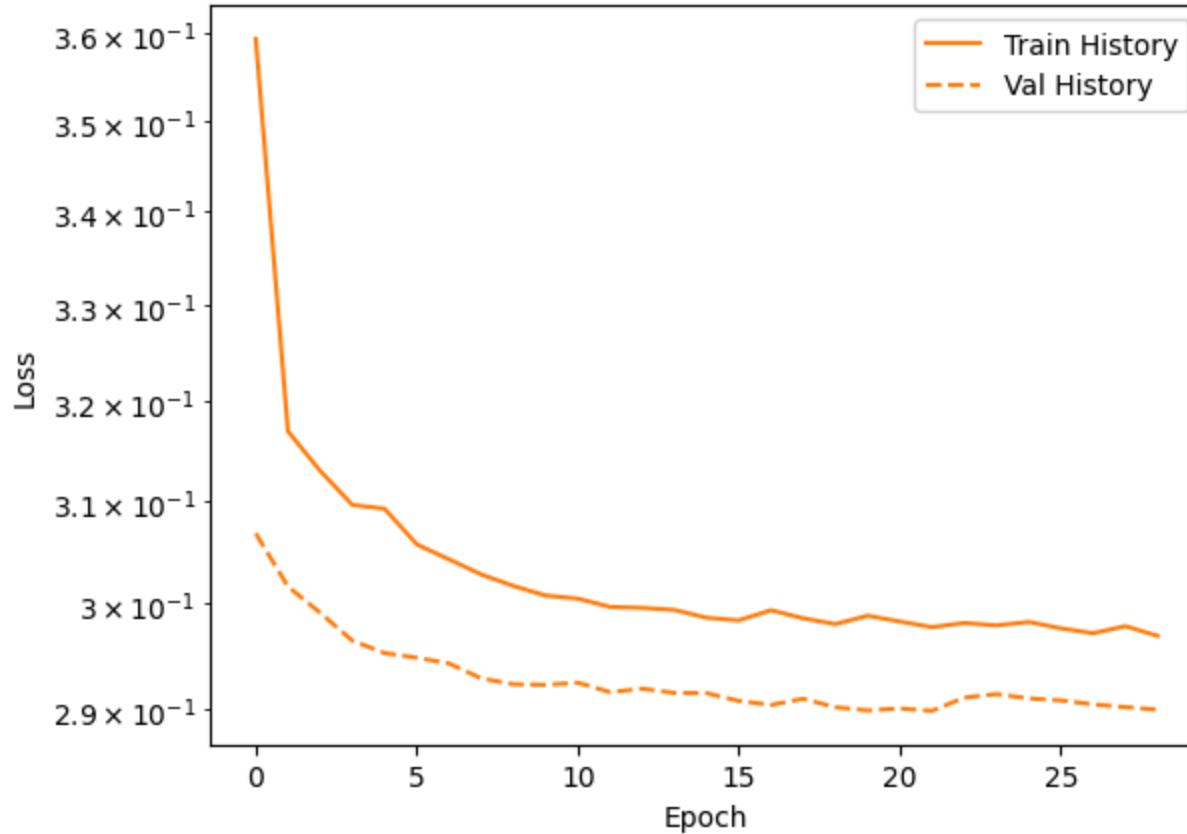


819/819 ————— 0s 414us/step

Training completed in: 180.4948s

819/819 ————— 0s 355us/step

##### ([32]) #####

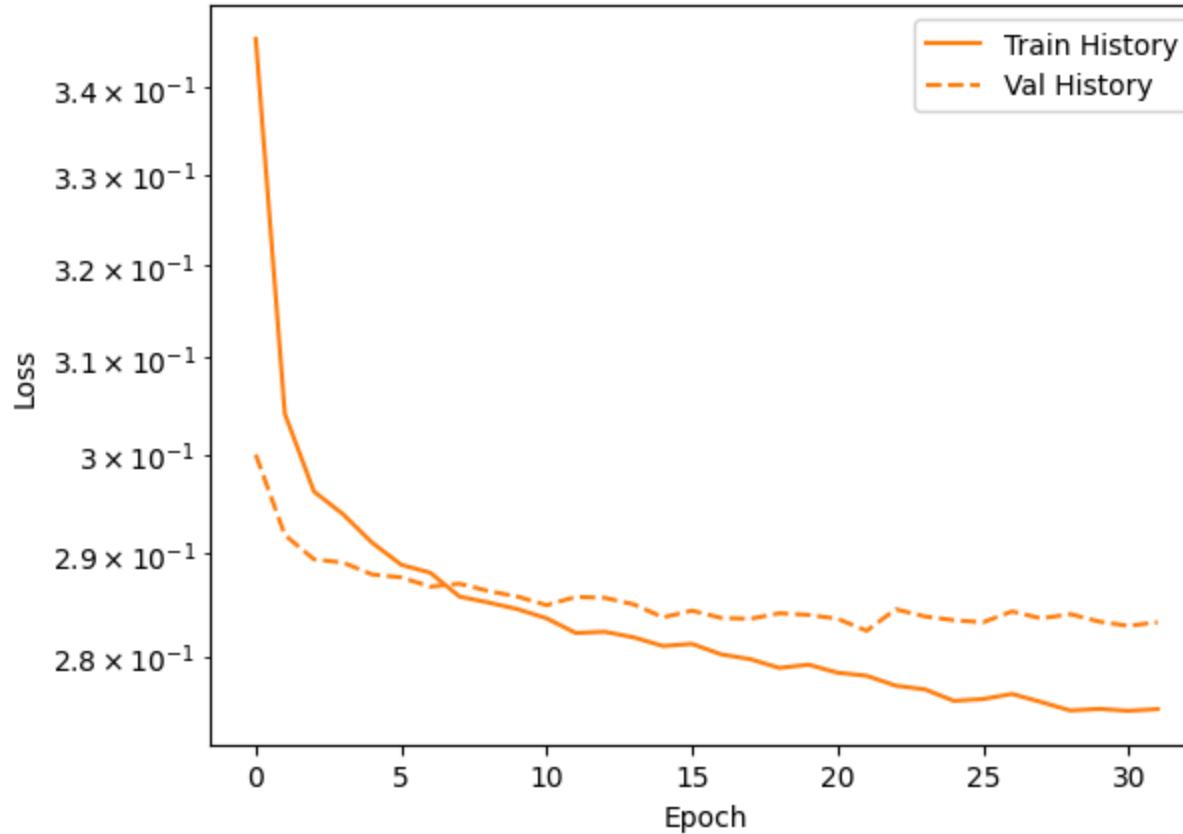


819/819 ————— 0s 420us/step

Training completed in: 59.557s

819/819 ————— 1s 782us/step

##### ([64, 32]) #####

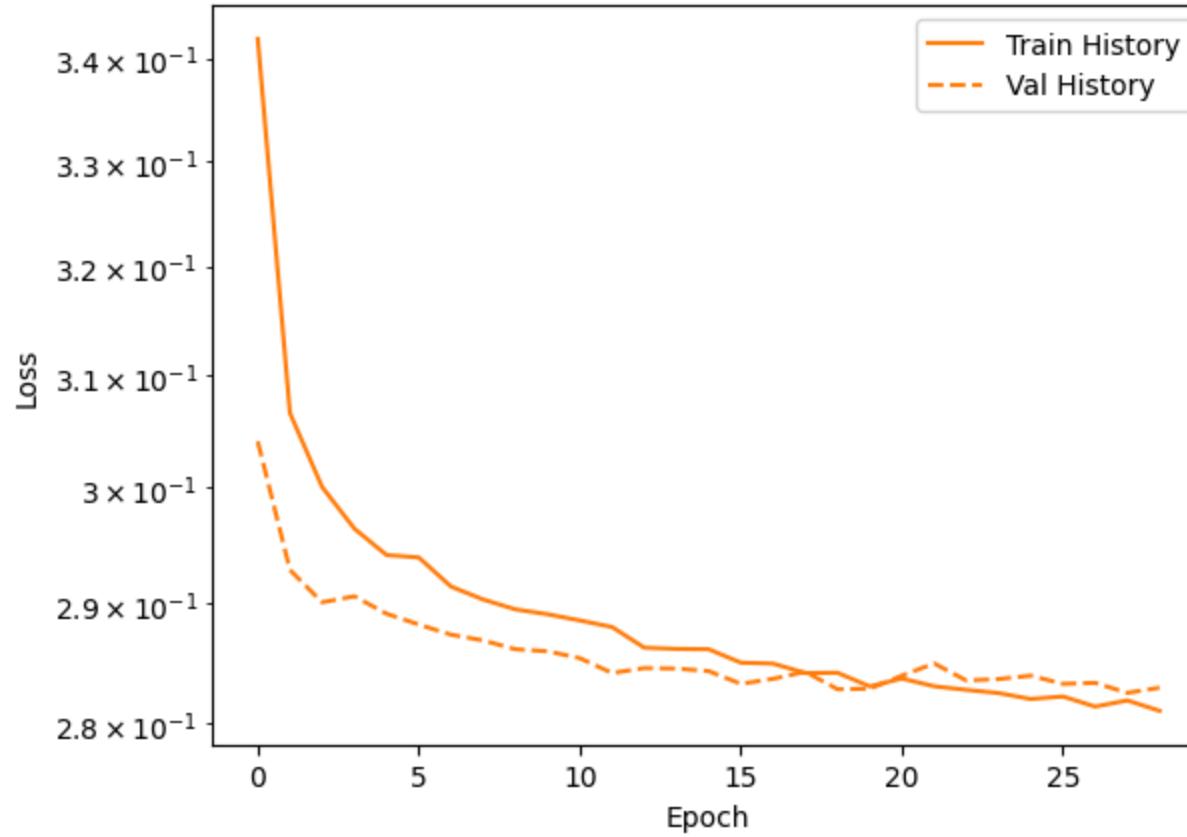


819/819 ————— 0s 439us/step

Training completed in: 95.2356s

819/819 ————— 0s 381us/step

##### ([64, 16]) #####

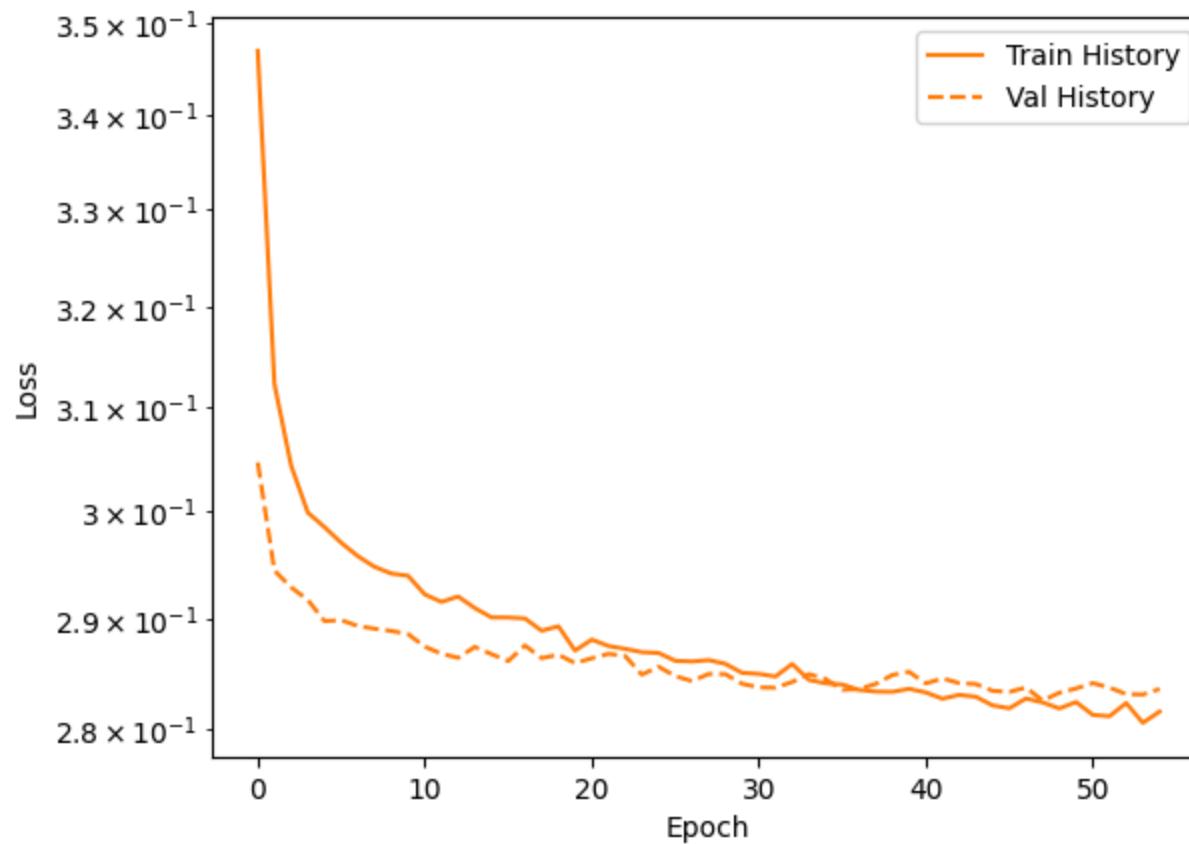


819/819 ————— 0s 537us/step

Training completed in: 69.8934s

819/819 ————— 0s 378us/step

##### ([32, 16]) #####

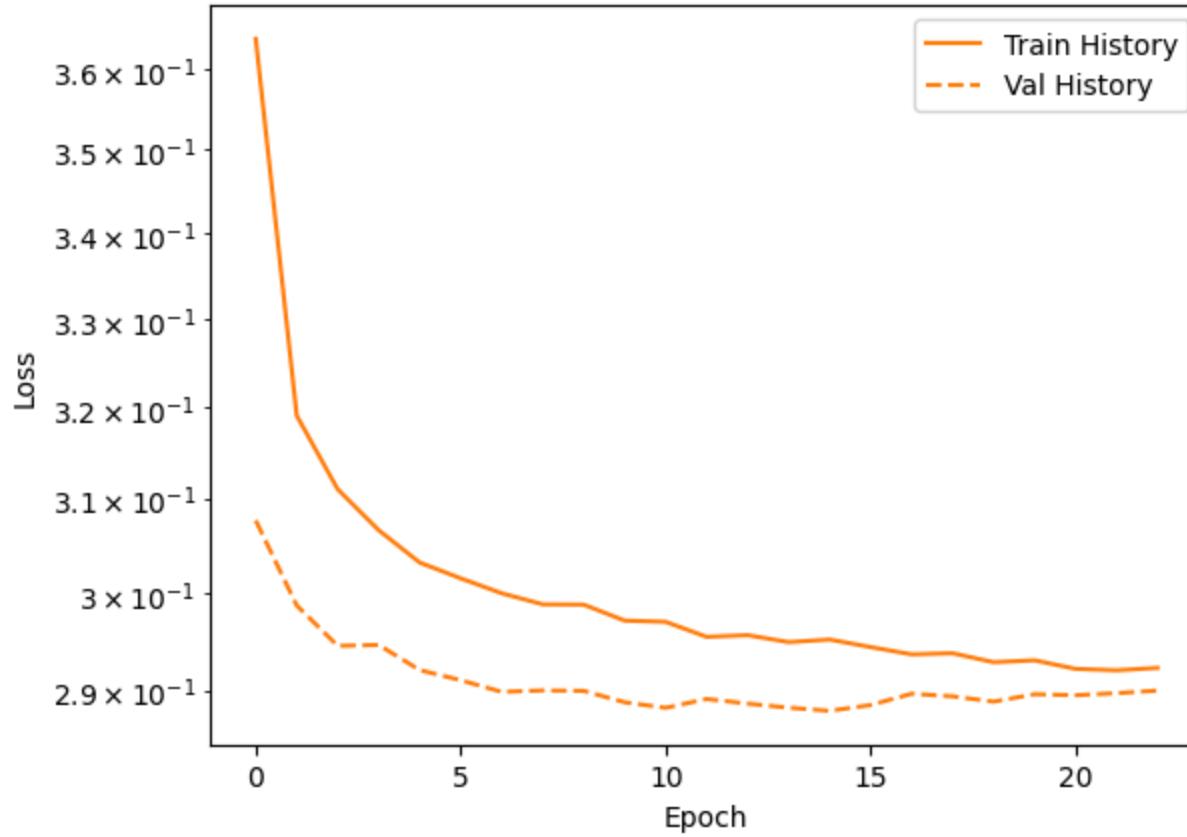


819/819 ————— 0s 429us/step

Training completed in: 131.2531s

819/819 ————— 0s 381us/step

##### ([32, 8]) #####

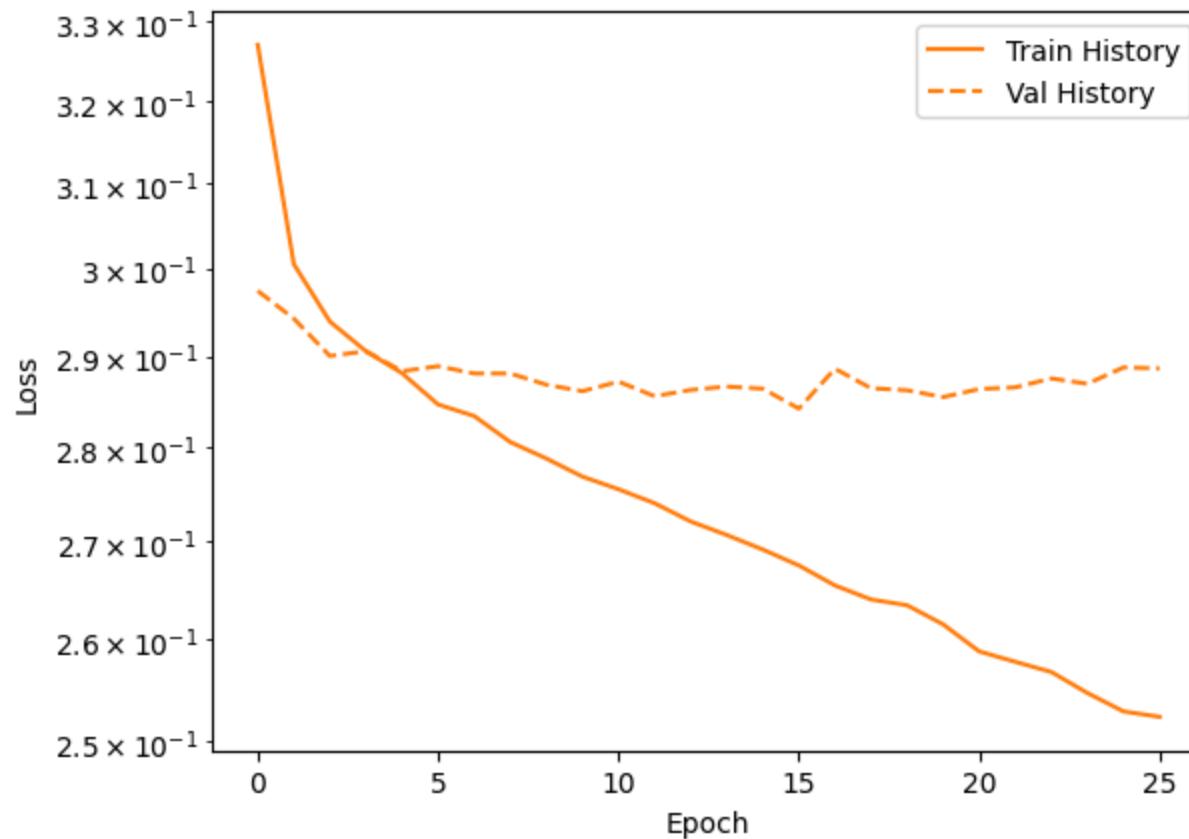


819/819 ————— 0s 432us/step

Training completed in: 55.303s

819/819 ————— 0s 370us/step

##### ([128, 64, 32]) #####

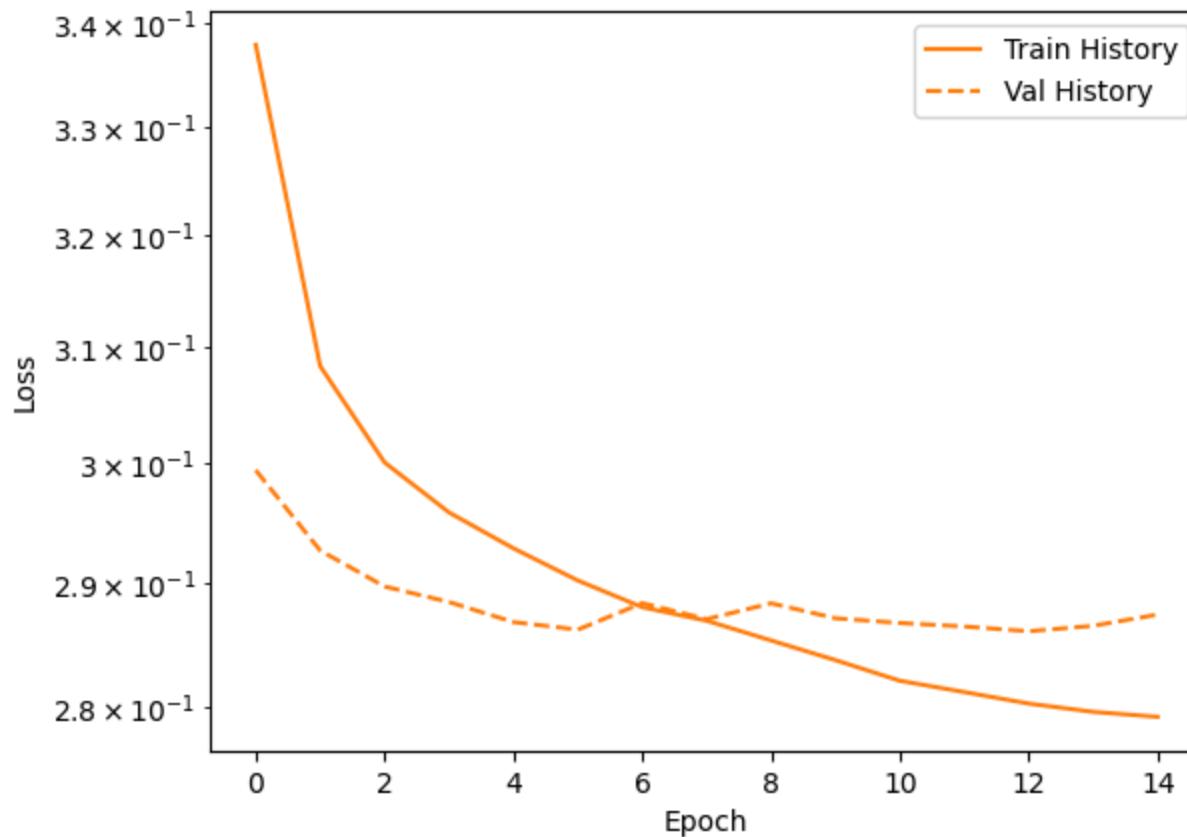


819/819  1s 1ms/step

Training completed in: 78.0594s

819/819  0s 424us/step

##### ([64, 32, 16]) #####

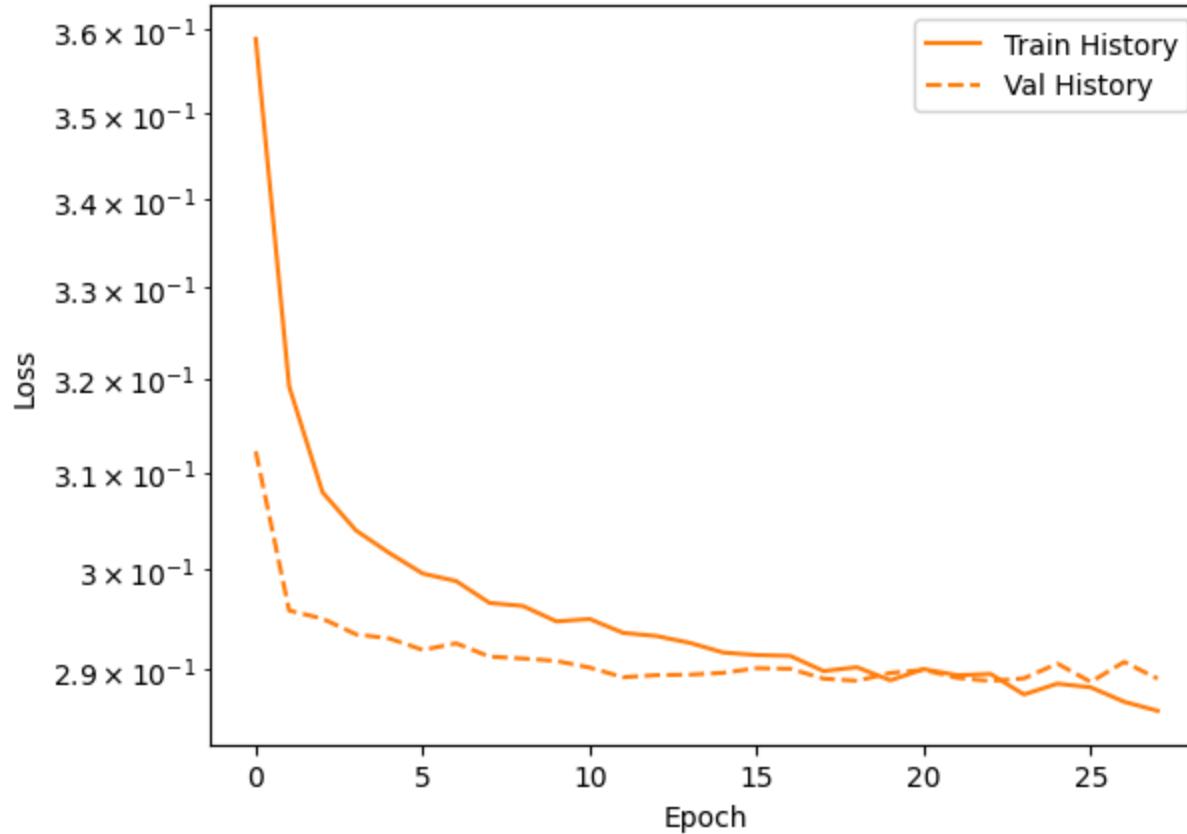


819/819 ███████████ 0s 493us/step

Training completed in: 44.084s

819/819 ███████████ 0s 384us/step

##### ([32, 16, 8]) #####

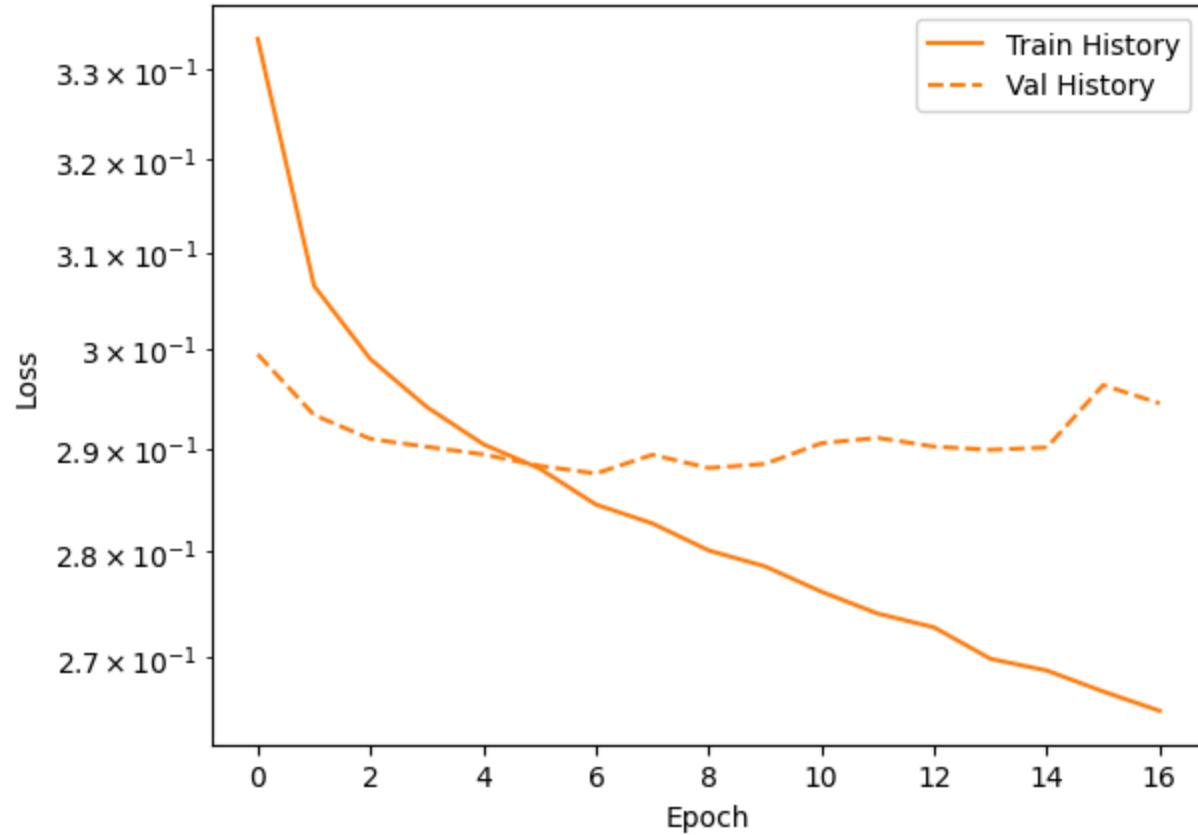


819/819 ————— 0s 447us/step

Training completed in: 71.4528s

819/819 ————— 0s 373us/step

##### ([128, 64, 32, 16]) #####



**819/819** ————— 1s 512us/step

Training completed in: 59.3132s

**819/819** ————— 0s 444us/step

Hidden Layers	Neurons per Layer	Accuracy	Precision	Recall	F1 Score	Brier Score	Time
1	[64]	0.881619	0.914160	0.940669	0.927225	0.118381	180.4948
1	[32]	0.875320	0.911084	0.935813	0.923283	0.124680	59.5570
2	[64, 32]	0.878450	0.912870	0.937908	0.925220	0.121550	95.2356
2	[64, 16]	0.878221	0.914769	0.935241	0.924892	0.121779	69.8934
2	[32, 16]	0.877877	0.913270	0.936622	0.924798	0.122123	131.2531
2	[32, 8]	0.875205	0.908421	0.939003	0.923459	0.124795	55.3030
3	[128, 64, 32]	0.876999	0.910544	0.938812	0.924462	0.123001	78.0594
3	[64, 32, 16]	0.877343	0.910316	0.939574	0.924714	0.122657	44.0840
3	[32, 16, 8]	0.876694	0.912072	0.936479	0.924114	0.123306	71.4528
4	[128, 64, 32, 16]	0.876885	0.916651	0.931099	0.923818	0.123115	59.3132

Best Model:

Hidden Layers	1
Neurons per Layer	[64]
Accuracy	0.881619
Precision	0.91416
Recall	0.940669
F1 Score	0.927225
Brier Score	0.118381
Time	180.4948

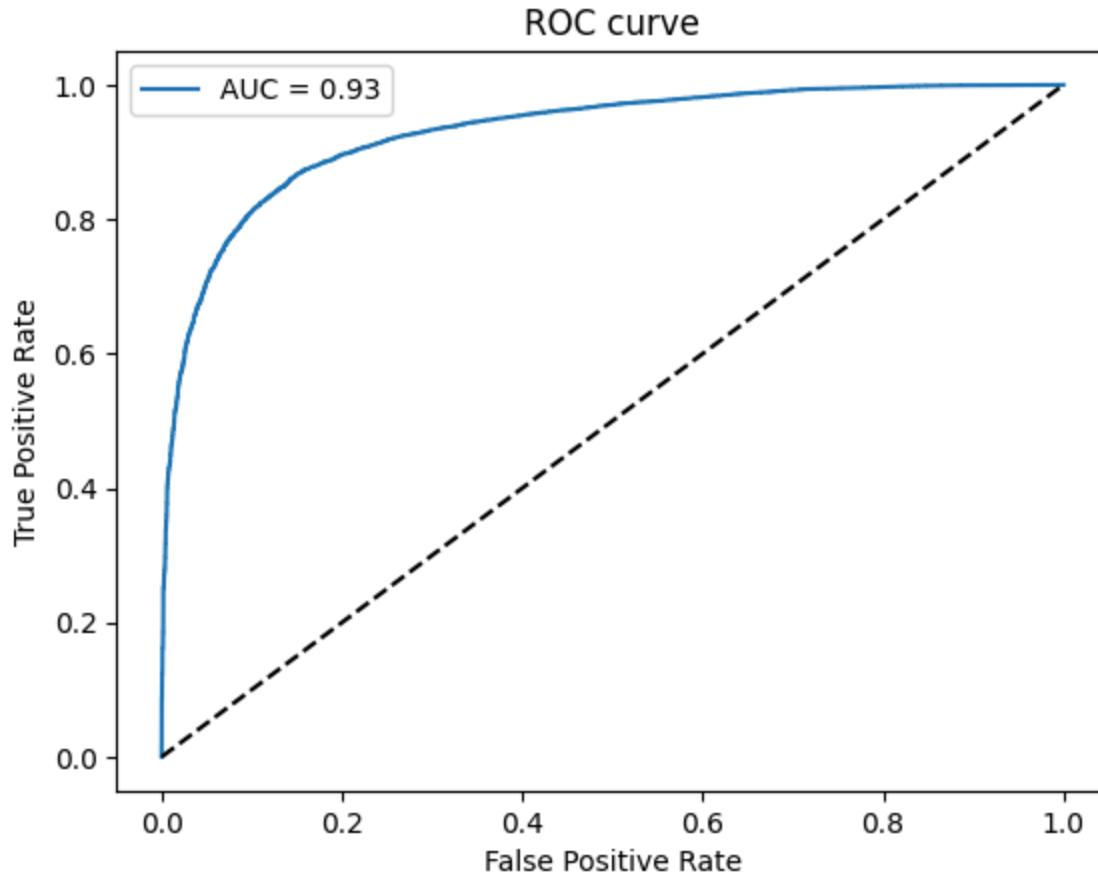
In [229]:

```
all_models_results_df = model_selection(X_all, y)
print(all_models_results_df.to_string(index=False))
# Find the best model
best_model = all_models_results_df.loc[all_models_results_df['F1 Score'].idxmax()]
print("\nBest Model:")
print(best_model.to_string())
```

```
#####
([32, 16]) #####
819/819 0s 460us/step
Training completed in: 95.1631s
819/819 0s 409us/step
Hidden Layers Neurons per Layer Accuracy Precision Recall F1 Score Brier Score Time
2 [32, 16] 0.886505 0.914666 0.946764 0.930438 0.113495 95.1631
```

Best Model:

Hidden Layers	2
Neurons per Layer	[32, 16]
Accuracy	0.886505
Precision	0.914666
Recall	0.946764
F1 Score	0.930438
Brier Score	0.113495
Time	95.1631



## Testing Best Models

```
In [37]: ## MAIN TESTING DRIVER
test_pass_df, test_event_df, test_related_df, test_frames_df = gather_data(test_ids)

# Only store those rows that have corresponding 360 entry in frames_df
test_clean_pass_df = clean_passes(test_pass_df, test_frames_df)

test_new_metrics_df, test_clean_pass_df = create_new_metrics(test_clean_pass_df, test_frames_df)
# Add new metrics to our main_df
test_clean_pass_df = pd.concat([test_clean_pass_df, test_new_metrics_df], axis=1)
```

Matches : 51

```

/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
/Users/sparshbinjrajka/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/statsbombpy/
api_client.py:21: NoAuthWarning: credentials were not supplied. open data access only
    warnings.warn(
Data Gathering completed in: 118.27s
Player_within_distances completed in 8.76s
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/4125588332.py:9: DeprecationWarning: DataF
rameGroupBy.apply operated on the grouping columns. This behavior is deprecated, and in a future version of
pandas the grouping columns will be excluded from the operation. Either pass `include_groups=False` to excl
ude the groupings or explicitly select the grouping columns after groupby to silence this warning.
    opposition_positions = frames_df[frames_df['teammate'] == False].groupby('event_uuid').apply(lambda g: g
[['x', 'y']].values).to_dict()
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2822652700.py:17: RuntimeWarning: invalid
value encountered in divide
    distances = np.abs(A * points[..., 0] + B * points[..., 1] + C) / np.sqrt(A**2 + B**2)
Closest_defender_passing_line completed in 27.46s

```

```
In [38]: # Aggregate old data
complete_pass_df = pd.concat([clean_pass_df, test_clean_pass_df], axis=0)
complete_event_df = pd.concat([event_df, test_event_df], axis=0)
complete_related_df = pd.concat([related_df, test_related_df], axis=0)
complete_frames_df = pd.concat([frames_df, test_frames_df], axis=0)
```

```
In [39]: #store dependent variable
y_complete_true = complete_pass_df["outcome_id"].to_frame()
y_complete_true = standardise_target(y_complete_true)
```

```
#store independent variables
X_complete_basic = complete_pass_df[basic_features + created_features]
