**Abstract**

The objective of this work is to elaborate on the basic principles of probabilistic theory and showcase the practical use of the sport of basketball in everyday life. The concepts of theoretical and experimental probability are introduced and their importance in risk assessment and choice is addressed. In this scope, in addition to player performance assessment and development of strategies, use of statistical models, game metrics, and also advanced methods of analysis are covered. Performance and forecasting are analyzed, and important ideas including combinatorial analysis, total and conditional probabilities, Markov chains, expected value, to mention a few, are focused on, as illustrations on the use of these ideas in performance analysis and forecasting are provided.

Such analysis indeed proves that rudimentary metrics like pace of play, true shooting percentage are significant in winning close games, meaning the efficiency of the players and the level of tactical alteration are very high. This study recognizes the necessary degree of predictability in sport, but states the focus on the influence of probability on the quality of decision making particular to the game and its strategy. Future directions, then, would be focused on studying external factors, such as, but not limited to the weather, culture, fan power, youth systems, in order to broaden understanding and improve outcome forecasts of the game. Overall this article highlights the importance of probability in creating and sustaining the thrill of games at both the strategic level and in terms of the fans themselves.

**Introduction**

***Background***

The concept of probability is associated with the development of or speculation about mathematical practices. More formally, probability theory is the branch of mathematics that deals with the numerical analysis of random events and the application of rules to determine in what such events belong in a range. The major concepts of probability theory include random variables, probability distributions, and sample spaces, among other concepts, thus enabling combinatorial analysis of random events.

Types of probability theory are two: theoretical probability and experimental probability. Theoretical probability is the measure of the likelihood which is concluded through pure logic and does not involve an experiment. On the contrary, experimental probability is the ratio of the number of trials in which a favorable outcome occurs and the total number of trials performed.

The field of probability has several fields of application such as risk assessment, genetics, and insurance. Therefore, in large scale endeavors, there will be a need to detect patterns and estimate values with a high degree of accuracy from the data values.

***Objective***

Exploring real-life applications makes learning more effective and aids in informed decision-making. It helps us apply theoretical concepts to daily situations, enhancing understanding and comprehension. This approach simplifies the grasp of complex ideas and highlights the importance of practical knowledge.

***Scope***

1*. Statistical Models* – This section reviews models like logistic regression, random forest, and Bayesian methods used to predict basketball game outcomes from historical and real-time data.

2*. In-game metrics Analysis* – This section assesses the weight of certain game statistics like shooting percentage, assist and rebound in converting the winning probability, which they highly influence.

3. *Game Strategy Development* – This looks at adjustment of approaches based on probability evaluations by the coaches within closing minutes, especially when the games are tightly contested.

4. *Player Performance Evaluation* – The paper considers the case of team performance and winning probabilities with the emphasis on performance indicators like shooting or defending for a particular player on the team.

5. *Advanced Analytical Techniques* **–** The focus here is on the application of machine earning and high-level analytics for enhancing the accuracy of predicting the outcomes of the games.

***Structure***

The paper will follow the format recommended by the instructor. It’s divided into five parts; preliminaries, application, analyzation, conclusion, and referencing. Preliminaries will be first introduced serving as guides to terminologies encountered within, starting with concepts, their formulas, additional theorems, and clarification of notations. It’ll be followed by a broader explanation using real life applications mainly about the involvement of Combinatorics, Total and Conditional Probability, Mutually and Non-mutually Events, Markov Chain, Expected Value, and Binomial and Poisson Distribution in a Basketball Sport, and a case study of a game between Golden State Warriors and Oklahoma City Thunder. Through highlighting the findings and interpreting these, challenges will be spotted, hence, the analysis part. Conclusion will then be the closing remarks where the summary, implications, and future directions of the study can be found while every source used as basis will be credited in the reference part right at the end.

