Modeling Penalty Kick Behavior using Discrete Choice Models

Varshini Gayathri Suresh (469038)
Abishai Srinivasan (471538)
Carlos Wan Lee Cham Perez (470847)

12.05.2025

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Introduction

Commonly regarded as the world's largest sporting activity, football is governed under a strict code of regulation laid down by the International Football Association Board (IFAB). A penalty kick is awarded when a foul deserving punishment with a direct free kick is committed inside a team's own penalty box. It is a one-on-one contest between the shooter and the goalkeeper from 12 yards (11 meters), with only the keeper allowed to defend the shot. Penalty kicks can be taken under two circumstances: in regular play (as a penalty for a foul) or in penalty shootouts, which are used to determine the winner of matches at the knockout stage of competition when scores are tied after extra time. In shootouts, each team takes five alternating penalties; if still even, the game proceeds under sudden death. Shots may be directed in various manners—traditionally delineated by direction (left, center, right) and height (top vs. bottom corners)—creating six general target areas such as "top right" or "bottom left."

Although penalty kicks can appear easy, they involve advanced decision-making in situations of high psychological pressure, under the influence of the player's behavior, goalkeeper's action, match state, and previous performance. According to FIFA statistics, 75% to 80% of penalty kicks are successfully scored in top-class tournaments, but this is changeable based on tactical and psychological variables. The strategic nature of penalties has motivated researchers to think of them as discrete choice problems, in which a penalty taker chooses from a finite set of options to maximize scoring probability.

This study investigates the use of Discrete Choice Models (DCMs)—specifically the Multinomial Logit—to predict the outcome of penalty kicks. Using historical statistics from premier-level competitions such as the FIFA World Cup and UEFA Champions League, the analysis approximates each direction of shot's utility based on player characteristics (e.g., footedness), contextual characteristics (e.g., game pressure), and goalkeeper action. The model includes Biogeme estimates, an open-source Python software tool created for discrete choice modeling. The study not only contributes to sports analytics but also demonstrates the way econometric methods can represent human decision-making in high-pressure environments.

Problem Description

The penalty is among the most pivotal moments during a game of football, often determining the fate of closely contested matches. The structure is a one-against-one affair, with the attacking player attempting to score from 11 meters, opposed only by the goalkeeper. This isolates the interaction, eliminating the dynamic complexity of open play, and places the scenario in a structured high-stakes environment where both the kicker and goalkeeper must make simultaneous strategic decisions. The decision by the player is what spot to aim for (e.g., top-left, center-right), while the goalkeeper decides where to dive. These decisions are made under uncertainty and are shaped by psychological, physiological, and situational determinants.

Penalty shootouts further amplify this pressure, as they decide the winner of tied knockout-phase matches. Each side alternates five attempts, and if still tied, the match enters sudden death. The rules are straightforward: the ball must move forward, and the goalkeeper must stay on the line until the ball is struck.

Under this structured decision context, penalty kick behaviors are well-suited to discrete choice modeling, particularly using the Multinomial Logit (MNL) approach. The finite number of well-defined alternatives—such as six target regions within the goal—allows the kicker's decision to be represented probabilistically, influenced by explanatory variables.

This micro-level analysis uses a dataset of penalties with covariates including the player's dominant foot, direction and number of goalkeeper movements, and various performance percentages. The goal is to develop an MNL model that explains and predicts shot direction based on these variables. By focusing on footedness, goalkeeper movement, and choice, the model aims to uncover systematic patterns in penalty-shooting behavior and the impact of the goalkeeper's actions.

Literature Review

The literature review provides an overview and assists in identifying interesting and potential predictor variables for modeling penalty-taker behavior. A successful line of inquiry in the literature uses penalty kicks as a lens for studying psychological, strategic, and situational decision-making under pressure. Approaches range from game theory and behavioral economics to empirical modeling and machine learning, highlighting diverse factors that may influence shot direction and penalty success.

Azar and Bar-Eli (2023) examine penalty kicks through behavioral economics and game theory, emphasizing the concept of mixed-strategy Nash equilibrium where both players randomize actions to maintain unpredictability. They also identify action bias in goalkeepers—who often dive prematurely—and loss aversion in kickers, who tend to prefer safer lower shot placements to avoid personal blame in case of a miss. These findings emphasize psychological pressure, strategic randomization, and risk-averse choice as key behavioral variables.

Anbarcı et al. (2021) extend this perspective through an analysis of penalty shootout formats. Their dynamic model demonstrates that traditional ABAB shooting orders confer systematic advantages to the first kicker. They argue that performance outcomes are sensitive to the sequence of kicks, and recommend adopting ABBA or randomized formats for improved fairness. Hence, shooting order and turn-based pressure are identified as influential situational factors.

Akıncıoğlu et al. (2024) adopt a data-driven machine learning approach, analyzing sixteen variables to predict penalty outcomes. Significant predictors include footedness, shot zone, match time, current score, and player experience. Their findings confirm the value of including technical and contextual variables in predictive models of penalty-taker behavior.

Hunter et al. (2022) focus on biomechanical and tactical interaction between kickers and goalkeepers. They highlight trade-offs between shot speed, accuracy, and placement. Additionally, the goalkeeper's reaction time—referred to as leave-time—is a critical determinant. These findings support the integration of biomechanical precision and technical decision-making in performance analysis.

Brinkschulte et al. (2023) explore the combined effects of skill and psychological pressure using over 1,700 penalty events from international competitions. They find that

pressure increases miss probability, while player skill buffers against such effects. High market value and team quality are associated with reduced likelihood of failed attempts, emphasizing the dual importance of psychological and ability-based variables.

Krumer (2020) investigates whether shootouts are decided by chance or skill. Analyzing 586 shootouts in European national cup competitions, the study finds that team ability—proxied by league division—significantly predicts outcomes. Each higher division improves win probability by approximately four percentage points. This supports the inclusion of team ability as a crucial variable in shootout modeling.

Together, these studies provide a comprehensive foundation for variable selection. From cognitive biases and procedural fairness to statistical modeling and biomechanical performance, the literature underscores the multifactorial nature of penalty kick scenarios. This study draws on these insights to construct a discrete choice model that incorporates psychological, contextual, technical, and strategic variables to predict penalty outcomes.

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