

Beyond Expected Goals: A Probabilistic Framework for Shot Occurrences in Soccer

Jonathan Pipping, Tianshu Feng, and Paul Sabin

University of Pennsylvania

August 7, 2025

What Does It Mean to “Deserve” a Win?

- **Match Analysis:** After a match, commentators often remark that a team “didn’t deserve the result.” But what is this judgment based on?
- **Traditional Measure:** Expected Goals (xG), which estimates the quality of shots *taken*. But is that the right metric?
- **Our Question:** Which is more notable – getting a shot off, or making it?
 - <https://youtu.be/s1aQb1bgPdQ?si=aZEeb5Mbl3tmkruG&t=64>
 - <https://youtu.be/s1aQb1bgPdQ?si=aZEeb5Mbl3tmkruG&t=164>

What Are Expected Goals (xG)?

- **Expected Goals (xG):** a metric that estimates the probability that a shot is scored
 - Depends on factors like distance from goal, angle to goal, shot type, and player positions
 - Estimated by XGBoost models trained on historical shot data
- **Applications:**
 - Estimating the quality of a shot
 - Measuring of team performance over a match or season
 - Residualizing provides a measure of shooter skill

Limitations of xG

- **Selection Bias:** Models are only trained on *observed* shots
 - Skilled attackers take more shots and are more successful on them
 - Any chance without a recorded shot isn't in the training data
- **Aggregation Issues:** An incomplete measure of team performance
 - Threatening attacks with no recorded shots are omitted
 - Rebounded chances are double-counted

Example 1: No Recorded Shot

- **Match:** Manchester City v Real Madrid (Feb 19, 2025)
- **Question:** Which one had a higher chance of being a goal?
 - <https://youtu.be/s1aQb1bgPdQ?si=aZEeb5Mbl3tmkruG&t=295> - 0.03 xG with outside shot
 - <https://youtu.be/s1aQb1bgPdQ?si=aZEeb5Mbl3tmkruG&t=310> - 0.00 xG because no shot occurred

Example 2: > 1 xG on a Possession

- **Match:** Orlando City vs. Philadelphia Union (February 22, 2025)
- **Video Link:**
https://youtu.be/vZODSAzF83w?si=ghu2hurGbVjmbd_7&t=363
- **Sequence:** Multiple shots in one possession totaling 1.63 xG

Time	Player	Shot Outcome (xG)
78:01	Brekalo	Shot Blocked (0.05)
78:02	Muriel	Shot Post (0.52)
78:04	Pasalic	Shot Post (0.68)
78:05	Pasalic	Shot Goal (0.38)

Table: Sequence of shots leading to a goal, totaling 1.63 xG.

Our Target Metric: xG+

- A more complete picture of goal expectancy
 - Accounts for high-threat attacks with no shots
 - Avoids double-counting rebounded chances
- At each frame t , let xG+ be the probability of a goal:

$$\begin{aligned}\text{xG+}_t &= \mathbb{P}_t(\text{goal scored}) \\ &= \mathbb{P}_t(\text{goal scored} \mid \text{shot taken}) \cdot \mathbb{P}_t(\text{shot taken}) \\ &= \text{xG}_t \cdot \text{xShot}_t\end{aligned}$$

- Then define xG+ over a possession with n frames:

$$\text{xG+}_{\text{poss}} = 1 - \prod_{t=1}^n (1 - \mathbb{P}_t(\text{goal scored}))$$

- Estimating this value requires fitting two models: xG and xShot

- **Source:** Gradient Sports (formerly PFF FC) video tracking and event data from the 2022-2025 English Premier League
- **Key Features:**
 - Player positions (x, y) at 30 frames per second
 - Ball position (x, y, z) at 30 frames per second
 - Shot events and outcomes
 - Team possession indicators
 - Player and team identifiers