X_complete_basic = standardise_features(X_complete_basic)

X_complete_imp = complete_pass_df[imp_features]
X_complete_imp = standardise_features(X_complete_imp)

X_complete_all = complete_pass_df[all_features]
X_complete_all = standardise_features(X_complete_all)

X_complete_dict = {"basic":X_complete_basic, "imp":X_complete_imp, "all":X_complete_all}
```

```
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:3: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame.  
Try using .loc[row_indexer,col_indexer] = value instead
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df["is_under_pressure"] = np.where(df["under_pressure"].isnull(), 0, 1)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:4: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df.drop(columns=["under_pressure"], axis=1, inplace=True)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:5: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df.rename(columns={"is_under_pressure": "under_pressure"}, inplace=True)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:8: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df.fillna(0, inplace=True)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:8: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df.fillna(0, inplace=True)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:10: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame.  
Try using .loc[row_indexer,col_indexer] = value instead
```

See the caveats in the documentation: [https://pandas.pydata.org/pandas-docs/stable/user\\_guide/indexing.html#returning-a-view-versus-a-copy](https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df[object_columns] = df[object_columns].astype(int)  
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:3: SettingWithCopyWarning:  
A value is trying to be set on a copy of a slice from a DataFrame.  
Try using .loc[row_indexer,col_indexer] = value instead
```

```
See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html
#returning-a-view-versus-a-copy
    df["is_under_pressure"] = np.where(df["under_pressure"].isnull(), 0, 1)
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:4: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html
#returning-a-view-versus-a-copy
    df.drop(columns=["under_pressure"], axis=1, inplace=True)
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:5: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html
#returning-a-view-versus-a-copy
    df.rename(columns={"is_under_pressure":"under_pressure"}, inplace=True)
no under pressure
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:8: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html
#returning-a-view-versus-a-copy
    df.fillna(0, inplace=True)
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/2834275.py:10: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html
#returning-a-view-versus-a-copy
    df[object_columns] = df[object_columns].astype(int)
```

## Best Models Retrained

```
In [41]: # Best Models Retrained

# Split data into train and test

# Basic
X_train_basic, X_test_basic, y_train_basic, y_test_basic = train_test_split(X_complete_basic, y_complete_t
scaler_basic = StandardScaler()
X_train_basic = scaler_basic.fit_transform(X_train_basic)
X_test_basic = scaler_basic.transform(X_test_basic)
```

```

# Imp
X_train_imp, X_test_imp, y_train_imp, y_test_imp = train_test_split(X_complete_imp, y_complete_true, train_size=0.7)
scaler_imp = StandardScaler()
X_train_imp = scaler_imp.fit_transform(X_train_imp)
X_test_imp = scaler_imp.transform(X_test_imp)

# All
X_train_all, X_test_all, y_train_all, y_test_all = train_test_split(X_complete_all, y_complete_true, train_size=0.7)
scaler_all = StandardScaler()
X_train_all = scaler_all.fit_transform(X_train_all)
X_test_all = scaler_all.transform(X_test_all)

## DT
print("#####\t DT MODELS\t#####")

# Basic
start_time = time.time()
model_dt_basic = tree.DecisionTreeClassifier(criterion='entropy', max_depth=6, random_state=1234)
history_dt_basic = model_dt_basic.fit(X_train_basic, y_train_basic)
print(f"Basic trained in: {time.time() - start_time}s")

# Imp
start_time = time.time()
model_dt_imp = tree.DecisionTreeClassifier(criterion='entropy', max_depth=5, random_state=1234)
history_dt_imp = model_dt_imp.fit(X_train_imp, y_train_imp)
print(f"Imp trained in: {time.time() - start_time}s")

# All
start_time = time.time()
model_dt_all = tree.DecisionTreeClassifier(criterion='entropy', max_depth=6, random_state=1234)
history_dt_all = model_dt_all.fit(X_train_all, y_train_all)
print(f"All trained in: {time.time() - start_time}s")

## XGB
print("#####\t XGB MODELS\t#####")

# Basic
start_time = time.time()
model_xgb_basic = XGBClassifier(n_estimators=2000, max_depth=7, learning_rate=0.01, eval_metric="logloss",
history_xgb_basic = model_xgb_basic.fit(X_train_basic, y_train_basic)

```

```

print(f"Basic trained in: {time.time() - start_time}s")

# Imp
start_time = time.time()
model_xgb_imp = XGBClassifier(n_estimators=2000, max_depth=7, learning_rate=0.01, eval_metric="logloss", random_state=42)
history_xgb_imp = model_xgb_imp.fit(X_train_imp, y_train_imp)
print(f"Imp trained in: {time.time() - start_time}s")

# Basic
start_time = time.time()
model_xgb_all = XGBClassifier(n_estimators=2000, max_depth=7, learning_rate=0.01, eval_metric="logloss", random_state=42)
history_xgb_all = model_xgb_all.fit(X_train_all, y_train_all)
print(f"All trained in: {time.time() - start_time}s")