**Preliminaries**

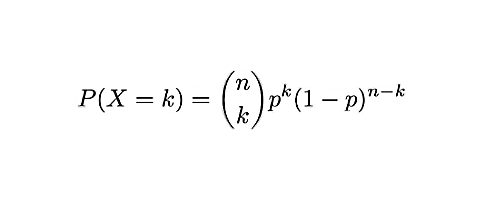
***Concepts***  
1. *Combinatorics* - It is a branch of mathematics that concerns on the counting, arrangement, and combination of a discrete structures (Grunbaum, 2024). In basketball for instance, teams consist of a specific number of players and different combinations of these players will be created.   
2. *Total Probability* - Is the simplification of finding probabilities into smaller components (superprof, n. d.). Example a basketball game with various phases such as leading, tying and trailing. Considering each phase’s probability, we can calculate the overall probability of winning.   
3. *Conditional Probability* - is the likelihood of an event, given that another event has occurred (Eldridge, 2024). Winning chances for a basketball team can be different depending on the period of the game, thus underlining a conditional probability scenario.   
4. *Mutually Exclusive, and Non-Mutually Exclusive Events* – Two or more events which cannot occur at the same time are called mutually exclusive events. On the other hand, when an event occurs with another event, then that event is NME. The skill level and probability of controlling a game is employed to ensure NME events occur. Also, if the skills were assessed appropriately, then altered positions would give a different result due to some events being ME.   
5. *Markov Chains* - It is a stochastic process in which the next state depends only on the current state and not the previous states (Oxford Languages, n. d.). In mathematics, consider a situation where the outcome of a game can either be a win, a loss or draw to the same. In such a process the win and loss states are considered to be absorbing states of the Markov chain.

6. *Expected Value* - Based on a random event's probability, expected value aids in estimating the average result. This can be used in basketball to estimate how many points a team will typically score in a game on average. The predicted value of points per possession can be computed using past data, which helps with performance projections.

7. *Binomial and Poisson Distributions* - It is helpful to model discrete events in a basketball game using these distributions. The Poisson distribution can be used to estimate the number of scoring events over a certain time period, such as a quarter or game, whereas the binomial distribution can be used to predict the number of successful shots out of a fixed number of tries.

***Formulas***

1. BINOMIAL DISTRIBUTION

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Where:

* P(X=k) = probability of getting exactly k successes in n trials
* n = number of trials
* k = number of successes
* p = probability of success in a single trial
*  = combinations or “n choose k”

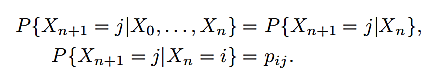
1. POISSON DISTRIBUTION

**f(x) =(e– λ λx)/x!**

Where:

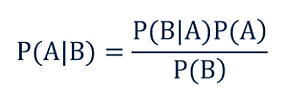
* e is the base of the logarithm
* x is a Poisson random variable
* λ is an average rate of value

1. MARKOV CHAINS

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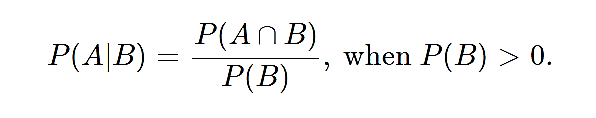
The pij is the probability that the Markov chain jumps from state i to state j. These transition probabilities satisfy j∈S pij = 1, i ∈ S, and the matrix P=(pij ) is the transition matrix of the chain.

1. BAYESIAN PROBABILITY

Where:  ****

* P(A|B) – the probability of event A occurring, given event B has occurred
* P(B|A) – the probability of event B occurring, given event A has occurred
* P(A) – the probability of event A
* P(B) – the probability of event B

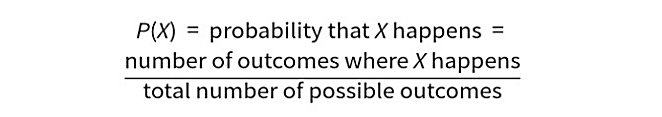
1. CONDITIONAL PROBABILITY



Where:

* P(A∣B) = probability of event A occurring given that B has occurred
* P(A∩B) = joint probability of A and B
* P(B) = probability of B

1. COMBINATORICS AND PROBABILITY

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You can use combinatorics to calculate the “total number of possible outcomes”.