- **Filtering:** Keep frames where the ball is in play and a team has clear possession
- **Smooth Ball Tracking:** Linearly interpolate ball positions to fill in missing frames
- **Define Attacking Sequences:**
 - Start: team gains possession in their attacking third
 - End: defending team regains possession or ball exits attacking third
- **Field Standardization:** Flip right-to-left attacks 180° to make all attacks go left-to-right

- **Ball Features:**

- Distance from goal (r_{ball})
- Angle to goal (θ_{ball})
- Ball height (z_{ball})
- Ball speed (v_{ball})

- **Player Features:**

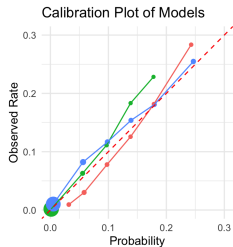
- Position of 5 closest offensive teammates relative to the ball (r_{off}, θ_{off})
- Position of 5 closest non-GK defenders relative to the ball (r_{def}, θ_{def})
- Position of goalkeeper relative to the goal (r_{gk}, θ_{gk})

- **Goal Openness:**

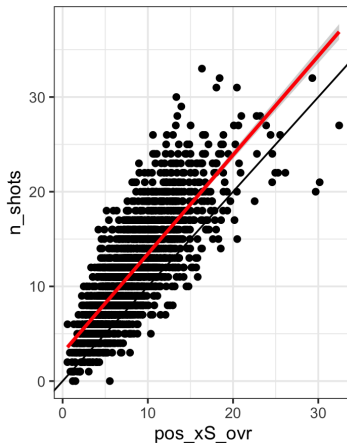
- Model defenders as circles with diameter 0.75m
- Draw tangent lines from the ball to defenders and find where they meet the goal line
- Call the percentage of the goal that's unobstructed `openGoal`

- **Training Data:** All data from the 2022-2025 Premier League seasons
- **Features:** Ball features, player features, and goal openness
- **Models:**
 - **xG:** 5-fold cross-validated XGBoost model estimating the probability that a shot is scored
 - **xShot:** 5-fold cross-validated XGBoost model estimating the probability that a shot occurs *in the next second*
- **Evaluation Metric:** Log loss

Results



metric — xG — xG+ — xShot n ● 2e+05 ● 4e+05 ● 1e+06



Cross-Validation Study

- **Objective:** Evaluate $xG+$ performance using cross-validated Poisson models
- **Dataset:** 3 seasons of match data (114 folds total)
- **Method:** Train on all matchdays except one, predict goals on held-out data
- **Goal:** Determine how well adjusted $xG+$ explains actual goals scored

Cross-Validation Setup

- **Setup:** Each matchday treated as a fold: $38 \text{ matchdays} \times 3 = 114$ folds
- **For each fold:**
 - Train on all matchdays except one to acquire adjusted metrics
 - Poisson regression on team goals using training data
 - Predict goals scored on held-out matchday test data

Metrics and Aggregation Methods

Metrics:

- **xS**: Probability a player takes a shot in the next second
- **xG**: Probability that a shot is scored
- **xG+**: $xS \times xG$, the probability of scoring in the next second

Aggregation Methods:

- 1 **Max-per-possession**: Take maximum 1-second prediction in each possession
- 2 **At-least-one-per-possession**: $1 - \prod(1 - p)$ across possession
- 3 **Sum-of-shots**: Traditional xG summed over actual shots

Fitted on training data for each fold:

$$\text{metric} \sim (1|\text{season}) + (1|\text{season:team}) + (1|\text{season:opp}) + \text{home}$$

Extracted Effects:

- Team attack (per season)
- Opponent defense (per season)
- Season effect
- Home field advantage

Secondary Poisson Model

Train Poisson regression on adjusted metrics:

$$\text{goals} \sim \text{home} + \text{season} + \text{team_off} + \text{opp_def}$$

Purpose: Assess predictive utility of each adjusted metric on actual goals

Cross-Validation Results

Table: Mean Squared Error (MSE) by Metric and Aggregation Method

Aggregation Method	xG+	xS	xG
At-least-one-per-possession	2.84	2.90	2.94
Max-per-possession	2.84	2.87	2.91
Sum-of-shots			2.90