## NN Models
print("#####\t NN MODELS\t#####")

# Basic
start_time = time.time()
model_nn_basic = create_nn_model(X_train_basic.shape[1], 1, [64])
history_nn_basic = model_nn_basic.fit(X_train_basic, y_train_basic, epochs=100, batch_size=32, verbose=0)
print(f"Basic trained in: {time.time() - start_time}s")
plt.semilogy(history_nn_basic.epoch, history_nn_basic.history['loss'], color=colors[1], label='Train NN Basic')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()
plt.show()

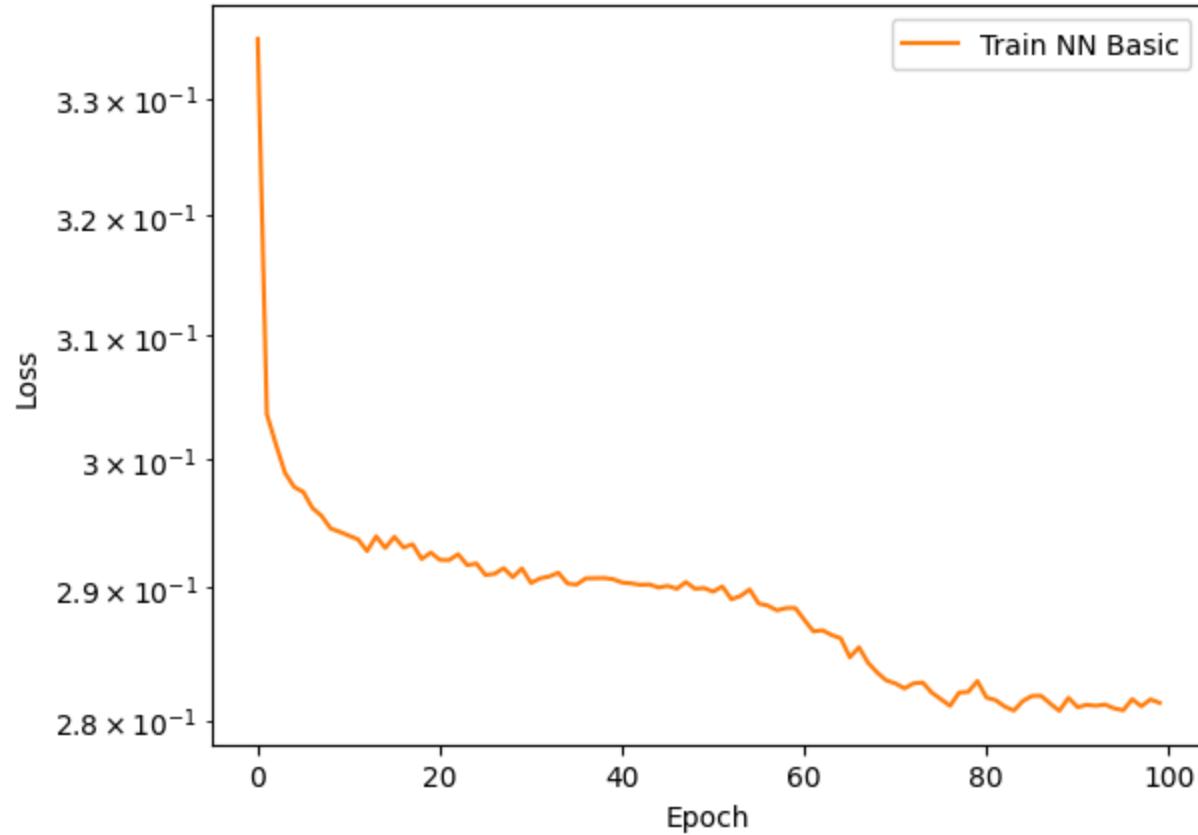
# Imp
start_time = time.time()
model_nn_imp = create_nn_model(X_train_imp.shape[1], 1, [64])
history_nn_imp = model_nn_imp.fit(X_train_imp, y_train_imp, epochs=100, batch_size=32, verbose=0)
print(f"Imp trained in: {time.time() - start_time}s")
plt.semilogy(history_nn_imp.epoch, history_nn_imp.history['loss'], color=colors[0], label='Train NN Imp')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()
plt.show()

# All

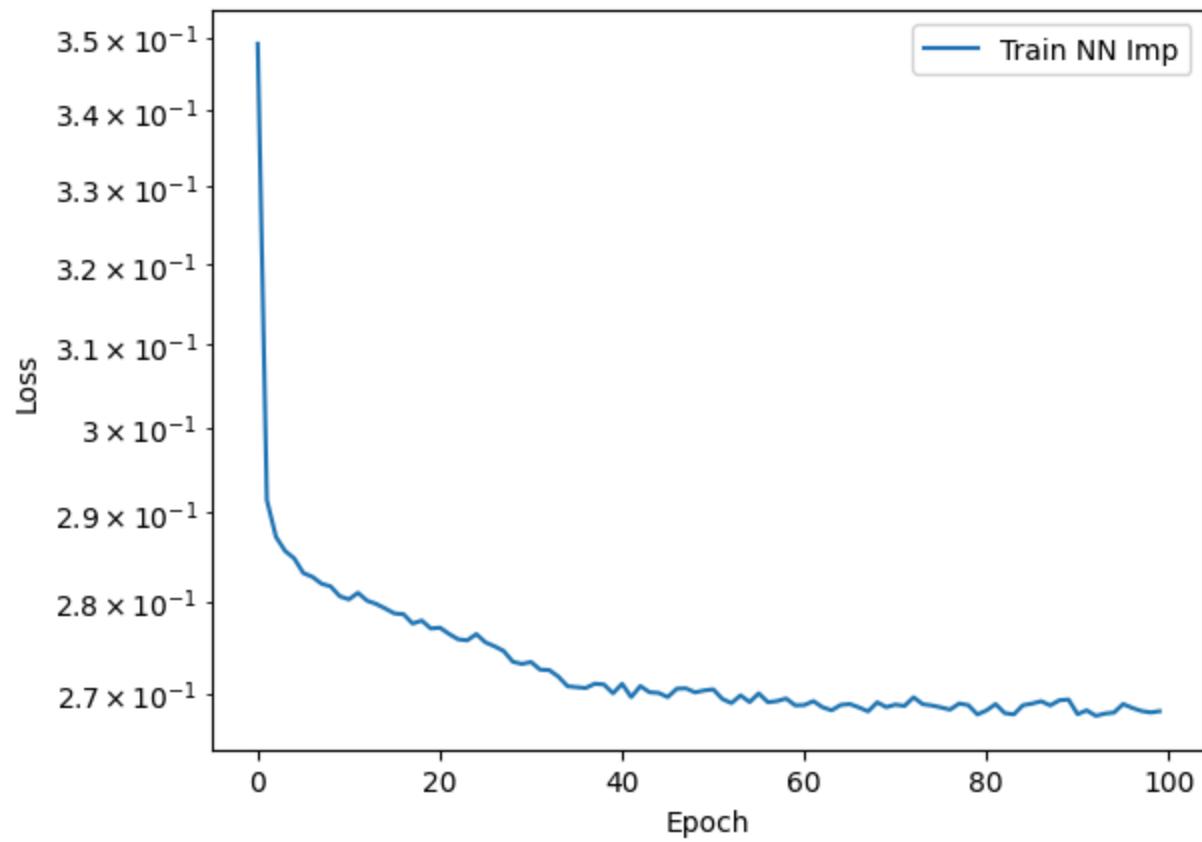
```

```
start_time = time.time()
model_nn_all = create_nn_model(X_train_all.shape[1], 3, [64, 32, 16])
history_nn_all = model_nn_all.fit(X_train_all, y_train_all, epochs=100, batch_size=32, verbose=0)
print(f"All trained in: {time.time() - start_time}s")
plt.semilogy(history_nn_all.epoch, history_nn_all.history['loss'], color=colors[1], label='Train NN All')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()
plt.show()
```

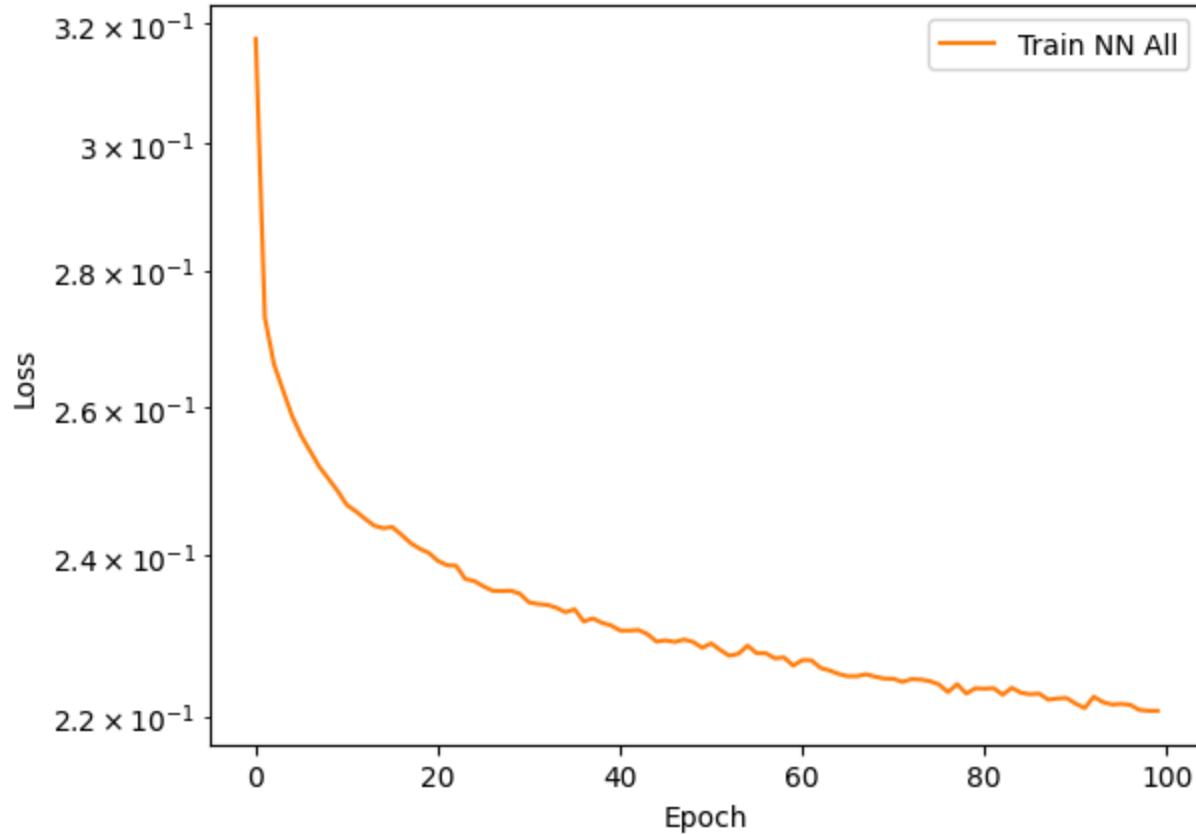
```
#####
DT MODELS #####
Basic trained in: 0.704503059387207s
Imp trained in: 0.809283971786499s
All trained in: 0.8810849189758301s
#####
XGB MODELS #####
Basic trained in: 9.884250164031982s
Imp trained in: 8.800477743148804s
All trained in: 10.097381114959717s
#####
NN MODELS #####
Basic trained in: 263.8121871948242s
```



Imp trained in: 252.7270691394806s



All trained in: 328.0943570137024s



```
In [130]: # Get testing results
best_models = [model_dt_basic, model_dt_imp, model_dt_all,
               model_xgb_basic, model_xgb_imp, model_xgb_all,
               model_nn_basic, model_nn_imp, model_nn_all]
data_vars = [(X_test_basic,y_test_basic), (X_test_imp,y_test_imp), (X_test_all,y_test_all)]
accuracies = []
predicted_probs = []

model_types = ["DT", "XGB", "NN"]
data_types = ["Basic", "Imp", "All"]

for i in range(len(model_types)):
    for j in range(len(data_types)):
        X_test_, y_test_ = data_vars[j]
        if i < 2:
```

```

        prob = best_models[3*i + j].predict_proba(X_test_)[:, 1]
    else:
        prob = best_models[3*i + j].predict(X_test_).ravel()
    pred = np.where(prob > 0.8, 1, 0)
    accuracies.append(balanced_accuracy_score(y_test_, pred))
    predicted_probs.append(prob)

print("#####\tAccuracy#####")
for i in range(len(model_types)):
    for j in range(len(data_types)):
        print(f"Model:{model_types[i]}\t{data_types[j]}\tAccuracy: {accuracies[3*i + j]}")

```

**1660/1660** ━━━━━━ 1s 375us/step  
**1660/1660** ━━━━━━ 1s 359us/step  
**1660/1660** ━━━━━━ 1s 420us/step  
##### Accuracy #####
Model: DT Basic Accuracy: 0.8185370868176206
Model: DT Imp Accuracy: 0.8225653786443822
Model: DT All Accuracy: 0.8272811546893237
Model: XGB Basic Accuracy: 0.8533828548206761
Model: XGB Imp Accuracy: 0.8596550234422761
Model: XGB All Accuracy: 0.8714383279039448
Model: NN Basic Accuracy: 0.8472900173424837
Model: NN Imp Accuracy: 0.8558249789758112
Model: NN All Accuracy: 0.8516975133581739

In [168]:

```

df_probs = pd.DataFrame(list(map(list, zip(*predicted_probs))))
desired_mean = 0.75

# Calculate current means and scaling factors
current_means = df_probs.mean()
scaling_factors = desired_mean / current_means

# Vectorized scaling operation
scaled_array = np.where(df_probs.values > current_means.values+0.15,
                       1 - (1 - df_probs.values) * scaling_factors.values,
                       df_probs.values * scaling_factors.values)

# Create a new DataFrame with scaled values
scaled_df = pd.DataFrame(scaled_array, columns=df_probs.columns, index=df_probs.index)

# Clip values to ensure they remain between 0 and 1

```

```
final_scaled_df = scaled_df.clip(0, 1)

new_probs = []
for column in final_scaled_df.columns:
    new_probs.append(final_scaled_df[column].tolist())

final_scaled_df.describe()
```

Out[168...]

	0	1	2	3	4	5	6
<b>count</b>	53114.000000	53114.000000	53114.000000	53114.000000	53114.000000	53114.000000	53114.000000
<b>mean</b>	0.782984	0.775398	0.781566	0.788802	0.789200	0.791318	0.785330
<b>std</b>	0.244852	0.242378	0.255916	0.278593	0.284777	0.294318	0.265676
<b>min</b>	0.000000	0.000000	0.000000	0.000787	0.000443	0.000752	0.000050
<b>25%</b>	0.621824	0.675847	0.660575	0.684788	0.691151	0.715765	0.668962
<b>50%</b>	0.874458	0.868773	0.885748	0.887840	0.966803	0.971637	0.878996
<b>75%</b>	0.986888	0.981232	0.987575	0.993663	0.993667	0.993936	0.989194
<b>max</b>	1.000000	0.998269	1.000000	0.999882	0.999922	0.999975	0.999771

In [189...]

X\_complete\_all

Out [189...]

	duration	pass_length	pass_angle	pass_height_id	end_x	end_y	body_part_id	sub_type_id	x	y	tech
0	1.511008	26.681080	-2.883887		1.0	35.2	33.3	40.0	65.0	61.0	40.1
1	1.463245	21.345960	1.256453		1.0	44.2	54.1	38.0	0.0	37.6	33.8
2	2.867591	43.871746	-0.465686		3.0	89.6	35.6	40.0	0.0	50.4	55.3
3	0.957823	13.010765	-0.785398		1.0	89.6	10.4	38.0	0.0	80.4	19.6
4	2.681273	37.980650	3.044020		1.0	51.8	14.1	38.0	0.0	89.6	10.4
...	...	...	...		...	...	...	...	...	...	...
53884	0.807326	7.615773	1.332187		1.0	91.8	45.6	38.0	0.0	90.0	38.2
53885	3.425210	27.655200	-0.808412		1.0	118.3	2.2	38.0	0.0	99.2	22.2
53887	0.727240	15.110923	1.804540		1.0	99.2	19.2	40.0	0.0	102.7	4.5
53888	0.811935	12.553884	0.392340		1.0	110.3	23.9	38.0	0.0	98.7	19.1
53889	1.390506	15.147607	2.577395		1.0	96.5	36.6	40.0	0.0	109.3	28.5

177046 rows × 29 columns

In [169...]

```
len(new_probs[0])
```

Out [169...]

53114

xT

In [148...]

```
xt_df = complete_related_df[['match_id', 'id', 'index', 'type_name']].merge(
    complete_event_df[['match_id', 'id', 'index', 'type_name', 'comp_id', 'seas_id',
                       'possession_team_id', 'end_x', 'end_y', 'x', 'y', 'player_name', 'outcome_name']],
    on=['match_id', 'id', 'index', 'type_name'], how='left').sort_values(by=['match_id', 'index'])
xt_df = xt_df[xt_df["type_name"].isin(['Pass', 'Carry', 'Shot'])].reset_index(drop=True).drop_duplicates()
```

In [149...]

```
xt_df = complete_event_df.dropna(subset=["end_x", "end_y"])
xt_df = xt_df[xt_df["type_name"] != "Goal Keeper"]
```

```
xt_df = clean_passes(xt_df, complete_frames_df)
# xt_df[["x", "y", "end_x", "end_y"]].describe()
# xt_df.columns
```

## Take 1

In [150...]

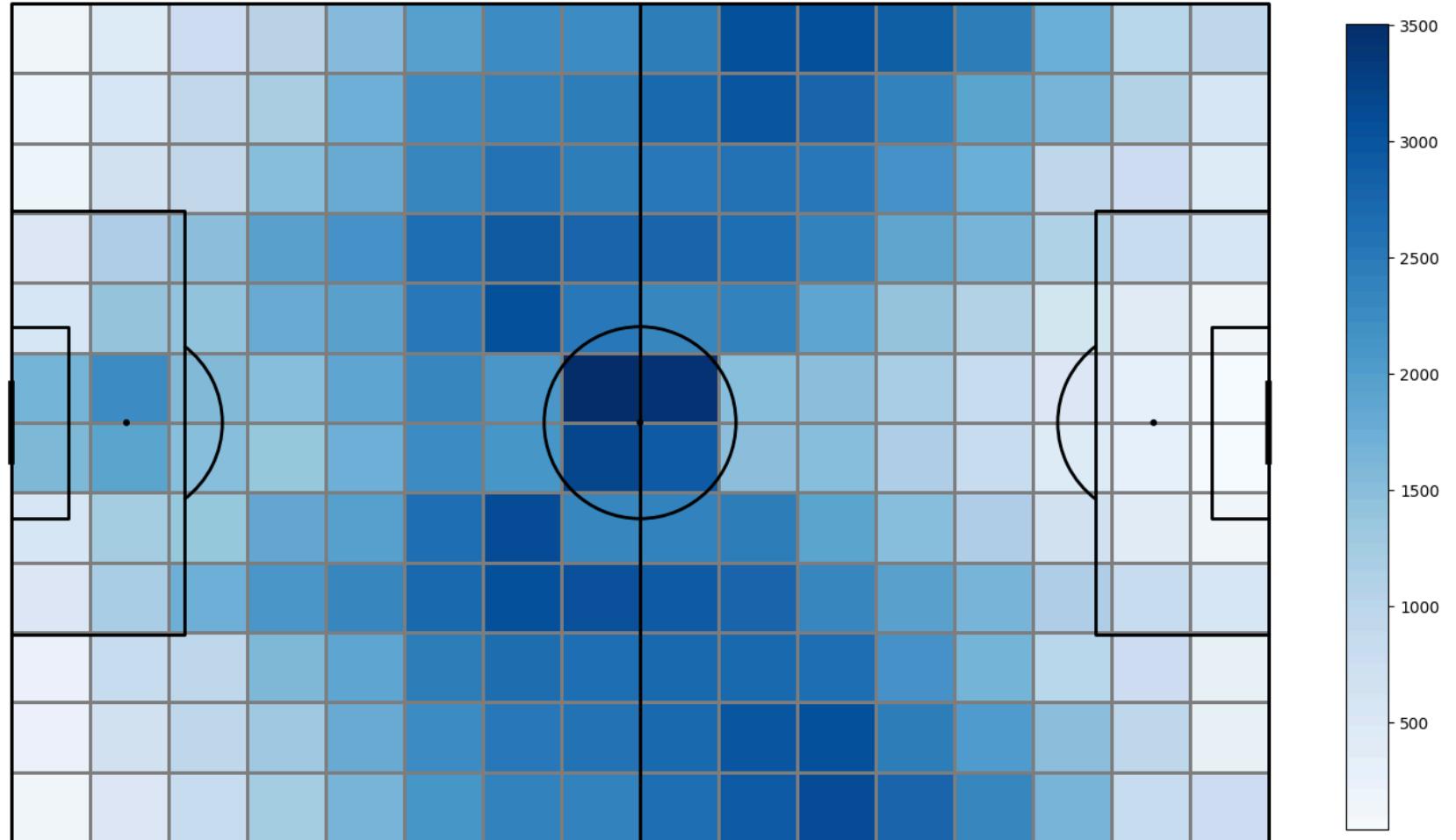
```
# next_event = df.shift(-1, fill_value=0)
# df["nextEvent"] = next_event["subEventName"]