1. LAW OF LARGE NUMBERS

There are two law of large numbers, weak and strong.

*Weak Law of Large Numbers*: Let X1, X2,X3, . . . be a sequence of independent random variables with common distribution function. Set µ = E(Xj ) and σ 2 = Var(Xj ). As usual we define

*Sn = X1 + X2 + · · · + Xn*

and let

*S ∗ n = Sn /n  − µ.*

*Strong Law of Large Numbers*: As above, let X1, X2, X3 . . . denote an infinite sequence of independent random variables with common distribution.

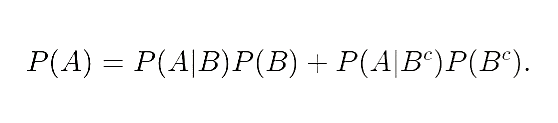
Set : *Sn = X1 + · · · + Xn.*

Let µ = E(Xj ) and σ 2 = Var(Xj ). The weak law of large numbers says that for every sufficiently large fixed n the average Sn/n is likely to be near µ. The strong law of large numbers ask the question in what sense can we say limn→∞ Sn(ω) n = µ.

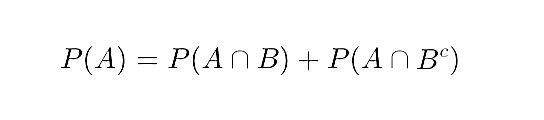
*lim n→∞ Sn(ω)/ n  = µ.*

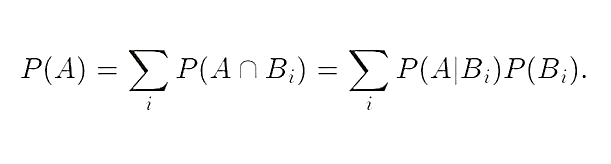
1. LAW OF TOTAL PROBABILITY

In particular, if you want to find ***P(A)***, you can look at a partition of***S***, and add the amount of probability of ***A*** that falls in each partition. We have already seen the special case where the partition is ***B***  and ***Bc***: we saw that for any two events ***A*** and ***B*** ,

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and using the definition of conditional probability, ***P(A∩B)=P(A|B)P(B)***, we can write

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We can state a more general version of this formula which applies to a general partition of the sample space ***S.***

Law of Total Probability: If ***B1,B2,B3,⋯i***s a partition of the sample space ***S***, then for any event ***A*** we have

1. VARIANCE AND STANDARD DEVIATION

Variance is symbolically represented by ***σ2, s2, or Var(X)***.

***Var (x) = E[(X - µ)^2]***

X = Random variable

“µ” is equal to E(X) so the above equation may also be expressed as,

Var(X) = E[(X – E(X))2]

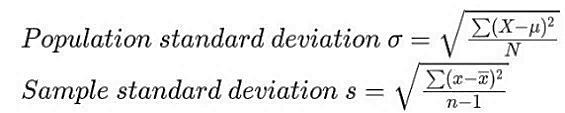
Var(X) = E[ X2 -2X E(X) +(E(X))2]