Cross-Validation Results

Table: Mean Absolute Error (MAE) by Metric and Aggregation Method

Aggregation Method	xG+	xS	xG
At-least-one-per-possession	1.86	1.87	1.89
Max-per-possession	1.86	1.86	1.89
Sum-of-shots			1.87

- **Question:** Does this framework provide insight into individual player skills?
- **Methodology:**
 - Aggregate chances for the closest player to the ball within a possession
 - Sum up per game & season for each of xG , xS , and $xG+$
 - Compare actual shots & goals to expected metrics
 - Analyze year-over-year performance consistency
- **Key Finding:** Players *do not* consistently over-perform their expected goals (xG)

- **Key Finding:** Players *do* consistently over-perform as shot takers!
- **Implication:** Generally, elite goal scorers are the ones converting chances into shots, not converting shots into goals!

Table: Year to Year Correlation (Stability) vs. Expected (Per Game)

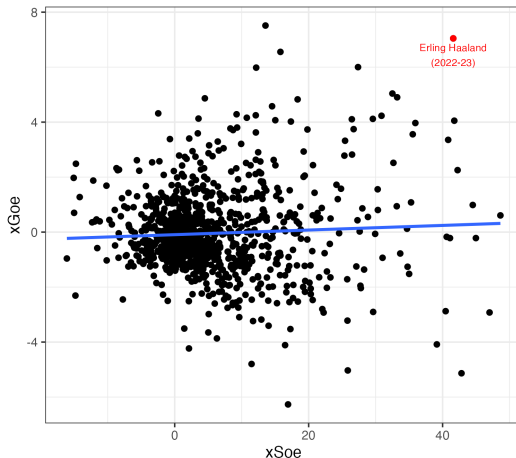
xG	xS	xG+
0.12	0.63	0.35

Player Ability

- **Example:** Haaland's record breaking season (36 goals)
- **Key Insight:** Required both higher shots and goals than expected

Shots & Goals vs Expected (xSoe vs xGoe)

English Premier League (2022-2025). Min. 5 Shots



Top Over-Expectation Performers (Per Game)

xG+ Over Expected

Season	Player	xG+ OE	Goals	Games	Chances
2022-23	Erling Haaland	0.52	36	35	444
2023-24	Erling Haaland	0.44	30	31	513
2024-25	Omar Marmoush	0.41	10	16	293
2024-25	Yoane Wissa	0.35	22	35	429
2024-25	Mohamed Salah	0.33	27	38	1042
2024-25	Chris Wood	0.31	23	36	330
2023-24	Cole Palmer	0.30	19	34	693
2024-25	Alexander Isak	0.30	25	34	558
2023-24	Alexander Isak	0.30	19	28	351
2022-23	Harry Kane	0.29	25	38	589

xG Over Expected

Season	Player	xG OE	Goals	Games	Chances
2024-25	Omar Marmoush	0.41	10	16	293
2024-25	Chris Wood	0.31	23	36	330
2024-25	Michael Keane	0.21	3	10	19
2022-23	Erling Haaland	0.52	36	35	444
2022-23	Roberto Firmino	0.25	10	21	253
2022-23	Martin Ødegaard	0.22	15	37	942
2023-24	Heung-min Son	0.28	20	35	751
2022-23	Matias Viña	0.26	3	10	66
2022-23	Alexander Isak	0.24	11	22	346
2023-24	Taiwo Awoniyi	0.26	7	19	125

Note: Minimum 10 Games with a Chance

- **Best Metric for Team Prediction:** $xG+$
- **Best Aggregation Method:** At-least-one-per-possession
- **Player Evaluation:** Shots over expected is more predictive of future player performance than goals over xG
- **Future Work:** An instantaneous or time-weighted $xShot$ model
- **Questions and Discussion**

Acknowledgements

- Special thanks to our data providers at Gradient Sports (formerly PFF FC)
- All work supported by the Wharton Sports Analytics & Business Initiative (WSABI)