# df["kickedOut"] = df.apply(lambda x: 1 if x.nextEvent == "Ball out of the field" else 0, axis = 1)
# #get move_df
# move_df = df.loc[df['subEventName'].isin(['Simple pass', 'High pass', 'Head pass', 'Smart pass', 'Cross']).&
# #filtering out of the field
# delete_passes = move_df.loc[move_df["kickedOut"] == 1]
move_df = xt_df[xt_df["type_name"] != "Shot"]
move_df = move_df.loc[((move_df["end_x"] != 0) & (move_df["end_y"] != 80)) & ((move_df["end_x"] != 120) &

#create 2D histogram of these
pitch = Pitch(line_color='black', pitch_type='custom', pitch_length=120, pitch_width=80, line_zorder = 2)
move = pitch.bin_statistic(move_df.x, move_df.y, statistic='count', bins=(16, 12), normalize=False)

fig, ax = pitch.grid(grid_height=0.9, title_height=0.06, axis=False,
                      endnote_height=0.04, title_space=0, endnote_space=0)
pcm = pitch.heatmap(move, cmap='Blues', edgecolor='grey', ax=ax['pitch'])
#legend to our plot
ax_cbar = fig.add_axes((1, 0.093, 0.03, 0.786))
cbar = plt.colorbar(pcm, cax=ax_cbar)
fig.suptitle('Moving actions 2D histogram', fontsize = 30)
plt.show()
#get the array
move_count = move["statistic"]
```

## Moving actions 2D histogram



```
In [151]: #get shot df
shot_df = xt_df.loc[xt_df['type_name'] == "Shot"]
# shot_df["x"] = shot_df.positions.apply(lambda cell: (cell[0]['x']) * 105/100)
# shot_df["y"] = shot_df.positions.apply(lambda cell: (100 - cell[0]['y']) * 68/100)

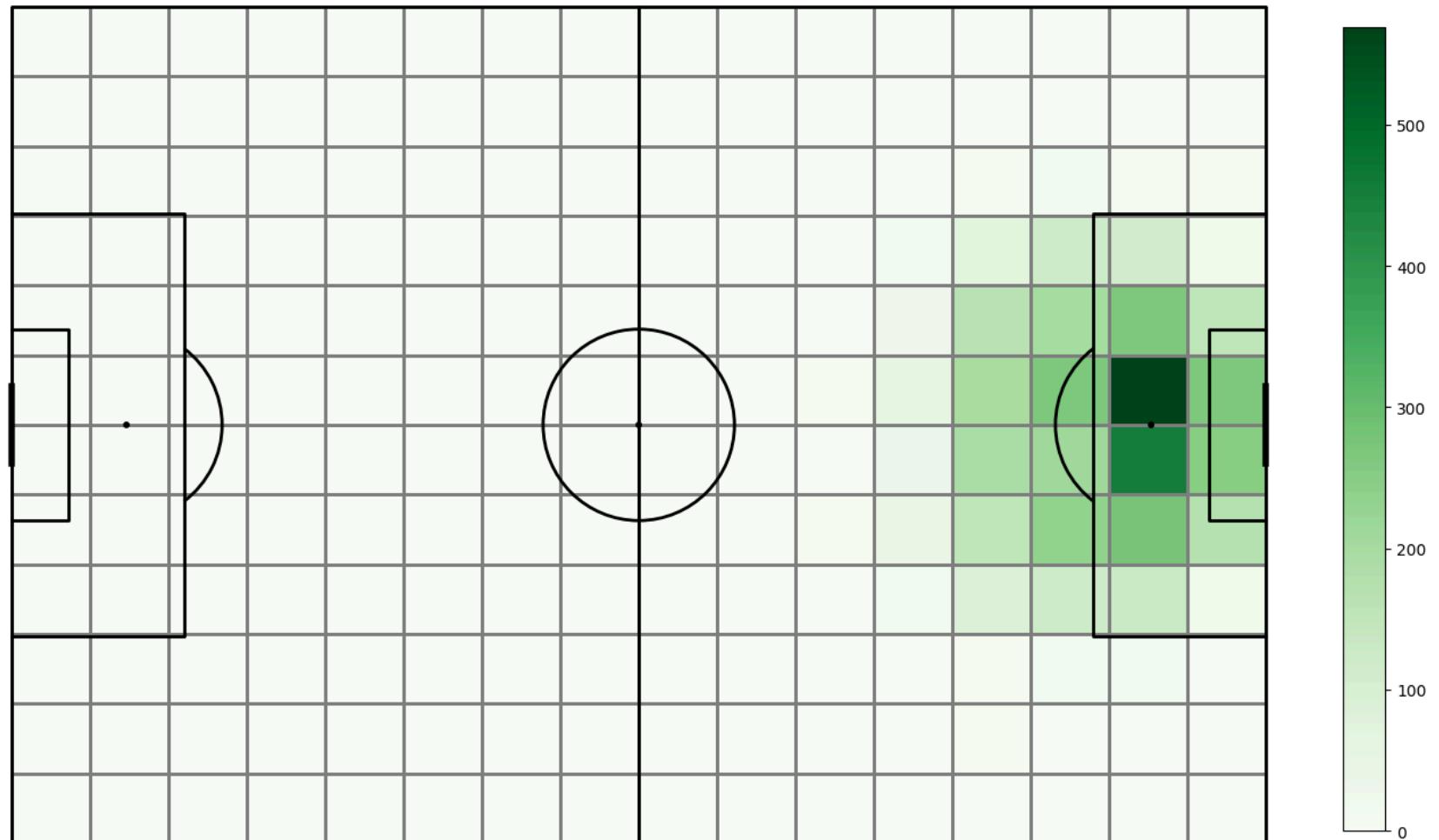
#create 2D histogram of these
```

```
shot = pitch.bin_statistic(shot_df.x, shot_df.y, statistic='count', bins=(16, 12), normalize=False)

fig, ax = pitch.grid(grid_height=0.9, title_height=0.06, axis=False,
                     endnote_height=0.04, title_space=0, endnote_space=0)
pcm = pitch.heatmap(shot, cmap='Greens', edgecolor='grey', ax=ax['pitch'])
#legend to our plot
ax_cbar = fig.add_axes((1, 0.093, 0.03, 0.786))
cbar = plt.colorbar(pcm, cax=ax_cbar)
fig.suptitle('Shots 2D histogram', fontsize = 30)
plt.show()

shot_count = shot["statistic"]
```

## Shots 2D histogram

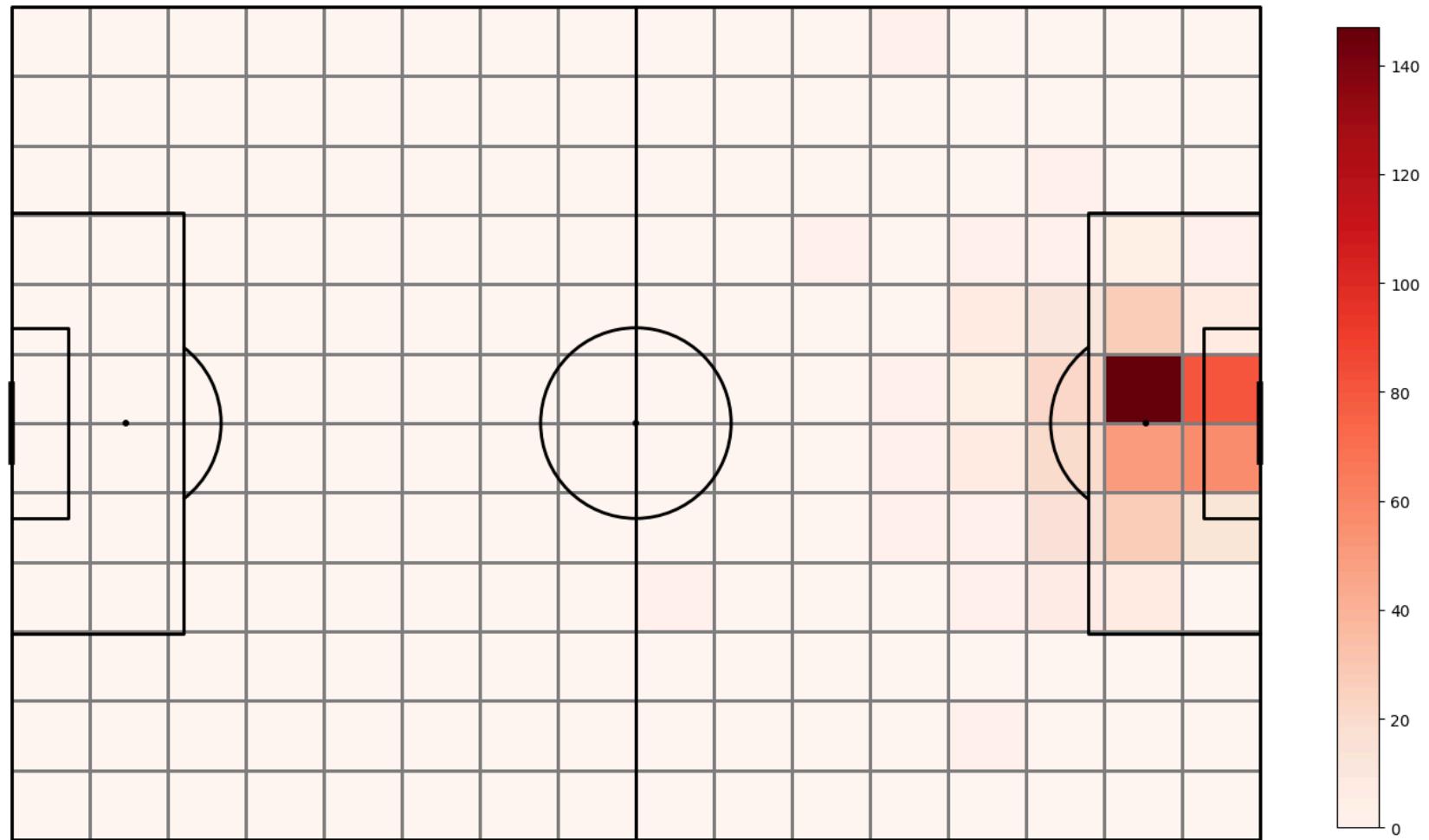


In [152]:

```
#get goal df
goal_df = xt_df.loc[xt_df["outcome_name"] == "Goal"]
goal = pitch.bin_statistic(goal_df.x, goal_df.y, statistic='count', bins=(16, 12), normalize=False)
goal_count = goal["statistic"]
```

```
fig, ax = pitch.grid(grid_height=0.9, title_height=0.06, axis=False,
                      endnote_height=0.04, title_space=0, endnote_space=0)
pcm = pitch.heatmap(goal, cmap='Reds', edgecolor='grey', ax=ax['pitch'])
#legend to our plot
ax_cbar = fig.add_axes((1, 0.093, 0.03, 0.786))
cbar = plt.colorbar(pcm, cax=ax_cbar)
fig.suptitle('Goal 2D histogram', fontsize = 30)
plt.show()
```

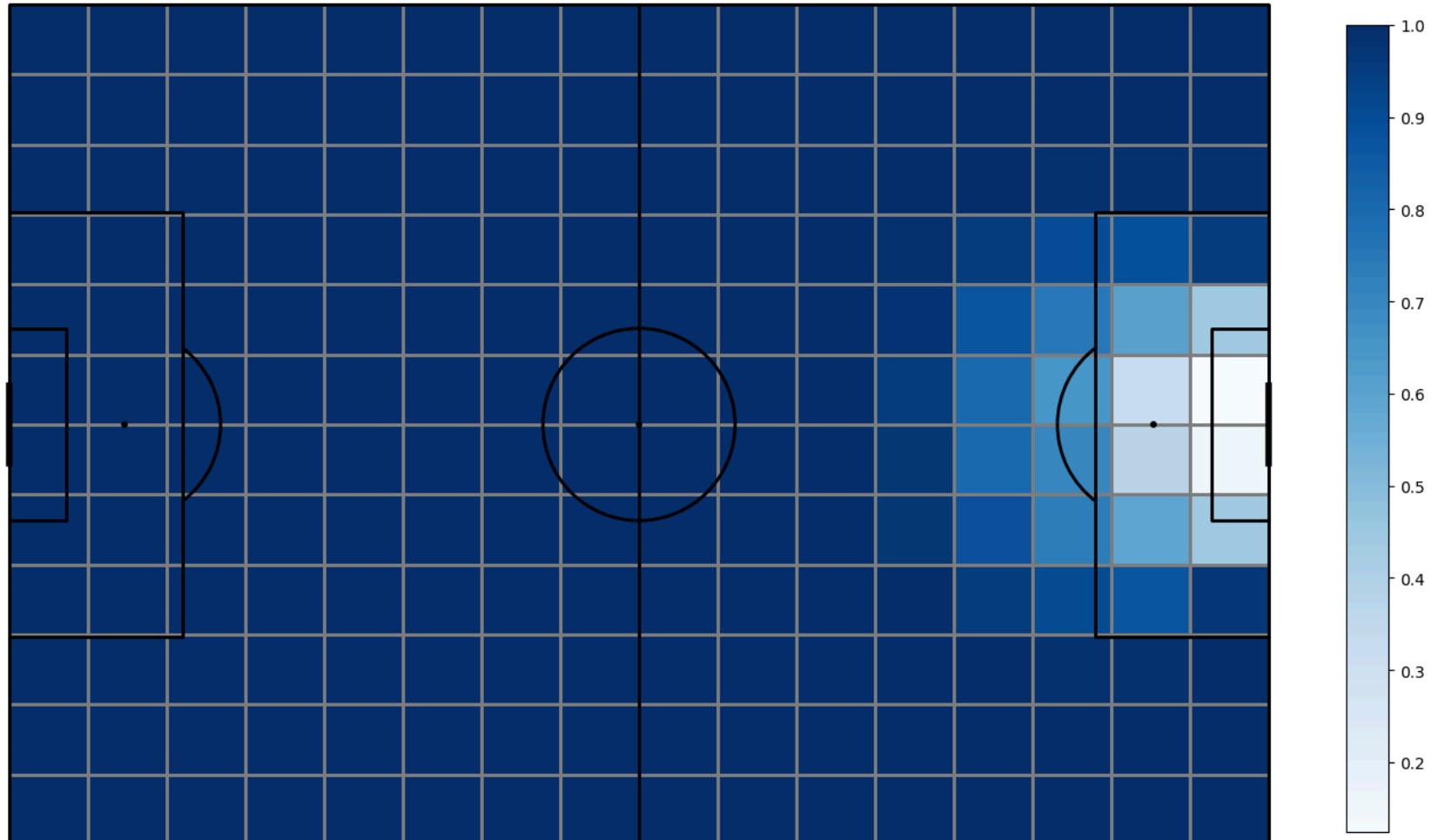
## Goal 2D histogram



```
In [153]:  
move_probability = move_count/(move_count+shot_count)  
#plotting it  
fig, ax = pitch.grid(grid_height=0.9, title_height=0.06, axis=False,  
                     endnote_height=0.04, title_space=0, endnote_space=0)  
move["statistic"] = move_probability
```

```
pcm = pitch.heatmap(move, cmap='Blues', edgecolor='grey', ax=ax['pitch'])
#legend to our plot
ax_cbar = fig.add_axes((1, 0.093, 0.03, 0.786))
cbar = plt.colorbar(pcm, cax=ax_cbar)
fig.suptitle('Move probability 2D histogram', fontsize = 30)
plt.show()
```

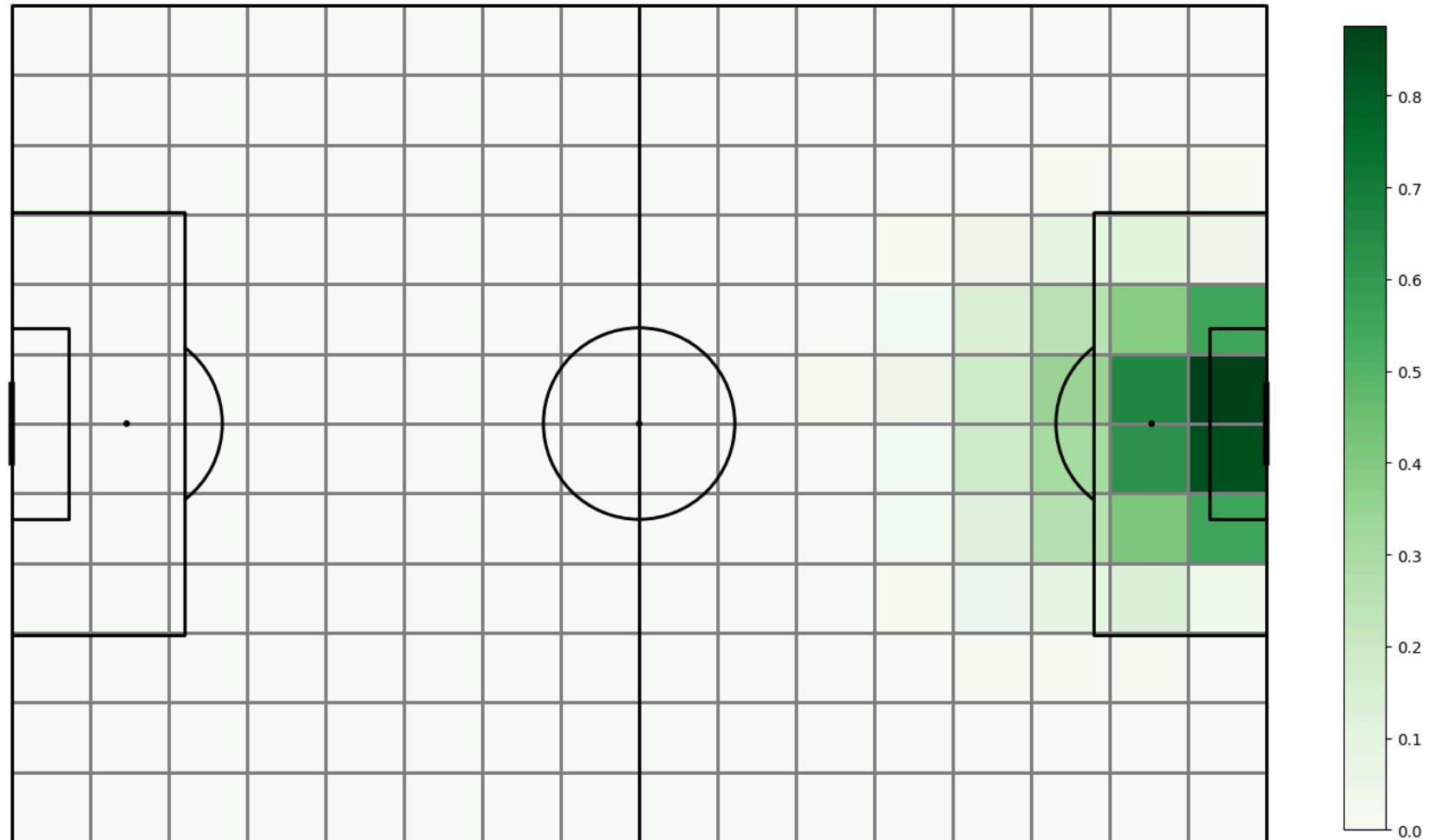
## Move probability 2D histogram



```
In [154]: shot_probability = shot_count/(move_count+shot_count)
#plotting it
fig, ax = pitch.grid(grid_height=0.9, title_height=0.06, axis=False,
                      endnote_height=0.04, title_space=0, endnote_space=0)
shot["statistic"] = shot_probability
```