Var(X) = E(X2) -2 E(X) E(X) + (E(X))2

Var(X) = E(X2) – (E(X))2

**Variance = (Standard deviation)²= σ²**

The corresponding formulas are hence,



Where X (or x) = Value of Observations

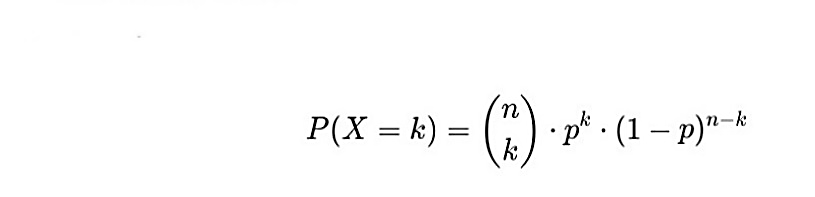
μ = Population mean of all Values

n = Number of observations in the sample set

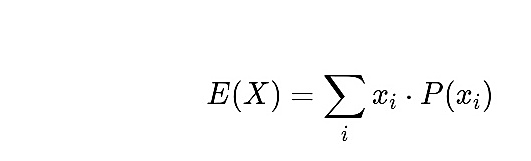
x¯=Sample mean

N = Total number of values in the population

***Theorems***

1. *Bayes’ Theorem -* Way to figure out conditional probability. The formal definition for the rule is:P(B∣A)=P(A)P(A∣B)P(B)​
2. *Binomial Distribution -* The binomial distribution evaluates the probability for an outcome to either succeed or fail. The formula is: b(x; n, P) = nCx \* Px \* (1 – P)^n – x
3. *Game theory -* Branch of applied mathematics that provides tools for analyzing situations in which players, make decisions that are interdependent. This interdependence causes each player to consider the other player’s possible decisions, or strategies, in formulating strategy. A solution to a game describes the optimal decisions of the players, who may have similar, opposed, or mixed interests, and the outcomes that may result from these decisions.
4. *Law of Large Numbers -* In statistics and probability theory, the law of large numbers is a theorem that describes the result of repeating the same experiment a large number of times. The result becomes closer to the expected value as the number of trials is increased.
5. *Variance and Standard Deviation -* Variance is a measure of how data points vary from the mean, whereas standard deviation is the measure of the distribution of statistical data. The basic difference between both is standard deviation is represented in the same units as the mean of data, while the variance is represented in squared units.
6. *Bernoulli’s Theorem -* Bernoulli’s Theorem states that as the number of independent and identically distributed trials (games) increases, the relative frequency of an event (such as winning) converges to its theoretical probability.
7. *Binomial Theorem -* The binomial theorem helps compute the probabilities of different outcomes when the number of trials (games) and the probability of success in each trial are known.

where *n*  is the number of games, *p* is the probability of winning a game, and k is the number of wins. The binomial distribution can model the probability of winning exactly *k* games out of n trials, given a fixed probability p of winning each game.

1. *Central Limit Theorem (CLT)* - The CLT states that the sum (or average) of a large number of independent, identically distributed random variables will tend to follow a normal distribution, regardless of the original distribution.
2. *Expected Value Theorem* - The expected value theorem provides the average outcome of a random event over a large number of trials.
3. *Chebyshev's Inequality* - This inequality gives an upper bound on the probability that the value of a random variable deviates from its expected value by more than a specified amount. In games, Chebyshev’s inequality can estimate how likely it is for a team’s performance (e.g., number of wins) to deviate significantly from its expected outcome.

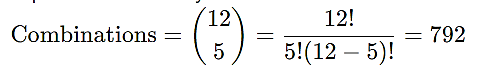


***Notation***

1. P(A): probability that event A will probably happen.
2. P(A|B): conditional probability of event A happening if event B has already happened.
3. nCx: the number of ways to choose x successes out of n trials.
4. E[X]: The expected value or mean of a random variable X.
5. Var(X): The variance of a random variable X, measuring the spread or variability of possible outcomes.
6. p: sample percentage or percentage of sample elements with a specific characteristic.
7. λ (lambda): is used in many mathematical areas, including probability, statistics, and physics; depending on the situation, it frequently represents a distinct idea.
8. *Pij*: Transition probability in a Markov chain from state i to state j.
9. f(x): symbolizes a function with respect to the variable x.
10. σ²: Variance, which measures how much a set of numbers deviates from their mean.
11. X: a group of population elements.
12. *k*: Number of successes in a binomial experiment.
13. *n*: quantity of components in a sample.
14. *e*: Euler's number, approximately 2.718, used in exponential functions.
15. C(*n,k*): Binomial coefficient, representing combinations of *n* items taken *k* at a time.
16. Central Limit Theorem (CLT) - A statistical theory that suggests that the average of many independent, identically distributed random variables will tend to follow a normal distribution, such as the average score across games.
17. Chebyshev’s Inequality - an inequality based on probability.
18. Transition Matrix - is a mathematical tool that's used to explain the probability of a system changing states.
19. Scoring Efficiency - is a measure of how well a team or individual turns opportunities (such as shots, possessions, or attacks) into real points or goals in sports.
20. Shooting Percentage - is the percentage of a player's shots that end up in goals.
21. Rebound Rate - A statistic that measures the proportion of rebounds a player or team collects, often factored into win probability models.
22. Possession - Refers to the control of the ball by a team, which influences win probabilities based on scoring opportunities.
23. Absorbing States - In Markov Chain models, these are the final states of the system, such as the win or loss outcome in a basketball game.

**Real-Life Application**

***Concepts Applied***

1**.** *Combinatorics* - In basketball, combinatorics can be used to evaluate the various ways a coach can assemble lineups from a group of players. Each player has unique skills (ex: shooting, blocking, passing), and different combinations of players can affect the outcome of the game. Example a coach has 12 players on the team and needs to select 5 for the starting lineup. The number of possible lineups is determined by combinations:

These combinations allow the coach to optimize the lineup based on players’ skills.

2. *Total Probability* - In basketball, a team’s probability of winning could depend on whether they are leading, tied, or trailing during the game.

**P(Win)=P(Leading)P (Win ∣ Leading) +P(Tied)P (Win ∣ Tied) +P(Trailing) P (Win ∣ Trailing)**

This allows to balance each game phase’s impact on the overall chance of winning.

3. *Conditional Probability* - In basketball, the probability of winning can change based on game developments, such as the score difference, game location, or remaining time. If a team is leading by 10 points with 5 minutes left, the conditional probability of winning increases because the condition makes win. Expressed as: **P (Win ∣ Leading by 10 with 5 minutes left) =0.85**

4*. Mutually Exclusive and Non-Mutually Exclusive Events* - In basketball if two outcomes are mutually exclusive, like winning or losing a game, the probability of both occurring together is zero. However, if we consider non-mutually exclusive events like scoring a basket and getting fouled, the probabilities can be added, and the events can happen together. For example:

**P(Scoring and Getting Fouled)=P(Scoring)+P(Fouled)−P(Both)**

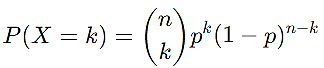
Allows teams to exploit situations where events occur together, like drawing fouls while scoring.

5. *Markov Chains* - Markov chains are useful for modeling the progression of a basketball game, where the next state depends only on the current state, not the history of the game. Consider a basketball game as a series of transitions between different states. For instance, if a team leads by 2 points, the probability of increasing their lead (or losing it) in the next possession can be calculated based on current conditions. The absorbing states in the Markov model are the final win or loss outcomes. **Final Outcome=Win or Lose (Absorbing States)**

This can predict the probability of absorbing into the *win* state given the current game state.

6. *Expected Value* - In basketball, this is useful for estimating a team’s average points per possession or a player's scoring output over a game. Suppose a team scores an average of 1.1 points per possession, and they have 90 possessions in a game. The expected total points they will score in the game can be calculated as: **E [Total Points] = 1.1×90=99**

This expected value can guide strategy, as teams aim to maximize points per possession by optimizing shot selection and player usage.

7. *Binomial and Poisson Distributions* **-** Binomial distribution can model the number of successful shots a player will make in a game, based on their shooting percentage. If a player takes 15 shots and has a 40% shooting percentage, the binomial distribution calculates the probability of making exactly 𝑘 shots.

Poisson distribution is useful for modeling events like scoring in a quarter. If a team averages 25 points per quarter, the Poisson distribution can predict the likelihood of scoring a certain number of points within that time frame.