```
pcm = pitch.heatmap(shot, cmap='Greens', edgecolor='grey', ax=ax['pitch'])
#legend to our plot
ax_cbar = fig.add_axes((1, 0.093, 0.03, 0.786))
cbar = plt.colorbar(pcm, cax=ax_cbar)
fig.suptitle('Shot probability 2D histogram', fontsize = 30)
plt.show()
```

## Shot probability 2D histogram



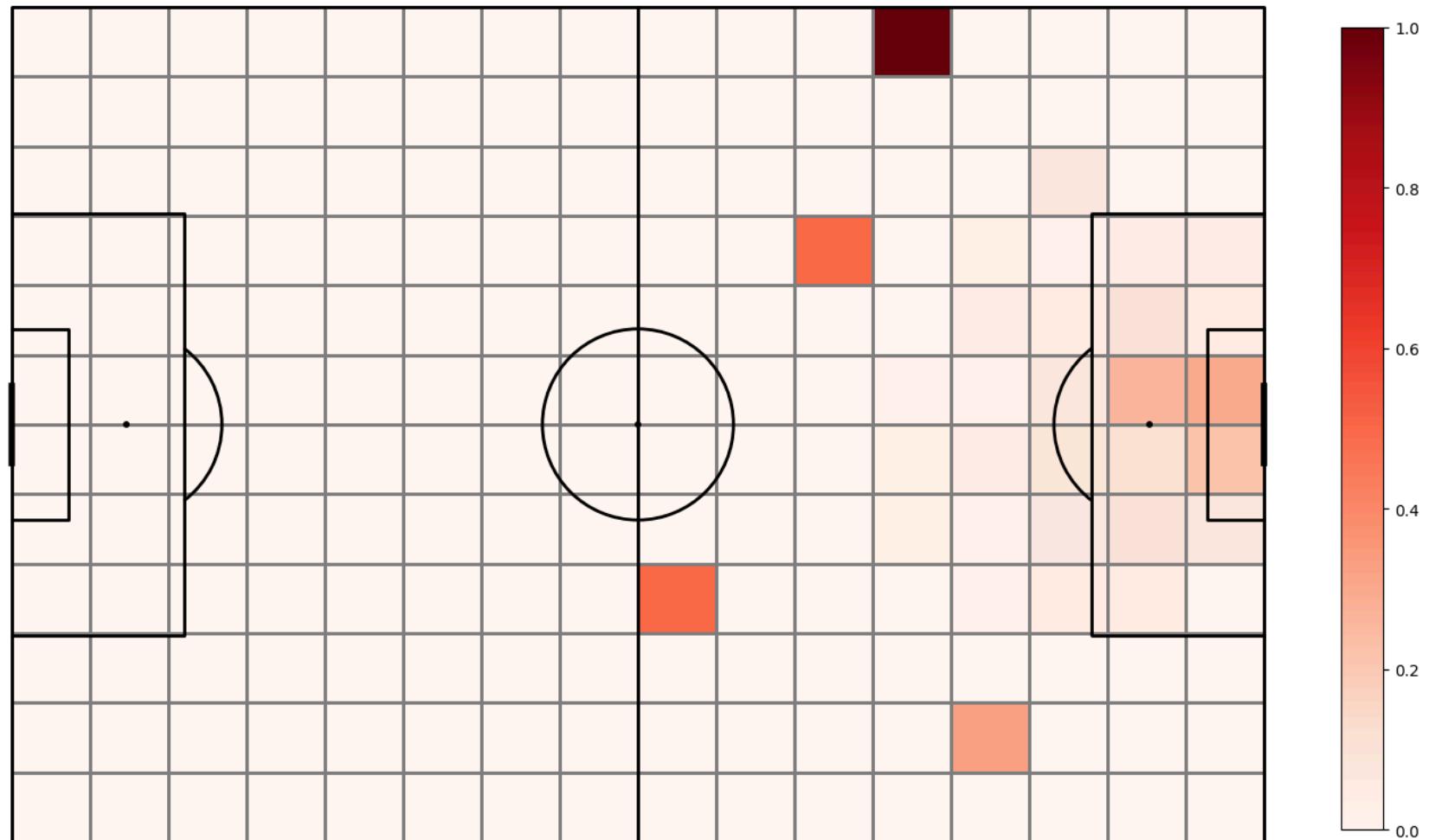
In [155]:

```
goal_probability = goal_count / shot_count
goal_probability[np.isnan(goal_probability)] = 0
#plotting it
fig, ax = pitch.grid(grid_height=0.9, title_height=0.06, axis=False,
                      endnote_height=0.04, title_space=0, endnote_space=0)
```

```
goal["statistic"] = goal_probability
pcm = pitch.heatmap(goal, cmap='Reds', edgecolor='grey', ax=ax['pitch'])
#legend to our plot
ax_cbar = fig.add_axes((1, 0.093, 0.03, 0.786))
cbar = plt.colorbar(pcm, cax=ax_cbar)
fig.suptitle('Goal probability 2D histogram', fontsize = 30)
plt.show()
```

```
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/1173137835.py:1: RuntimeWarning: invalid value encountered in divide
    goal_probability = goal_count/shot_count
```

## Goal probability 2D histogram



```
In [156]: from scipy.stats import binned_statistic_2d
```

```
#move start index - using the same function as mplsoccer, it should work
move_df["start_sector"] = move_df.apply(lambda row: tuple([i[0] for i in binned_statistic_2d(np.ravel(row),
values = "None", statistic="count",
```

```

bins=(16, 12), range=[[0, 120], [0, 80]],
expand_binnumbers=True)[3]]), axis = 1)

#move end index
move_df["end_sector"] = move_df.apply(lambda row: tuple([i[0] for i in binned_statistic_2d(np.ravel(row.end_sector), row.id, bins=(16, 12), range=[[0, 120], [0, 80]], expand_binnumbers=True)[3]]), axis = 1)

#df with summed events from each index
df_count_starts = move_df.groupby(["start_sector"])["id"].count().reset_index()
df_count_starts.rename(columns = {'id':'count_starts'}, inplace=True)

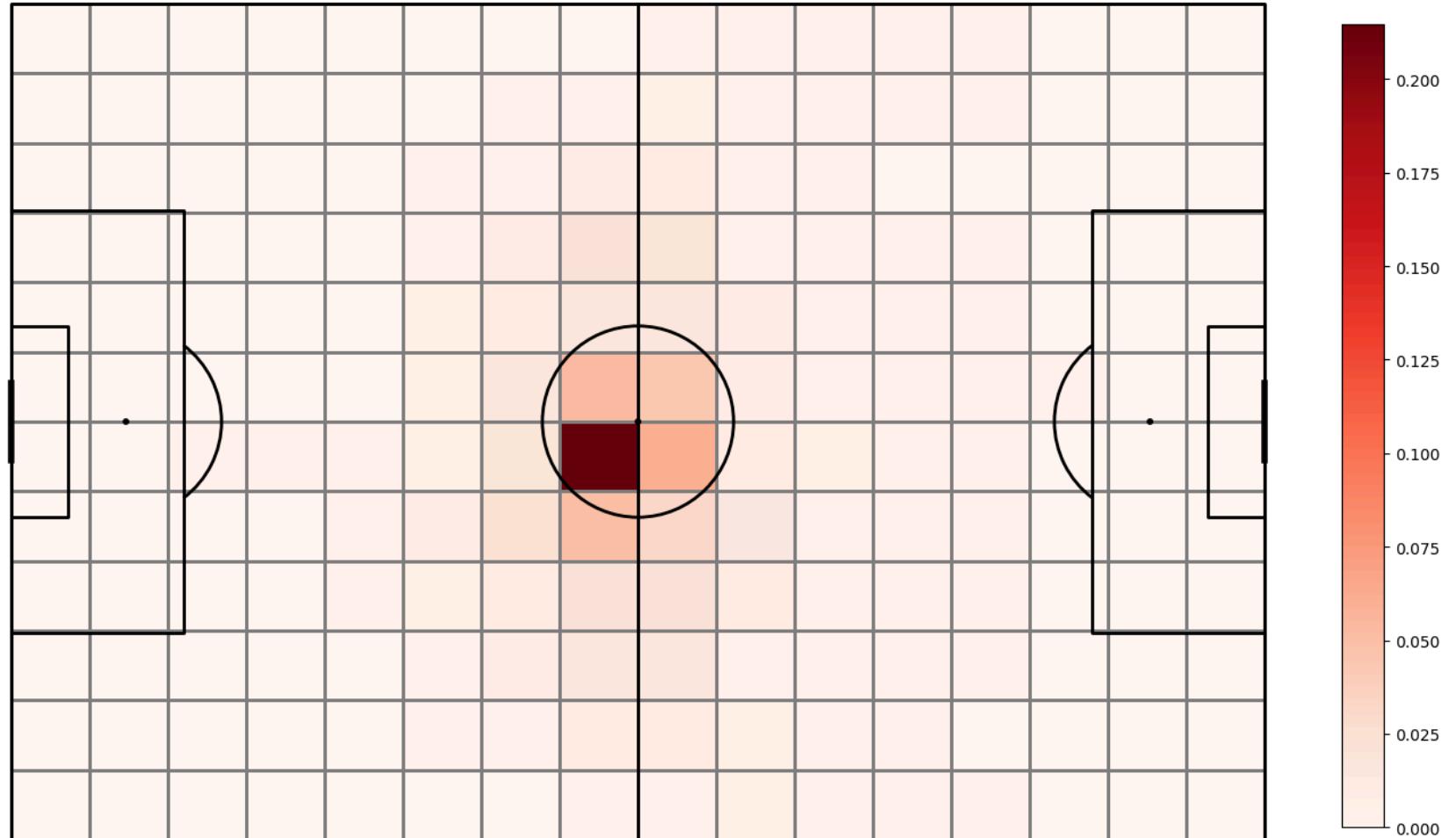
transition_matrices = []
for i, row in df_count_starts.iterrows():
    start_sector = row['start_sector']
    count_starts = row['count_starts']
    #get all events that started in this sector
    this_sector = move_df.loc[move_df["start_sector"] == start_sector]
    df_cound_ends = this_sector.groupby(["end_sector"])["id"].count().reset_index()
    df_cound_ends.rename(columns = {'id':'count_ends'}, inplace=True)
    T_matrix = np.zeros((12, 16))
    for j, row2 in df_cound_ends.iterrows():
        end_sector = row2["end_sector"]
        value = row2["count_ends"]
        T_matrix[end_sector[1] - 1][end_sector[0] - 1] = value
    T_matrix = T_matrix / count_starts
    transition_matrices.append(T_matrix)

#let's plot it for the zone [1,1] - left down corner
fig, ax = pitch.grid(grid_height=0.9, title_height=0.06, axis=False,
                      endnote_height=0.04, title_space=0, endnote_space=0)

#Change the index here to change the zone.
goal["statistic"] = transition_matrices[90]
pcm = pitch.heatmap(goal, cmap='Reds', edgecolor='grey', ax=ax['pitch'])
#legend to our plot
ax_cbar = fig.add_axes((1, 0.093, 0.03, 0.786))
cbar = plt.colorbar(pcm, cax=ax_cbar)
fig.suptitle('Transition probability for one of the middle zones', fontsize = 30)
plt.show()

```

## Transition probability for one of the middle zones



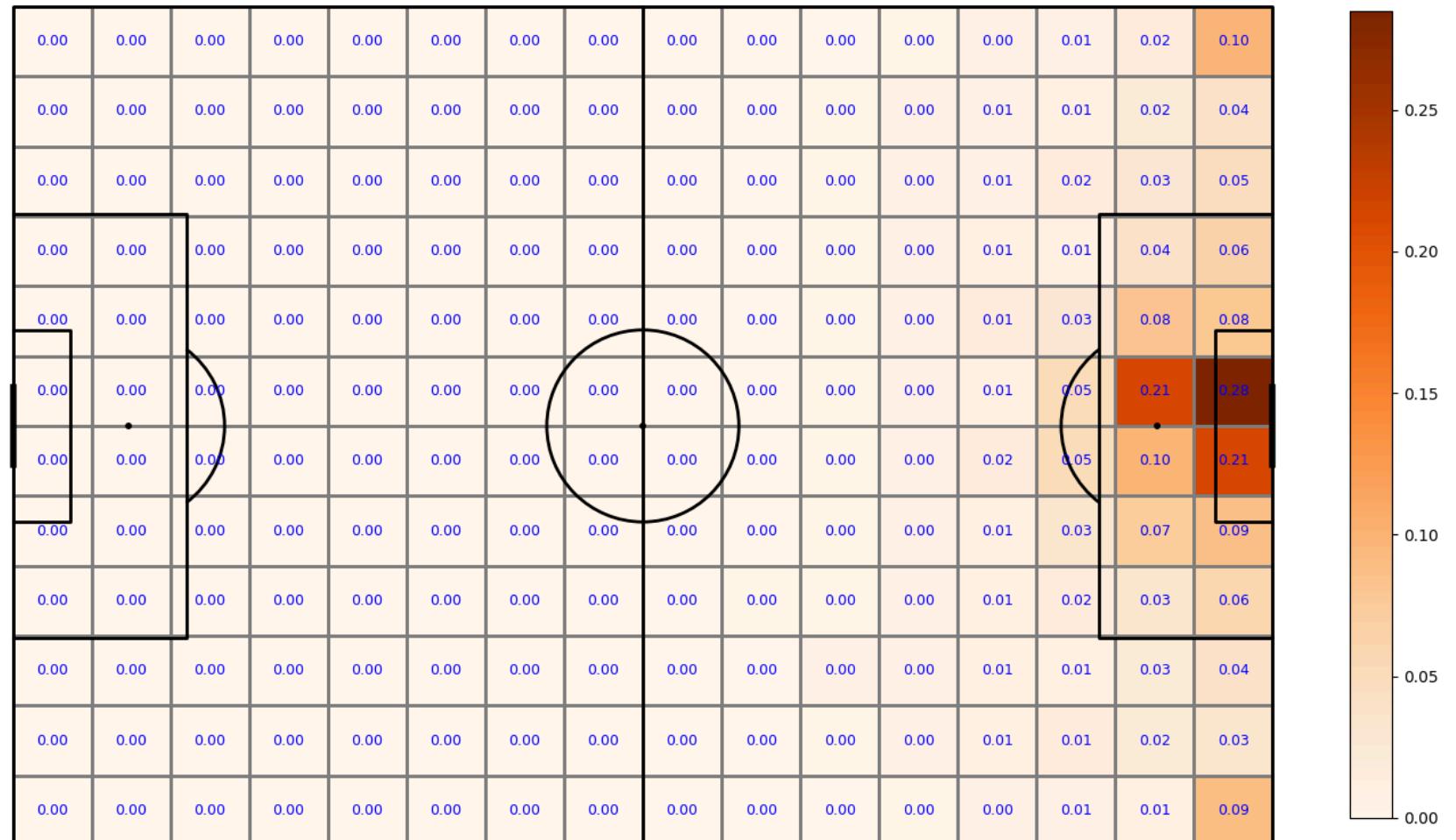
```
In [157]: transition_matrices_array = np.array(transition_matrices)
xT = np.zeros((12, 16))
for i in range(10):
    shoot_expected_payoff = goal_probability*shot_probability
    move_expected_payoff = move_probability*(np.sum(np.sum(transition_matrices_array*xT, axis = 2), axis =
xT = shoot_expected_payoff + move_expected_payoff
```