***Example***

*Real-life:* A study applied Bayesian Logistic Modeling to estimate NBA teams' winning probabilities during crucial fourth-quarter moments, where scoring dynamics and remaining time heavily impact outcomes. The model analyzed various game statistics, including offensive and defensive efficiency, along with player-specific metrics, to provide real-time estimates of a team's likelihood of winning.

Researchers used data from multiple NBA seasons to enhance predictive accuracy, revealing that winning probabilities can fluctuate dramatically within minutes based on scoring runs and defensive plays. This model not only offered statistical forecasts but also provided actionable insights for coaches, suggesting optimal strategies during high-pressure situations. The findings highlight how probabilistic modeling can improve strategic decisions in professional sports, increasing a team's chances of victory in closely contested games.

*Case Study***:** Game 6 of the 2016 Western Conference Finals

In Game 6 of the 2016 Western Conference Finals, the Golden State Warriors faced the Oklahoma City Thunder, entering the match with a series deficit of 3-2. With five minutes left in the fourth quarter, the Thunder led by 7 points, and win probability models gave them over a 90% chance of winning based on factors like time remaining, score differential, and team strengths. However, Klay Thompson and Stephen Curry rallied the Warriors with clutch three-pointers, culminating in Thompson setting a postseason record with 11 three-pointers. The Warriors ultimately won 108-101, defying the initial predictions.

The high probability forecast for the Thunder was influenced by several factors: the limited time left made it difficult for a trailing team to rally, the 7-point lead typically indicated a significant advantage, and historical data showed that teams in similar positions often secured victories. However, the models could not account for Thompson’s extraordinary performance. This case illustrates that while probability models can inform predictions, they cannot definitively capture the unpredictable dynamics of player performance and game flow, emphasizing both the utility and limitations of statistical analysis in basketball.

***Impact***

Probability plays a crucial role in our lives, especially in decision-making. By understanding its concepts, we can assess outcomes and risks before taking action, helping us avoid and resolve problems. Like in a basketball team, strategies and decisions are often based on probable outcomes, which can significantly impact the result of the game.

In everyday life, we constantly use probability to evaluate situations and make better choices. Whether it's solving problems or planning actions, understanding probability allows us to manage risks more effectively and make well-informed decisions, ultimately leading to better outcomes across different areas of life

The integration of probability and statistical models in basketball, as illustrated in the provided example, highlights their significant impact on decision-making and strategy formulation in sports. These models help teams optimize lineups, predict game outcomes, and assess performance under different conditions. While probability models provide actionable insights, they also underscore the unpredictability inherent in sports, especially during critical moments when game dynamics can shift rapidly, as seen in the Warriors' unexpected comeback in Game 6 of the 2016 Western Conference Finals.

**Analysis and Discussion**

***Summary of Findings***:

1.Combinatorics: Coaches optimize success by selecting the best five players from a twelve-player team based on matchups.

2.Total Probability: Analyzes each game phase's impact on success, helping teams adjust strategies accordingly.

3.Conditional Probability: Aids real-time decisions by recalculating win probabilities based on current developments like score and time.

4.Mutually Exclusive/Non-Mutually Exclusive Events: Helps form strategies by identifying whether events like winning/losing or scoring/getting fouled can happen simultaneously.

5.Markov Chains*:* Predicts the likelihood of moving toward a win, guiding in-game decisions.

6.Expected Value*:* Optimizes strategies like shot selection and player usage to improve performance.

7.Binomial and Poisson Distributions: Provides insights into team or player performance in specific scenarios.

A study utilized Bayesian Logistic Modeling to predict NBA win probabilities in critical moments, particularly during the fourth quarter, by analyzing factors such as efficiency and real-time data to inform strategy adjustments. This approach underscores the value of statistical modeling in guiding decision-making during high-pressure situations.

However, the Game 6 matchup of the 2016 Western Conference Finals between the Warriors and Thunder demonstrates that probabilistic models, while useful, cannot fully account for unpredictable factors like exceptional individual performances, highlighting the inherent uncertainty in sports. Overall, concepts of probability and combinatorics are vital in decision-making across various contexts, aiding in risk management and strategy formation in competitive environments like basketball.