```
#let's plot it!
fig, ax = pitch.grid(grid_height=0.9, title_height=0.06, axis=False,
                      endnote_height=0.01, title_space=0, endnote_space=0)
goal["statistic"] = xT
pcm = pitch.heatmap(goal, cmap='Oranges', edgecolor='grey', ax=ax['pitch'])
labels = pitch.label_heatmap(goal, color='blue', fontsize=9,
                             ax=ax['pitch'], ha='center', va='center', str_format="{0:,.2f}", zorder = 3)
#legend to our plot
ax_cbar = fig.add_axes((1, 0.093, 0.03, 0.786))
cbar = plt.colorbar(pcm, cax=ax_cbar)
txt = 'Expected Threat matrix after ' + str(i+1) + ' moves'
fig.suptitle(txt, fontsize = 30)
plt.show()
```

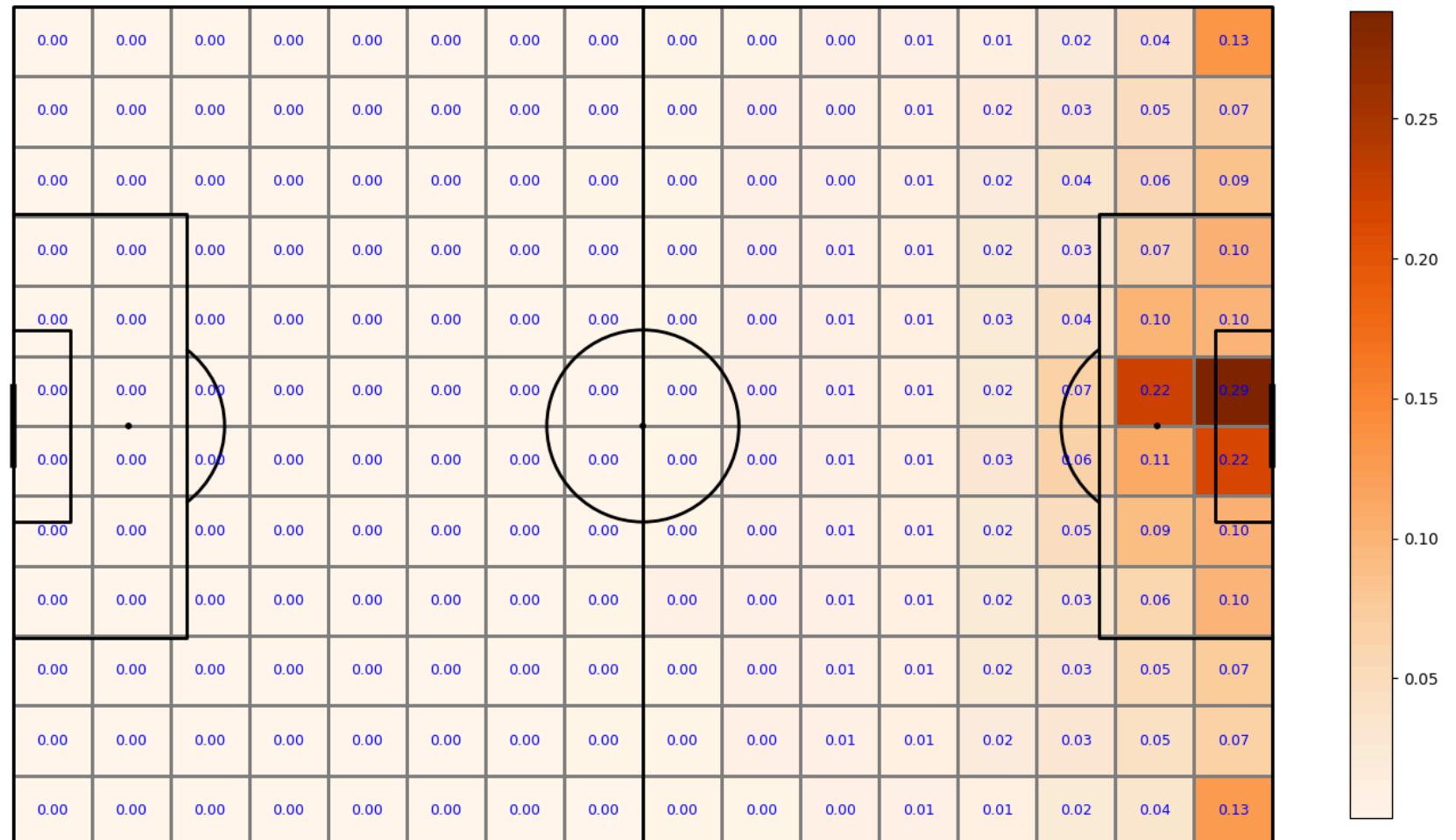
# Expected Threat matrix after 1 moves



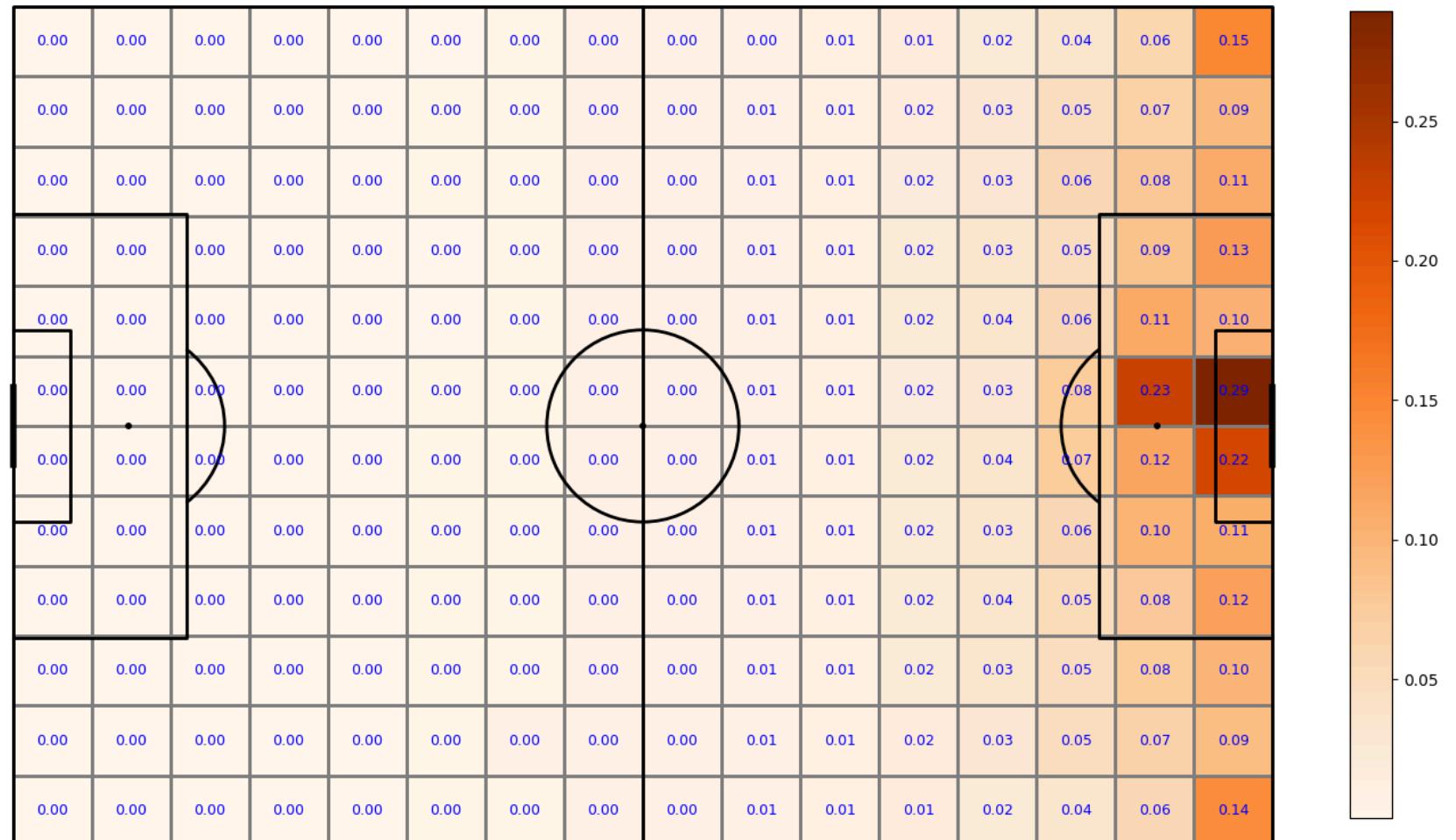
## Expected Threat matrix after 2 moves



# Expected Threat matrix after 3 moves



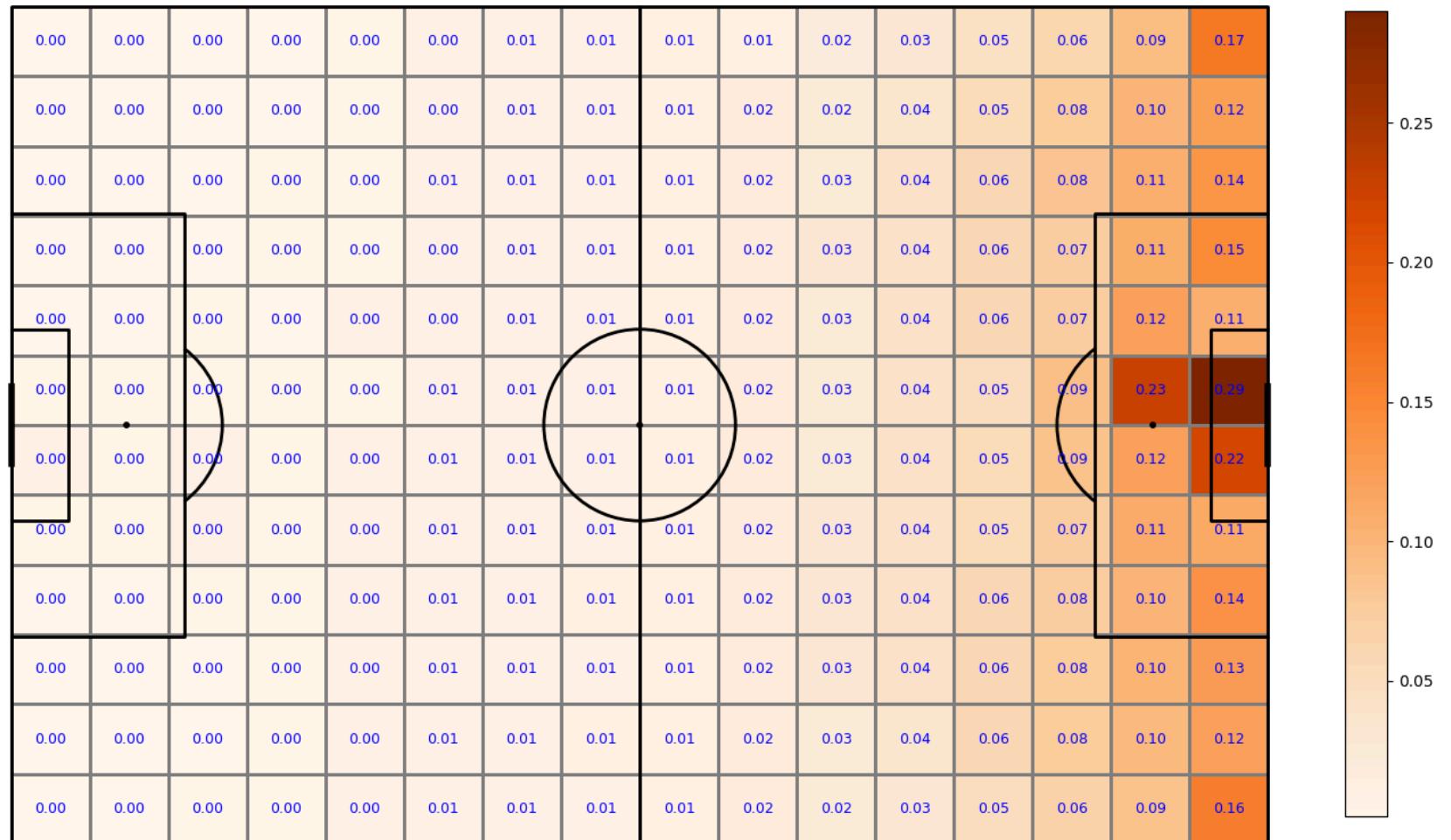
# Expected Threat matrix after 4 moves



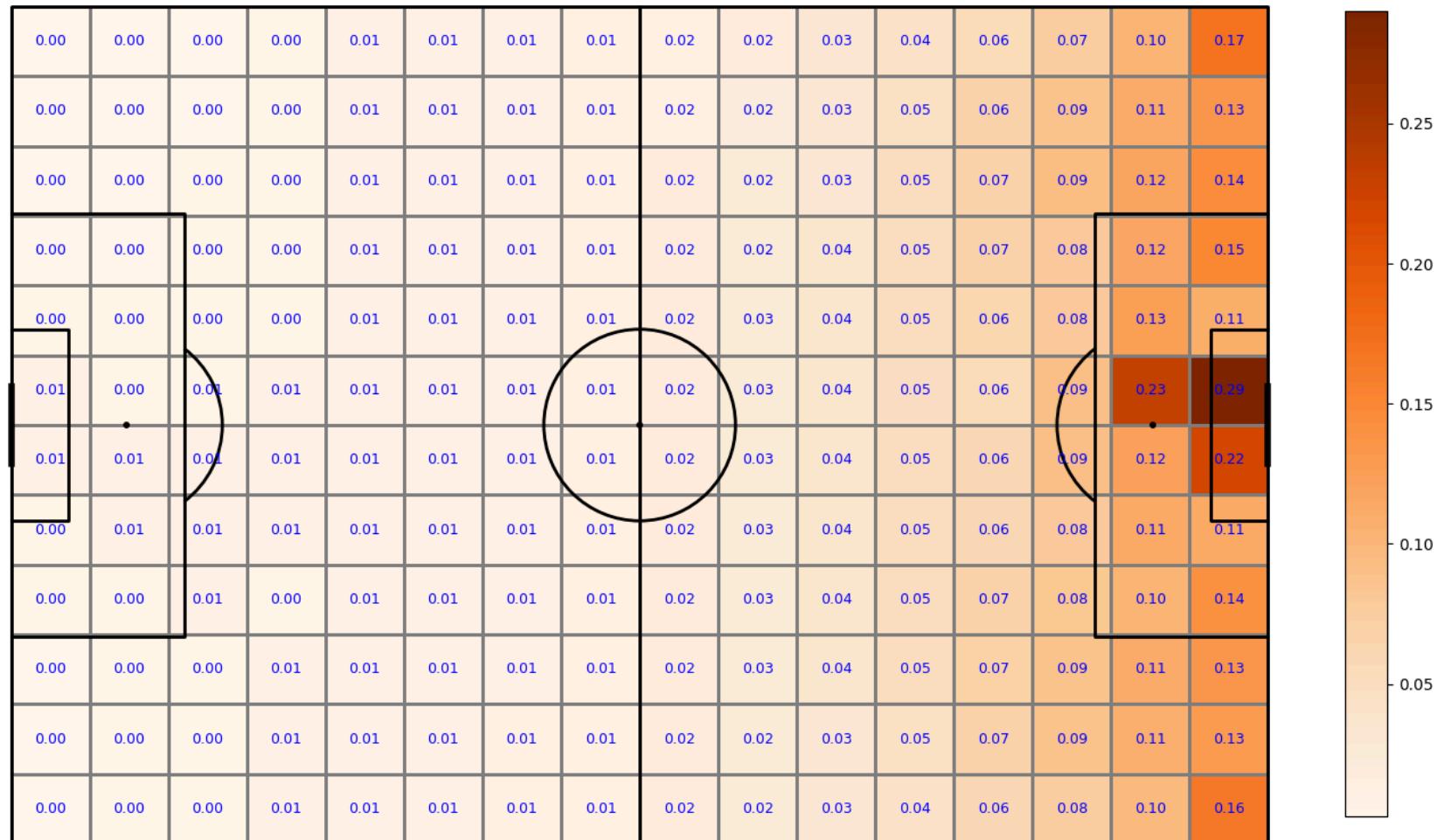
# Expected Threat matrix after 5 moves



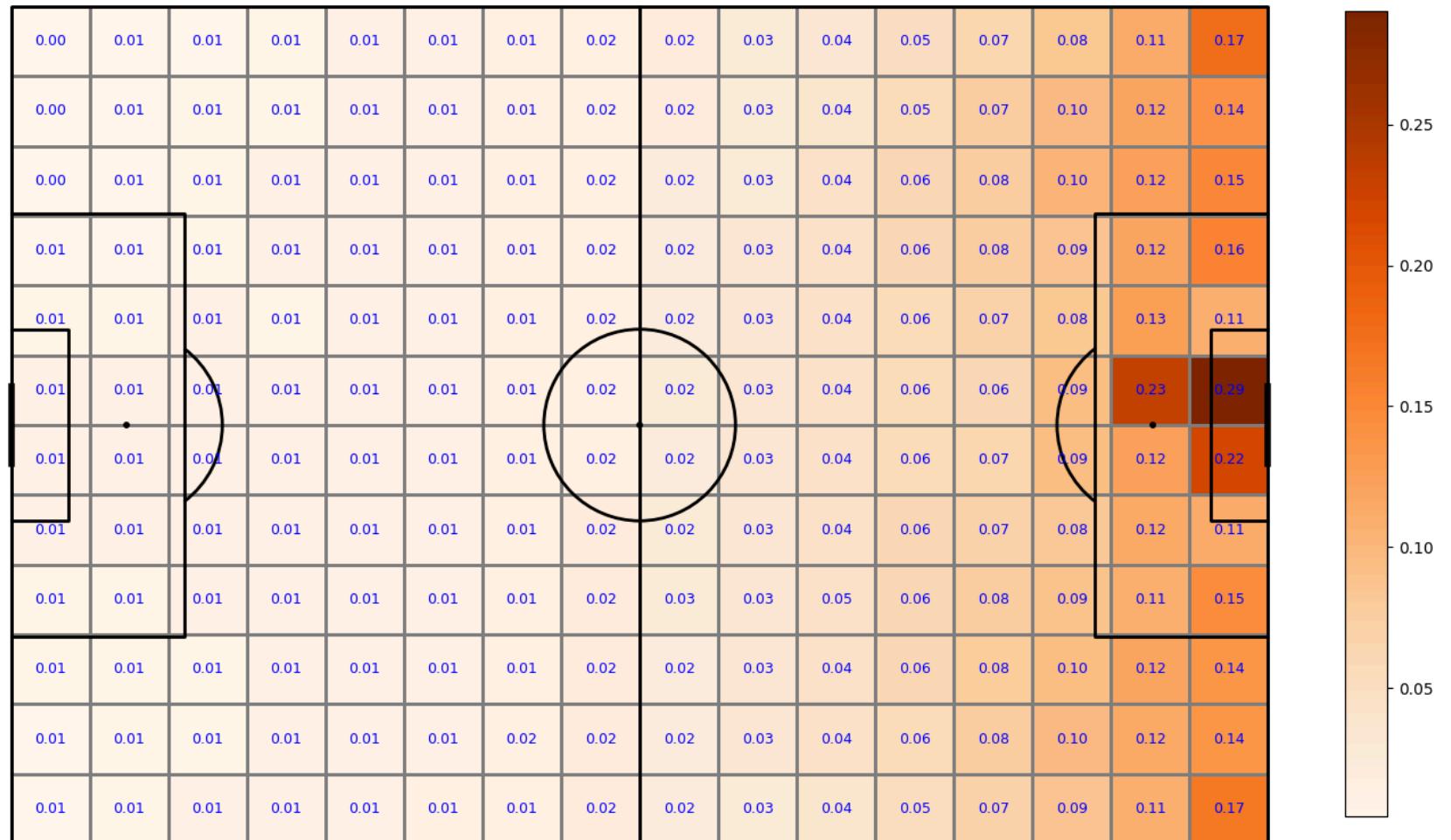
# Expected Threat matrix after 6 moves



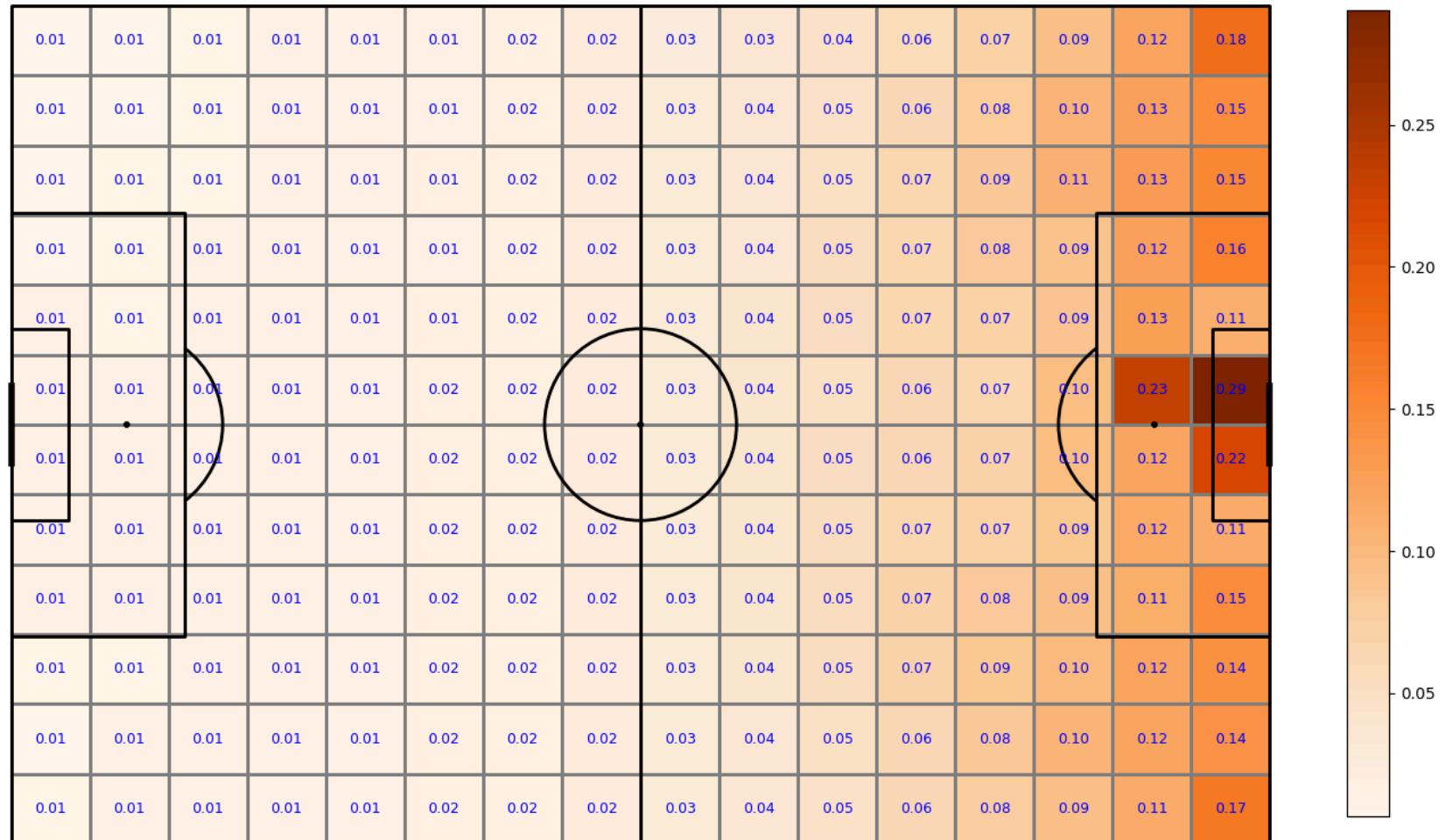
# Expected Threat matrix after 7 moves



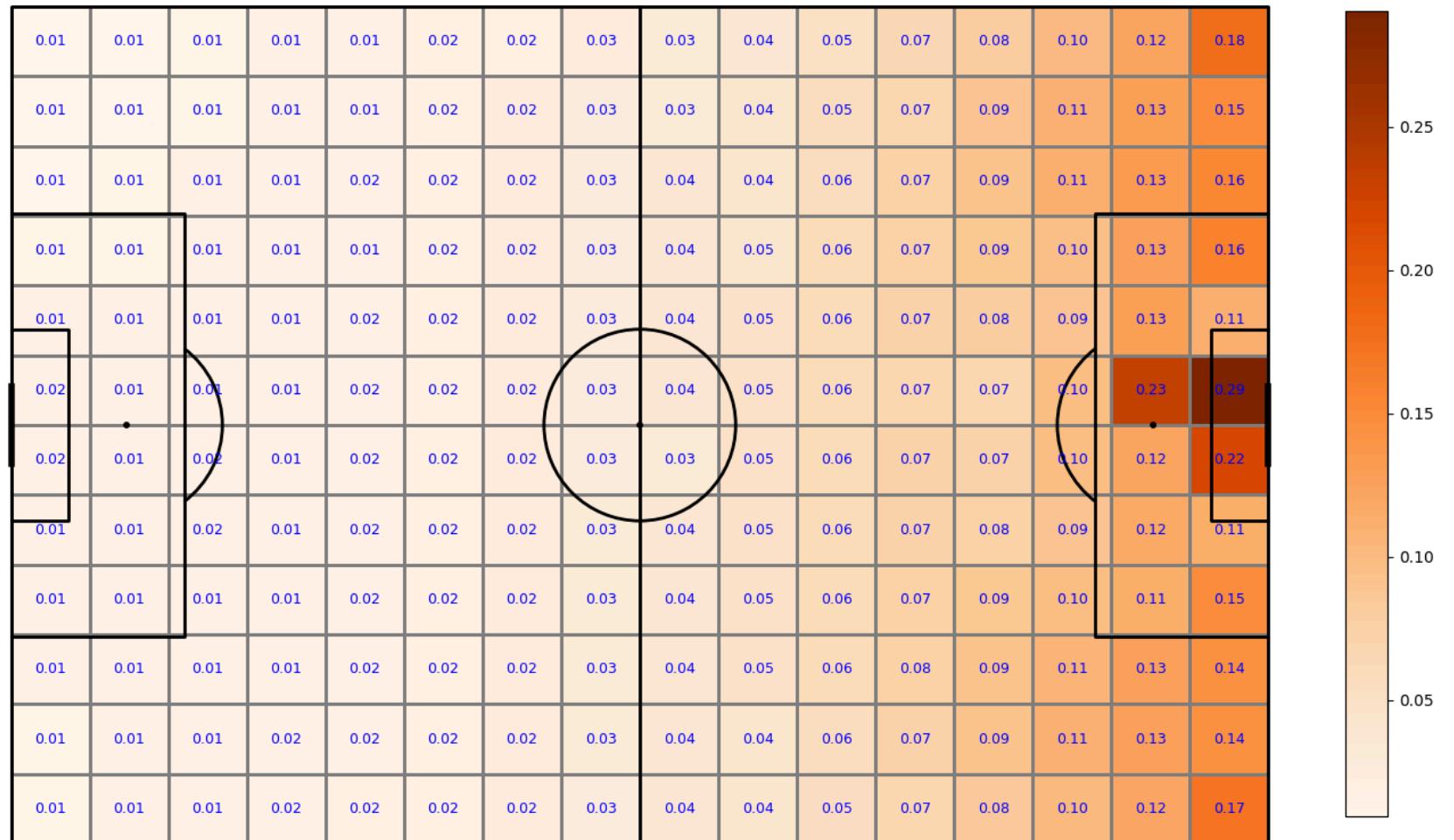
# Expected Threat matrix after 8 moves



# Expected Threat matrix after 9 moves



# Expected Threat matrix after 10 moves



Take 2

In [158...]

```
parser = Sbopen()
pitch = Pitch(line_zorder=2)

bins = (pitch.dim.positional_x[[0, 3, 4, 5, 6]], pitch.dim.positional_y)
```

```
event = xt_df.copy()

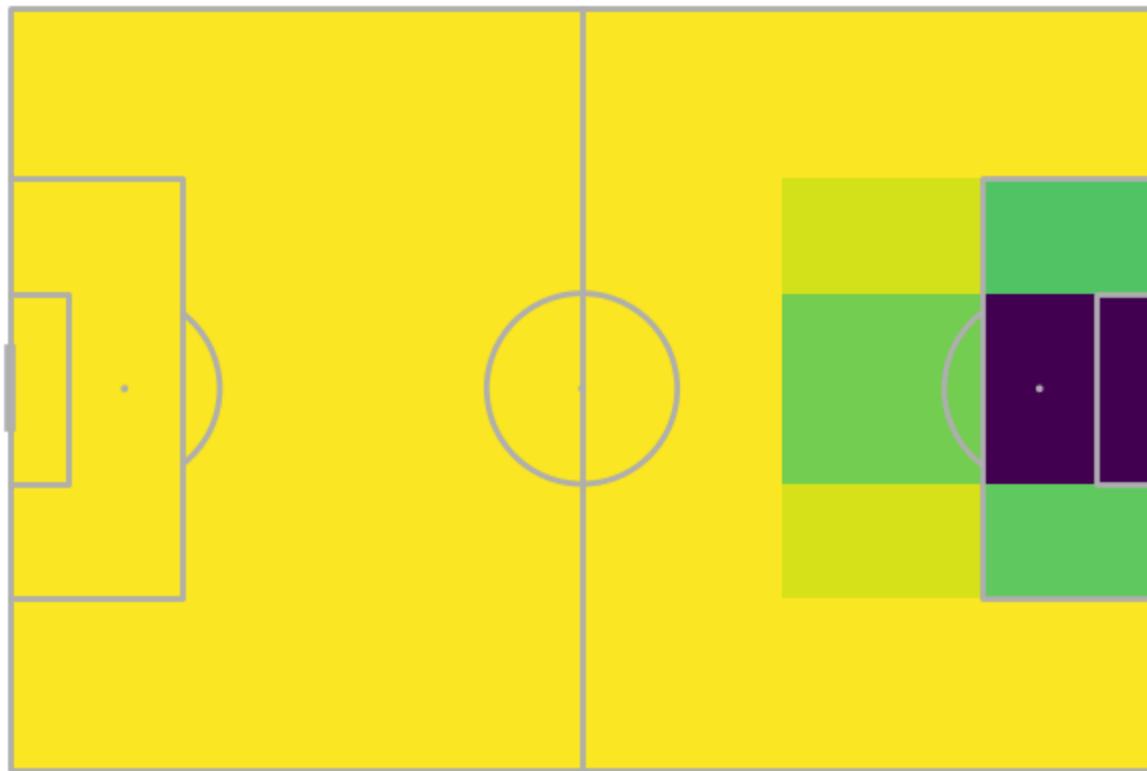
# boolean columns for working out probabilities
event['goal'] = event['outcome_name'] == 'Goal'
event['shoot'] = event['type_name'] == 'Shot'
event['move'] = event['type_name'] != 'Shot'

shot_probability = pitch.bin_statistic(event['x'], event['y'], values=event['shoot'],
                                         statistic='mean', bins=bins)
move_probability = pitch.bin_statistic(event['x'], event['y'], values=event['move'],
                                         statistic='mean', bins=bins)
goal_probability = pitch.bin_statistic(event.loc[event['shoot'], 'x'],
                                         event.loc[event['shoot'], 'y'],
                                         event.loc[event['shoot'], 'shot_statsbomb_xg'],
                                         statistic='mean',
                                         bins=bins)

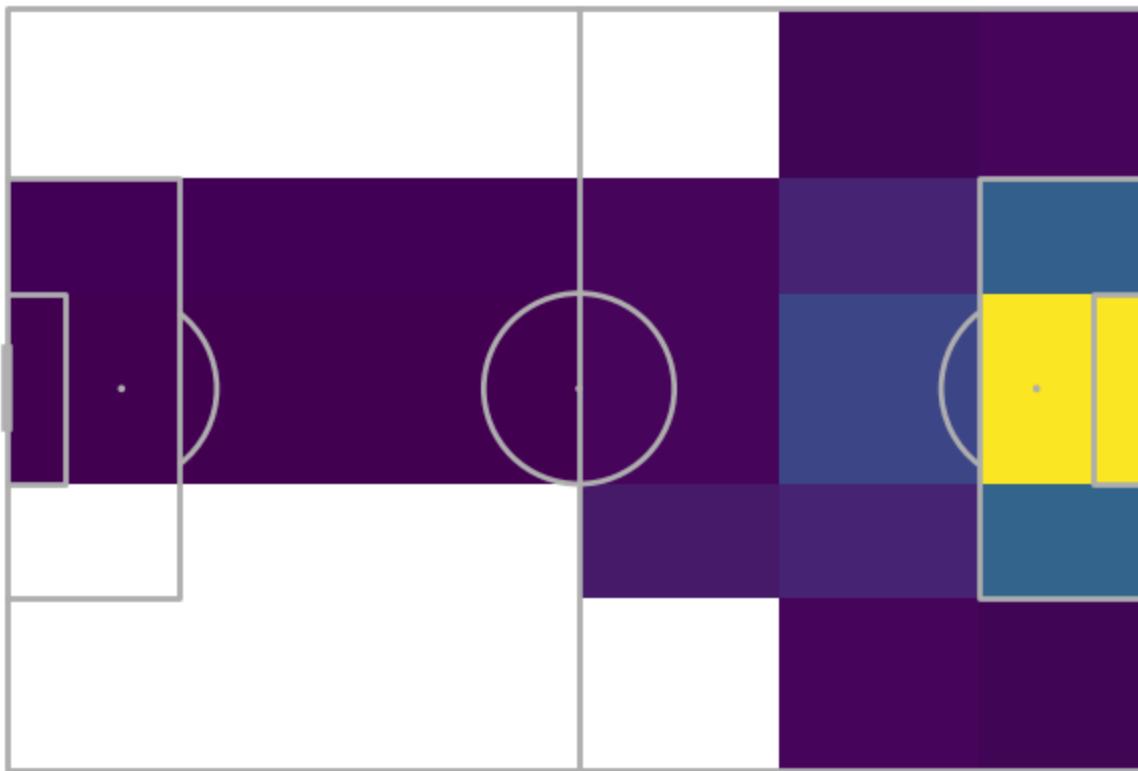
fig, ax = pitch.draw()
shot_heatmap = pitch.heatmap(shot_probability, ax=ax)
```



```
In [159]: fig, ax = pitch.draw()
move_heatmap = pitch.heatmap(move_probability, ax=ax)
```



```
In [160]: fig, ax = pitch.draw()
goal_heatmap = pitch.heatmap(goal_probability, ax=ax)
```



```
In [161]: move = event[event['move']].copy()
bin_start_locations = pitch.bin_statistic(move['x'], move['y'], bins=bins)
move = move[bin_start_locations['inside']].copy()

# get the successful moves
bin_end_locations = pitch.bin_statistic(move['end_x'], move['end_y'], bins=bins)
move_success = move[(bin_end_locations['inside']) & (move['outcome_name'].isnull())].copy()

bin_success_start = pitch.bin_statistic(move_success['x'], move_success['y'], bins=bins)
bin_success_end = pitch.bin_statistic(move_success['end_x'], move_success['end_y'], bins=bins)
df_bin = pd.DataFrame({'x': bin_success_start['binnumber'][0],
                      'y': bin_success_start['binnumber'][1],
                      'end_x': bin_success_end['binnumber'][0],
                      'end_y': bin_success_end['binnumber'][1]})
```

```

# calculate the bin counts for the successful moves
bin_counts = df_bin.value_counts().reset_index(name='bin_counts')

# create the move_transition_matrix
num_y, num_x = shot_probability['statistic'].shape
move_transition_matrix = np.zeros((num_y, num_x, num_y, num_x))
move_transition_matrix[bin_counts['y'], bin_counts['x'],
                      bin_counts['end_y'], bin_counts['end_x']] = bin_counts.bin_counts.values

# and divide by the starting locations for all moves (including unsuccessful)
# to get the probability of moving the ball successfully between grid cells
bin_start_locations = pitch.bin_statistic(move['x'], move['y'], bins=bins)
bin_start_locations = np.expand_dims(bin_start_locations['statistic'], (2, 3))
move_transition_matrix = np.divide(move_transition_matrix,
                                   bin_start_locations,
                                   out=np.zeros_like(move_transition_matrix),
                                   where=bin_start_locations != 0,
                                   )

```

In [162...]

```

move_transition_matrix = np.nan_to_num(move_transition_matrix)
shot_probability_matrix = np.nan_to_num(shot_probability['statistic'])
move_probability_matrix = np.nan_to_num(move_probability['statistic'])
goal_probability_matrix = np.nan_to_num(goal_probability['statistic'])

```

In [163...]

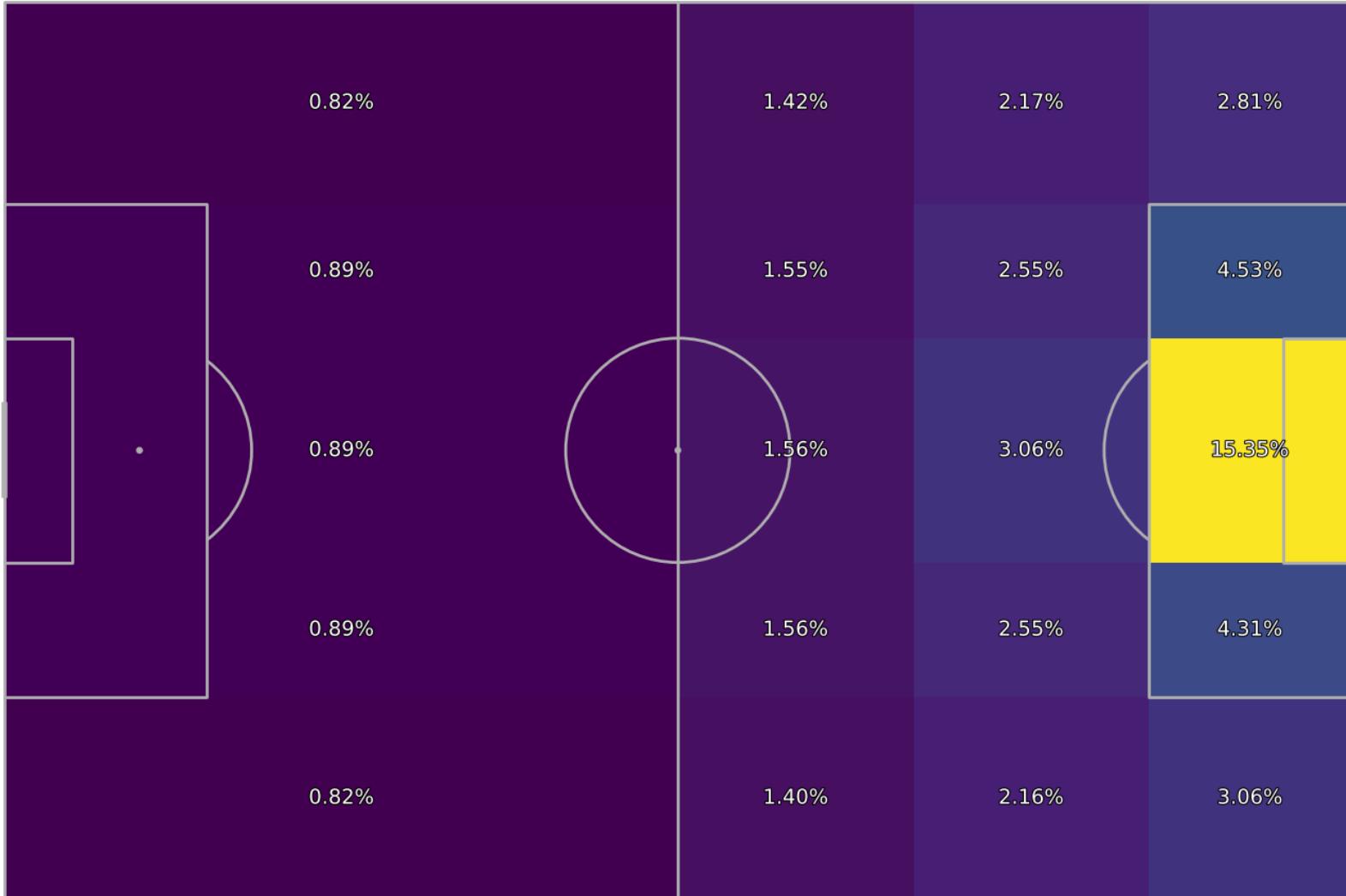
```

xt = np.multiply(shot_probability_matrix, goal_probability_matrix)
diff = 1
iteration = 0
while np.any(diff > 0.00001): # iterate until the differences between the old and new xt is small
    xt_copy = xt.copy() # keep a copy for comparing the differences
    # calculate the new expected threat
    xt = (np.multiply(shot_probability_matrix, goal_probability_matrix) +
           np.multiply(move_probability_matrix,
                       np.multiply(move_transition_matrix, np.expand_dims(xt, axis=(0, 1))).sum(
                           axis=(2, 3)))
    )
    diff = (xt - xt_copy)
    iteration += 1
print('Number of iterations:', iteration)

```

Number of iterations: 44

```
In [164]: path_eff = [path_effects.Stroke(linewidth=1.5, foreground='black'),
                 path_effects.Normal()]
# new bin statistic for plotting xt only
for_plotting = pitch.bin_statistic(event['x'], event['y'], bins=bins)
for_plotting['statistic'] = xt
fig, ax = pitch.draw(figsize=(14, 9.625))
_ = pitch.heatmap(for_plotting, ax=ax)
_ = pitch.label_heatmap(for_plotting, ax=ax, str_format='{:,.2%}',
                        color='white', fontsize=14, va='center', ha='center',
                        path_effects=path_eff)
```



```
In [165]: # first get grid start and end cells
grid_start = pitch.bin_statistic(move_success.x, move_success.y, bins=bins)
grid_end = pitch.bin_statistic(move_success.end_x, move_success.end_y, bins=bins)

# then get the xT values from the start and end grid cell
start_xt = xt[grid_start['binnumber'][1], grid_start['binnumber'][0]]
```

```
end_xt = xt[grid_end['binnumber'][1], grid_end['binnumber'][0]]  
  
# then calculate the added xt  
added_xt = end_xt - start_xt  
move_success['xt'] = added_xt
```

```
In [166]: # First group by comp_id and seas_id, then by player_name and sum their xt values  
player_xt = (move_success.groupby(['comp_id', 'seas_id', 'player_name'])['xt']  
             .sum()  
             .reset_index())  
  
# Then group by comp_id and seas_id and get top 5 players by xt value  
top_players = (player_xt.groupby(['comp_id', 'seas_id'])  
               .apply(lambda x: x.nlargest(5, 'xt'))  
               .reset_index(drop=True))  
  
# Sort the results for better readability  
top_players = top_players.sort_values(['comp_id', 'seas_id', 'xt'],  
                                      ascending=[True, True, False])  
top_players
```

```
/var/folders/y6/sbm28jw975q8__vq0y26t_tc0000gn/T/ipykernel_53961/1113814520.py:8: DeprecationWarning: DataFrameGroupBy.apply operated on the grouping columns. This behavior is deprecated, and in a future version of pandas the grouping columns will be excluded from the operation. Either pass `include_groups=False` to exclude the groupings or explicitly select the grouping columns after groupby to silence this warning.  
    .apply(lambda x: x.nlargest(5, 'xt'))
```

Out[166...]

	comp_id	seas_id	player_name	xt
0	9	281	Alejandro Grimaldo García	8.291243
1	9	281	Florian Wirtz	7.510969
2	9	281	Jeremie Frimpong	6.743476
3	9	281	Granit Xhaka	5.181923
4	9	281	Jonas Hofmann	5.111888
5	55	43	Luke Shaw	1.928062
6	55	43	Joakim Mæhle	1.763808
7	55	43	Toni Kroos	1.531897
8	55	43	Jorge Resurrección Merodio	1.525640
9	55	43	Lorenzo Insigne	1.501668
10	55	282	Lamine Yamal Nasraoui Ebana	2.165855
11	55	282	Toni Kroos	2.158600
12	55	282	Cody Mathès Gakpo	1.779042
13	55	282	Nicholas Williams Arthur	1.757075
14	55	282	Bruno Miguel Borges Fernandes	1.661044
15	72	107	Ona Batlle Pascual	2.380009
16	72	107	Teresa Abelleira Dueñas	2.301992
17	72	107	Alex Greenwood	2.043037
18	72	107	Sherida Spitse	2.011699
19	72	107	Jennifer Hermoso Fuentes	1.574947

In [231...]

```
len(move_success)
```

Out[231...]

295643

```
In [230... move_success.columns
```

```
Out[230... Index(['id', 'index', 'period', 'timestamp', 'minute', 'second', 'possession',  
       'duration', 'match_id', 'type_id', 'type_name', 'possession_team_id',  
       'possession_team_name', 'play_pattern_id', 'play_pattern_name',  
       'team_id', 'team_name', 'tactics_formation', 'player_id', 'player_name',  
       'position_id', 'position_name', 'pass_recipient_id',  
       'pass_recipient_name', 'pass_length', 'pass_angle', 'pass_height_id',  
       'pass_height_name', 'end_x', 'end_y', 'body_part_id', 'body_part_name',  
       'sub_type_id', 'sub_type_name', 'x', 'y', 'under_pressure',  
       'outcome_id', 'outcome_name', 'aerial_won', 'shot_statsbomb_xg',  
       'technique_id', 'technique_name', 'goalkeeper_position_id',  
       'goalkeeper_position_name', 'off_camera', 'pass_cross', 'counterpress',  
       'out', 'ball_recovery_recovery_failure', 'pass_switch',  
       'pass_assisted_shot_id', 'pass_shot_assist', 'shot_key_pass_id',  
       'shot_first_time', 'end_z', 'foul_won_defensive',  
       'substitution_replacement_id', 'substitution_replacement_name',  
       'dribble_overrun', 'ball_recovery_offensive',  
       'foul_committed_advantage', 'foul_won_advantage', 'block_deflection',  
       'foul_committed_card_id', 'foul_committed_card_name',  
       'pass_goal_assist', 'block_offensive', 'pass_cut_back',  
       'pass_deflected', 'shot_one_on_one', 'comp_id', 'seas_id',  
       'foul_committed_offensive', 'injury_stoppage_in_chain', 'pass_no_touch',  
       'pass_miscommunication', 'foul_committed_penalty', 'foul_won_penalty',  
       'block_save_block', 'shot_redirect', 'dribble_nutmeg', 'shot_deflected',  
       'bad_behaviour_card_id', 'bad_behaviour_card_name', 'shot_open_goal',  
       'dribble_no_touch', 'shot_follows_dribble', 'player_off_permanent',  
       'goal', 'shoot', 'move', 'xt'],  
      dtype='object')
```

```
In [182... set(X_complete_all.columns).difference(list(move_success.columns))
```

```
Out[182... {'avg_defender_distance', 'num_1_away', 'num_2_away', 'num_3_away'}
```

## Results

```
In [119... # Merge test_related and test_event  
xt_df = test_related_df[['match_id', 'id', 'index', 'type_name']].merge(  
    test_event_df[['match_id', 'id', 'index', 'type_name', 'possession_team_id', 'end_x', 'end_y', 'x', 'y',  
    on=['match_id', 'id', 'index', 'type_name'], how='left']).sort_values(by=['match_id', 'index'])
```

```

# Filter for Pass, Carry, and Shot
xt_df = xt_df[xt_df["type_name"].isin(['Pass', 'Carry', 'Shot'])].reset_index(drop=True).drop_duplicates()

# Identify Goal rows

# Get pass_carry events
how_many_rows_back = 8
new_indices = pd.Index([])
row_index = -1
for goal_loc in goal_locs:
    prev_index = row_index + 1
    row_index = xt_df.index.get_loc(goal_loc)
    new_indices = new_indices.union(xt_df.index[max(prev_index, row_index - how_many_rows_back):row_index])
pass_carry_df = xt_df.loc[new_indices].drop_duplicates().reset_index(drop=True)

# backfill
pass_carry_df['group'] = pass_carry_df['group'].bfill()
goal_locs = xt_df.index[xt_df["outcome_name"] == 'Goal']
xt_df['group'] = pd.NA
xt_df.loc[goal_locs, 'group'] = range(1, len(goal_locs) + 1)

```

/var/folders/y6/sbm28jw975q8\_\_vq0y26t\_tc0000gn/T/ipykernel\_53961/2579920309.py:25: FutureWarning: Downcasting object dtype arrays on .fillna, .ffill, .bfill is deprecated and will change in a future version. Call result.infer\_objects(copy=False) instead. To opt-in to the future behavior, set `pd.set\_option('future.no\_silent\_downcasting', True)`  
 pass\_carry\_df['group'] = pass\_carry\_df['group'].bfill()

In [120...]