***Interpretation***

1.*Combinatorics*: It emphasizes the need for strategic planning.

2.*Total probability*: Describes how different game situations affect the chances of winning.

3.*Conditional probability*: Emphasizes that if certain variables change, the likelihood of a positive outcome changes.

4.*Mutually and Non-Mutually Exclusive Events*: Understanding whether occurrences can occur together is crucial in sports and everyday life. Knowing that you can score and be fouled simultaneously in basketball opens up more options.

5.*Markov Chains*: We can analyze the strategic interactions among decision makers.

6.*Expected Value*: It quantifies the center of probability distribution among players under conditions of uncertainty. It is also conducted to evaluate the players options and assess risks.

7.*Binomial and Poisson Distributions*: It plays the evaluating performance that assesses the success rates like the player’s free throw percentage.

***Challenges***

1. *Complexity of Modeling Real-Life Scenarios*: Basketball's unpredictability and human factors make it hard for models like Markov chains or binomial distributions to capture all variables, as seen in Klay Thompson's unpredictable 2016 Finals performance.

2. *Dynamic Game Conditions*: Basketball's rapidly changing conditions such as momentum shifts, injuries, and pressure introduce variability that traditional models struggle to quantify in real time.

3. *Data Quality and Availability*: Probability models rely on high-quality historical data, which may not be available in amateur leagues or account for intangible factors like player mental state.

4. *Assumption of Independence*: Many models assume events are independent, but in basketball, actions are often interdependent (defensive stop leading to fast break), which can skew predictions.

5. *Over-Reliance on Historical Trends*: Models based on historical data can be less reliable in unique situations, as exceptional performances or new strategies may deviate from past trends.

**Conclusion**

***Summary***

The paper discusses probability theory and its relevance to real-life applications, especially in basketball. It covers key concepts like expected value, Markov chains, and probability distributions that aid in performance analysis, strategy optimization, and outcome prediction. Real-world examples, such as NBA win probability models, illustrate these theories' practical uses while acknowledging data limitations and the unpredictability of human performance, emphasizing that unforeseen events can still impact outcomes.

The study highlights crucial performance metrics, such as pace of play and true shooting percentage, that correlate with success in close games. It stresses the importance of player efficiency and strategic adaptability, noting that fatigue can hinder performance. By analyzing a decade's worth of NBA data, the research achieves a predictive model with a True Positive Rate of 0.93 and a False Positive Rate of 0.07, effectively integrating quantitative analysis with practical applications to enhance predictive analytics in professional basketball.

***Implications***

The paper discusses how probability theories aid in predicting game outcomes by analyzing players' winning chances and manipulating data to enhance predictions. Timely data collection is crucial, as even minor changes can significantly affect the outcome of a game. While analytical analysis is important, success in games also relies on players' skills and continuous improvement. A team that combines knowledge of player development with strategic data analysis could be formidable. Currently, teams rely heavily on player abilities and strategic plays. Coaches and strategists leverage probability concepts to optimize team compositions and game strategies, contributing to competitive dynamics.

This interplay of probability and strategy makes games more engaging. With probability concepts applied, teams can strategically adapt and outsmart each other, leading to unpredictable yet thrilling game scenarios that captivate both players and spectators.

***Future Directions***

The study on winning probabilities in sports opens avenues for future exploration, particularly regarding the impact of weather on game dynamics. For outdoor sports like soccer and kayaking, weather can disrupt gameplay and player safety. Future research could analyze historical player data to understand how weather changes influence performance and outcomes.

Cultural factors also play a significant role, as players' attitudes and teamwork can shape their perceptions and responses to game results. Additionally, fan influence, including crowd noise and support, can impact player performance. Understanding these contributions can enhance researchers' insights into the game. Finally, focusing on youth and developmental programs is crucial for skill enhancement, aiming to cultivate future professional players. The goal is to foster growth and improvement in individuals, emphasizing that sports should inspire personal development rather than solely validation through victories.

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