```

# # Merge test_related and test_event
# xt_df = test_related_df[['match_id', 'id', 'index', 'type_name']].merge(
#     test_event_df[['match_id', 'id', 'index', 'type_name', 'possession_team_id', 'end_x', 'end_y', 'x',
#     'on=['match_id', 'id', 'index', 'type_name'], how='left']].sort_values(by=['match_id', 'index'])

# # Filter for Pass, Carry, and Shot
# xt_df = xt_df[xt_df["type_name"].isin(['Pass', 'Carry', 'Shot'])].reset_index(drop=True).drop_duplicates()

# # Identify Goal rows
# goal_locs = xt_df.index[xt_df["outcome_name"] == 'Goal']
# # print(xt_df.loc[goal_locs].head(5))
# xt_df['group'] = pd.NA
# xt_df.loc[goal_locs, 'group'] = range(1, len(goal_locs) + 1)

```

```
# how_many_rows_back = 8
# prev_goal_index = -1
# pass_carry_df = pd.DataFrame()
# for goal_index in goal_locs:
#     start_index = max(prev_goal_index + 1, goal_index - how_many_rows_back)

# events = xt_df.loc[start_index:goal_index]
# def_half_events = list(events.index[events.end_x < 50])
# valid_events = events if not def_half_events else events.loc[def_half_events[-1]+1:]

# pass_carry_df = pd.concat([pass_carry_df, valid_events])

# prev_goal_index = goal_index

# # Reset index and assign groups
# pass_carry_df = pass_carry_df.reset_index(drop=True)
# pass_carry_df['group'] = pass_carry_df['group'].bfill()
```

In [121]: # pass\_carry\_df.head(10)

```
# Define colors for different types of events
color_map = {
    'Goal': 'green',
    'Shot': 'red',
    'Carry': 'blue',
    'Pass': 'orange',
}
# for index_ in range(len(best_models)):
for index_ in range(5,6):
    # Map the probabilities
    id_to_probability = dict(zip(test_clean_pass_df['id'], new_probs[index_]))

    # Create a pitch
    pitch = Pitch(pitch_type='statsbomb')

    # Grid of images
    fig, axs = plt.subplots(nrows=2, ncols=2, figsize=(24, 18))
    axs = axs.flatten()

    for ax_index, (ax, (group_number, group_df)) in enumerate(zip(axs[:len(pass_carry_df['group'].unique())
        pitch.draw(ax=ax)
```

```

goal_team_id = group_df.loc[group_df['outcome_name'] == 'Goal', 'possession_team_id'].iloc[0]

# Iterate over events with index tracking
event_indices = group_df.index.tolist()
for i, (_, event) in enumerate(group_df.iterrows(), start=1):

    if event['possession_team_id'] != goal_team_id:
        continue

    # Check if the current event should be skipped
    if i < len(event_indices) - 1:
        next_event_index = group_df.loc[event_indices[i], 'index']
        current_event_index = event['index']
        if next_event_index - current_event_index > 3:
            continue

    x, y = event['x'], event['y']
    end_x, end_y = event['end_x'], event['end_y']
    event_type = event['type_name']
    outcome = event['outcome_name']
    event_id = event['id']

    if event_id in id_to_probability:
        i = round(id_to_probability[event_id], 4)

    color = 'green' if outcome == 'Goal' else color_map[event_type]

    pitch.arrows(x, y, end_x, end_y, ax=ax, color=color, width=2)
    ax.text((x + end_x) / 2, (y + end_y) / 2, str(i), fontsize=12,
            ha='center', va='center', color='black')

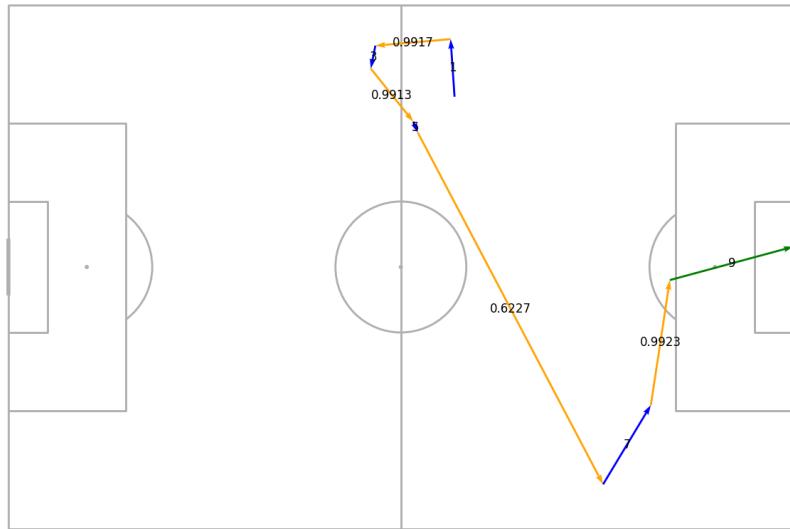
    ax.set_title(f'Group {group_number}')

# Hide any unused subplots
for ax in axs[len(pass_carry_df['group'].unique()):]:
    ax.set_visible(False)

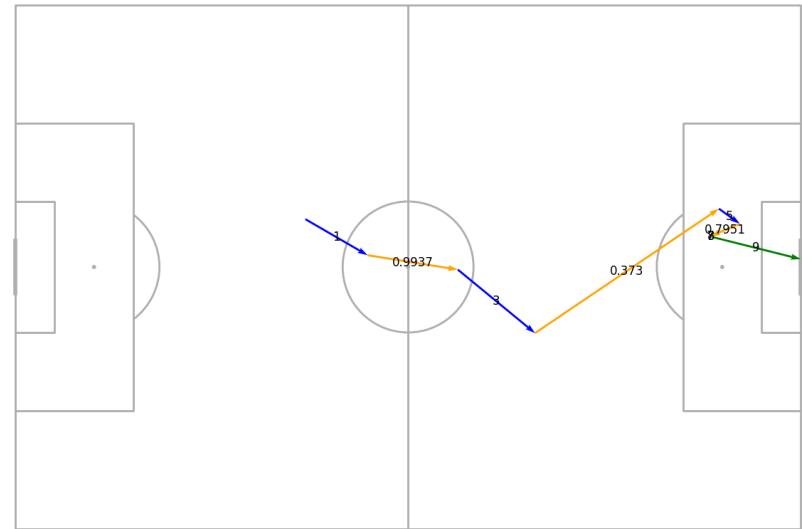
plt.tight_layout()
plt.savefig(f"Model #{index+1}.png")
plt.show()

```

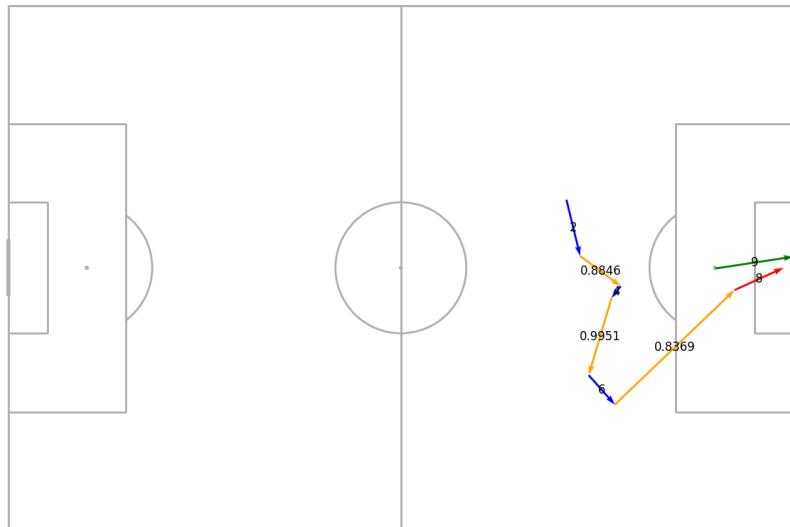
Group 1



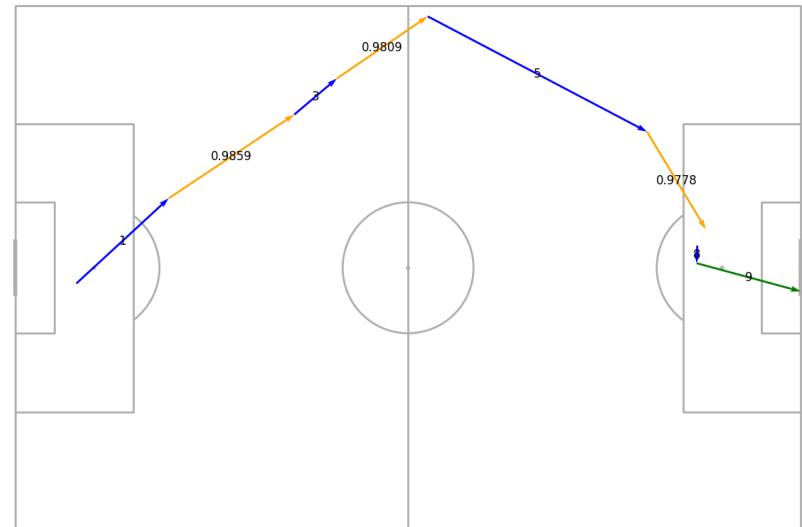
Group 2



Group 3



Group 4



## Voronoi (Space Creation)

```
In [69]: # get freeze frame data for game 3788741
parser = Sbopen()
```

```
frames, visible = parser.frame(3930158)
# frames
```

```
In [70]: # frame_idx = 20
# frame_id = visible.iloc[20].id

# visible_area = np.array(visible.iloc[frame_idx].visible_area).reshape(-1, 2)
# player_position_data = frames[frames.id == frame_id]

# teammate_locs = player_position_data[player_position_data.teammate]
# opponent_locs = player_position_data[~player_position_data.teammate]

visible_area = np.array(np.array(visible[visible.id == '0badc984-28cb-4036-9b0e-89ea7fc6820f'].visible_area))
player_position_data = frames[frames.id == '0badc984-28cb-4036-9b0e-89ea7fc6820f']

teammate_locs = player_position_data[player_position_data.teammate]
opponent_locs = player_position_data[~player_position_data.teammate]
```

```
In [71]: # draw plot
p = Pitch(pitch_type='statsbomb')
fig, ax = p.draw(figsize=(12,8))

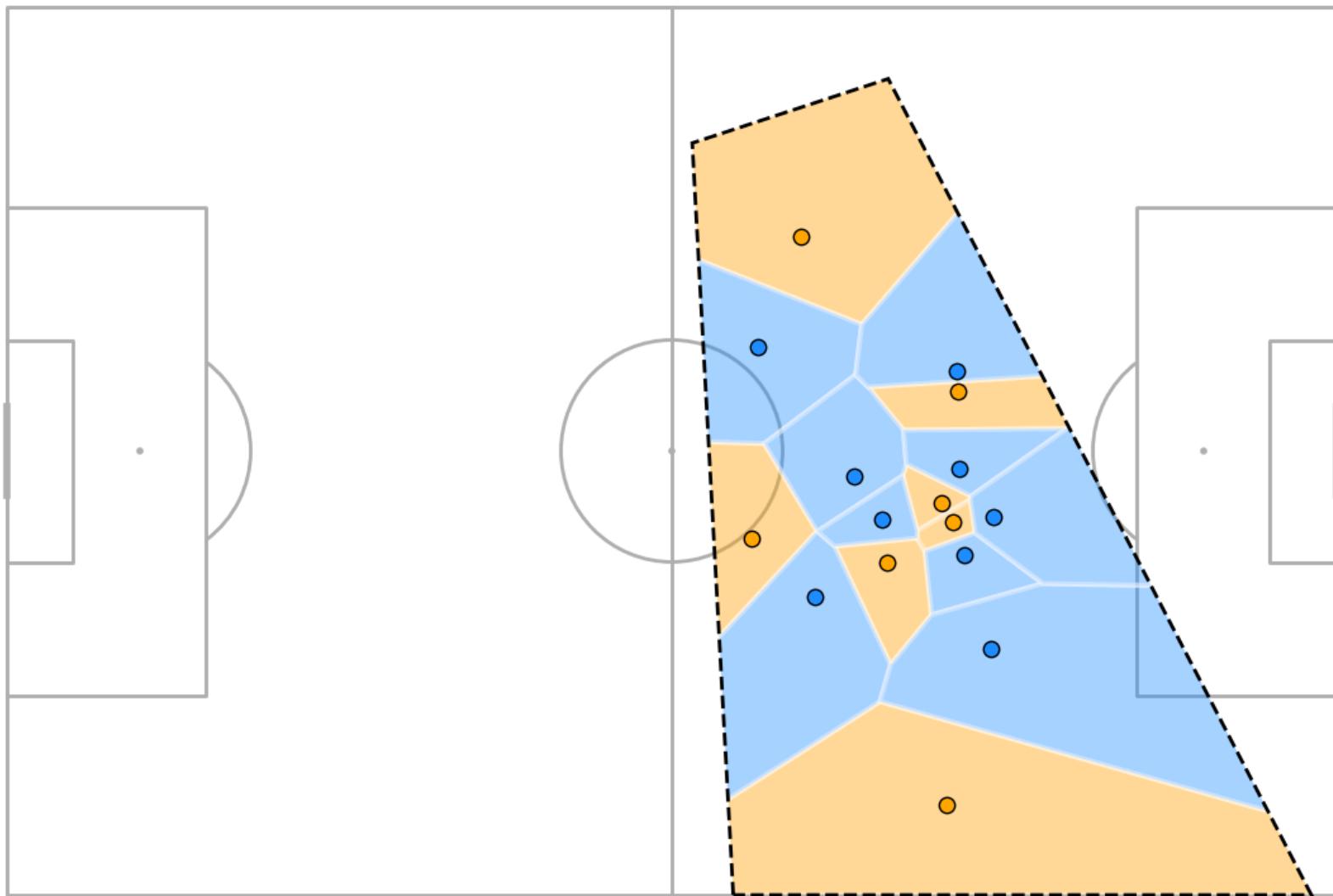
# Plot Voronoi
team1, team2 = p.voronoi(player_position_data.x, player_position_data.y,
                          player_position_data.teammate)
t1 = p.polygon(team1, ax=ax, fc='orange', ec='white', lw=3, alpha=0.4)
t2 = p.polygon(team2, ax=ax, fc='dodgerblue', ec='white', lw=3, alpha=0.4)

# Plot players
sc1 = p.scatter(teammate_locs.x, teammate_locs.y, c='orange', s=80, ec='k', ax=ax)
sc2 = p.scatter(opponent_locs.x, opponent_locs.y, c='dodgerblue', s=80, ec='k', ax=ax)

# Plot the visible area
visible = p.polygon([visible_area], color='None', ec='k', linestyle='--', lw=2, ax=ax)

# clip each player to the visible area
for p1 in t1:
    p1.set_clip_path(visible[0])
for p2 in t2:
    p2.set_clip_path(visible[0])
```

```
plt.show()
```



```
In [73]: from mplsoccer import Pitch
import pandas as pd
import numpy as np
```

```

from shapely.geometry import Polygon

def calculate_polygon_area(vertices):
    if len(vertices) < 3:
        return 0
    return Polygon(vertices).area

def calculate_voronoi_areas(pass_df, frames_df, related_df):
    pitch = Pitch()

    merged_df = pd.merge(pass_df, related_df, on=['match_id', 'id'])

    voronoi_areas = []
    ctr = 0
    for _, pass_event in merged_df.iterrows():
        start_time = time.time()
        ctr += 1
        pass_frames = frames_df[(frames_df['match_id'] == pass_event['match_id']) &
                                (frames_df['event_uuid'] == pass_event['id'])]

        receipt_frames = frames_df[(frames_df['match_id'] == pass_event['match_id']) &
                                    (frames_df['event_uuid'] == pass_event['id_related'])]

        if pass_frames.empty or receipt_frames.empty:
            voronoi_areas.append({
                'match_id': pass_event['match_id'],
                'id': pass_event['id'],
                'voronoi_area_pass': np.nan,
                'voronoi_area_receipt': np.nan
            })
            continue

        # Determine teams for pass moment
        pass_teams = pass_frames['teammate'].astype(int)

        # Determine teams for receipt moment
        receipt_teams = receipt_frames['teammate'].astype(int)

        # Calculate Voronoi for pass moment
        pass_team1, pass_team2 = pitch.voronoi(pass_frames['x'], pass_frames['y'], teams=pass_teams)

        # Calculate Voronoi for ball receipt moment

```

```

receipt_team1, receipt_team2 = pitch.voronoi(receipt_frames['x'], receipt_frames['y'], teams=receipt_teams)

# Combine team1 and team2 arrays
pass_voronoi = np.concatenate([pass_team1, pass_team2])
receipt_voronoi = np.concatenate([receipt_team1, receipt_team2])

# Calculate areas
pass_areas = [calculate_polygon_area(vertices) for vertices in pass_voronoi]
receipt_areas = [calculate_polygon_area(vertices) for vertices in receipt_voronoi]

# Find the passer's and receiver's Voronoi areas
passer_mask = pass_frames['actor'] == True
receiver_mask = receipt_frames['actor'] == True

pass_area = pass_areas[passer_mask.to_numpy().nonzero()[0][0]] if passer_mask.any() else np.nan
receipt_area = receipt_areas[receiver_mask.to_numpy().nonzero()[0][0]] if receiver_mask.any() else np.nan

voronoi_areas.append({
    'match_id': pass_event['match_id'],
    'id': pass_event['id'],
    'voronoi_area_pass': pass_area,
    'voronoi_area_receipt': receipt_area
})
print(f"Itr #{ctr} completed in {(time.time() - start_time):.4f}s")

return pd.DataFrame(voronoi_areas)

# Usage
voronoi_df = calculate_voronoi_areas(complete_pass_df, complete_frames_df, complete_related_df)

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KeyboardInterrupt                                Traceback (most recent call last)  
Cell In[73], line 74  
    71     return pd.DataFrame(voronoi_areas)  
    73 # Usage  
--> 74 voronoi_df = calculate_voronoi_areas(complete_pass_df, complete_frames_df, complete_related_df)  
  
Cell In[73], line 21, in calculate_voronoi_areas(pass_df, frames_df, related_df)  
    19 start_time = time.time()  
    20 ctr += 1  
--> 21 pass_frames = frames_df[(frames_df['match_id'] == pass_event['match_id']) &  
    22                 (frames_df['event_uuid'] == pass_event['id'])]  
    24 receipt_frames = frames_df[(frames_df['match_id'] == pass_event['match_id']) &  
    25                 (frames_df['event_uuid'] == pass_event['id_related'])]  
    27 if pass_frames.empty or receipt_frames.empty:  
  
File ~/Downloads/Football Papers + Models/ftblev/lib/python3.11/site-packages/pandas/core/ops/common.py:7  
6, in _unpack_zerodim_and_defer.<locals>.new_method(self, other)  
    72         return NotImplemented  
    74 other = item_from_zerodim(other)  
--> 76 return method(self, other)  
  
File ~/Downloads/Football Papers + Models/ftblev/lib/python3.11/site-packages/pandas/core/arraylike.py:40,  
in OpsMixin.__eq__(self, other)  
    38 @unpack_zerodim_and_defer("__eq__")  
    39 def __eq__(self, other):  
--> 40     return self._cmp_method(other, operator.eq)  
  
File ~/Downloads/Football Papers + Models/ftblev/lib/python3.11/site-packages/pandas/core/series.py:6119,  
in Series._cmp_method(self, other, op)  
    6116 lvalues = self._values  
    6117 rvalues = extract_array(other, extract_numpy=True, extract_range=True)  
-> 6119 res_values = ops.comparison_op(lvalues, rvalues, op)  
    6121 return self._construct_result(res_values, name=res_name)  
  
File ~/Downloads/Football Papers + Models/ftblev/lib/python3.11/site-packages/pandas/core/ops/array_ops.py:344,  
in comparison_op(left, right, op)  
    341     return invalid_comparison(lvalues, rvalues, op)  
    343 elif lvalues.dtype == object or isinstance(rvalues, str):  
--> 344     res_values = comp_method_OBJECT_ARRAY(op, lvalues, rvalues)  
    346 else:  
    347     res_values = _na_arithmetic_op(lvalues, rvalues, op, is_cmp=True)
```

```
File ~/Downloads/Football Papers + Models/ftblenv/lib/python3.11/site-packages/pandas/core/ops/array_ops.p
y:129, in comp_method_OBJECT_ARRAY(op, x, y)
  127     result = libops.vec_compare(x.ravel(), y.ravel(), op)
  128 else:
--> 129     result = libops.scalar_compare(x.ravel(), y, op)
  130 return result.reshape(x.shape)

KeyboardInterrupt:
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In [ ]: