



PROGRAM

September 23, 2017

Harvard University
Science Center, Lecture Halls C and D
1 Oxford Street
Cambridge, Massachusetts 02138

Symposium Co-Chairs:

Mark E. Glickman, Department of Statistics, Harvard University

Scott R. Evans, Department of Biostatistics, Harvard University

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2017 New England Symposium on Statistics in Sports

Breakfast and Registration: Foyer area

8:00am – 9:15am: Coffee, tea, pastries

Welcome Address

9:15am – 9:30am: Mark Glickman and Scott Evans

Morning Session: Lecture Hall C - Featured talks

- 9:30am – 10:00am: David Firth, University of Warwick and the Alan Turing Institute
“Fair standings in soccer and other round-robin leagues”
- 10:00am – 10:30am: Stephanie Kovalchik, Tennis Australia
“A shot taxonomy in the era of tracking data in professional tennis”
- 10:30am – 11:00am: Michael Lopez, Skidmore College; Benjamin Baumer, Smith College
“How often does the best team win?”
A unified approach to understanding randomness in North American sport”

Break: Foyer area

11:00am – 11:30am: Coffee and tea

Late-morning Parallel Sessions

11:30am – 1:00pm: Lecture Halls C and D

Lecture Hall C - Topics in basketball analytics

- 11:30am – 12:00pm: Konstantinos Pelechrinis, University of Pittsburgh
“LinNet: Probabilistic lineup evaluation through network embedding”
- 12:00pm – 12:30pm: Grace Dickman, Macalester College
“No ‘I’ in Team: A network analysis of Division I men’s basketball offenses”
- 12:30pm – 1:00pm: Suraj Keshri, Columbia University
“Automatic event detection in basketball games”

Lecture Hall D - Topics in football analytics

- 11:30am – 12:00pm: Harold Sackrowitz, Rutgers University
“Strategy implications of the NFL’s PAT rule”
- 12:00pm – 12:30pm: Ronen Yakubov, Craig Fernandez, University of Toronto
“Reducing NFL offensive play-type predictions to a practical model”
- 12:30pm – 1:00pm: Ronald Yurko, Carnegie Mellon University
“NFLWAR: A reproducible method for offensive player evaluation in football”

Lunch break: Foyer area

1:00pm – 2:00pm: Sandwiches, beverages, snacks

Afternoon Parallel Sessions

2:00pm – 3:30pm: Lecture Halls C and D

Lecture Hall C - Advances in player tracking/location analysis

2:00pm – 2:30pm: Devin Pleuler, Toronto Football Club

“Opposition analysis: Methods for forecasting style of play in soccer”

2:30pm – 3:00pm: Nathan Sandholtz, Simon Fraser University

“Replaying the NBA: Using Markov Decision Processes to test decision-making from the 2015-2016 regular season”

3:00pm – 3:30pm: Karl Pazdernik, North Carolina State University

*“Player tracking in American football:
Spatio-temporal modeling of defensive players’ intent”*

Lecture Hall D - Novel applications in sports analytics

2:00pm – 2:30pm: Brian Macdonald, Florida Panthers

“Using data analysis to predict attendance for NHL regular season games”

2:30pm – 3:00pm: Kyle Burris, Duke University

“Out of gas: Quantifying fatigue in MLB relievers”

3:00pm – 3:30pm: Martin Ingram, Silverpond

“A point-based Bayesian hierarchical model to predict the outcome of tennis matches”

Poster Session: Foyer area

3:30pm – 5:00pm: With snacks and beverages

Panel Discussion: Lecture Hall C

5:00pm – 6:30pm: *“Past, present and future of analytics in the NFL”*

Moderator: Aaron Schatz – Football Outsiders

Panelist: Dennis Lock – Miami Dolphins

Panelist: Karim Kassam – Pittsburgh Steelers

Panelist: Sandy Weil – Los Angeles Rams

Post-NESSIS Get-Together

7:00pm – 9:00pm: Tasty Burger, Harvard Square
40 JFK Street, Cambridge, MA 02138
(on the corner of JFK St. and Mt. Auburn St.)
<http://www.tastyburger.com/>

Please head downstairs after entering the restaurant.
Appetizers provided; Cash bar only.

Oral Presentation Abstracts

OUT OF GAS: QUANTIFYING FATIGUE IN MLB RELIEVERS

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The study of reliever usage is becoming increasingly important, now that managers are pulling their starting pitchers earlier than ever before. To address this need, we develop a framework for measuring the effect of fatigue for MLB relief pitchers by estimating how their effectiveness responds to workload. We predict the probability of a swinging strike using random forests to obtain a metric for the quality of a given pitch. Using this metric as a dependent variable, we fit a hierarchical Bayesian model with an autoregressive-like structure that models game-day pitch quality as a function of prior workload.

We find a strong signal that fastball quality is negatively affected by workload and that some components of curveball quality may be diminished as well. Moreover, we estimate that pitches thrown more than three days in the past have no effect on pitch quality and that a pitch thrown two days ago has between 25-45% of the effect as a pitch thrown yesterday. Finally, we find no substantial evidence that fatigue effects differ significantly between relievers.

NO “I” IN TEAM: A NETWORK ANALYSIS OF DIVISION I MEN’S BASKETBALL OFFENSES

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Sports contain interactions between players that are measurable, such as passing the ball through the offense or screening for teammates. These interactions result in outcomes which dictate the quality of the relationship based on productivity. The networks can be used as ways to look at who is the heart of the team – the player that makes everyone else go. This is recognized by coaches’ analysis of film when scouting, but is often neglected by statistics. We used four men’s Division I basketball teams and their game film from the 2015-2016 season to create networks that characterize their offense. We use weights based on significance of statistical categories to create an algorithm for weighted, directed edges between players. The resulting networks reveal patterns in teams’ offensive schemes and highlight star players as centers of the networks. There are distinct communities for each team based on who plays with whom as well as who interacts on the floor the

most. Weighted degree measures directly correlate to offensive production, whereas other centrality measures tell a story not seen in the box score. PageRank is the most telling centrality measure, revealing who the most important player on each team really is. The networks and the analysis confirm coaches' intuitions of how the offense flows and who should be defended. They could be used as reliable methods for scouting and preparing for opponents. Similarly, they could be used for player acquisition and termination by showing who truly fits well into the offense.

FAIR STANDINGS IN SOCCER AND OTHER ROUND-ROBIN LEAGUES

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A specialized extension of the Zermelo-Bradley-Terry model is developed for balanced round-robin leagues with simple win-draw-loss points systems such as the 3-1-0 system used in association football. The model allows schedule-strength differences to be eliminated coherently, to produce fully “retrodictive” match-by-match league standings that are more informative than the usual ranking based on accumulated points. Results from several seasons of major European soccer leagues are used to assess the model, and to calibrate it in aspects such as the frequency of draws and the “home advantage” effect. We consider also how to present the resulting fair-standings tables as transparently as possible.

A POINT-BASED BAYESIAN HIERARCHICAL MODEL TO PREDICT THE OUTCOME OF TENNIS MATCHES

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A well-established assumption in tennis is that points in a match are independent and identically distributed (iid). With this assumption, it is enough to specify the serve probabilities for both players to derive a wide variety of event distributions, such as the expected winner, number of sets, and number of games. However, models using this assumption, which I will refer to as “point-based”, have typically performed worse than other models in the literature at predicting the match winner.

I present a Bayesian hierarchical model for predicting the outcome of tennis matches. The model predicts the probability of winning a point on serve given surface, tournament and match date.

Each player is given a serve and return skill which is assumed to follow a Gaussian random walk over time. In addition, each player’s skill is assumed to vary by surface, and variable conditions at different tournaments are modeled as tournament-specific intercepts.

The serve probabilities estimated by the model are then used as inputs to the iid model to predict match outcomes. When evaluated on over 2,000 ATP matches in 2014, the model outperforms other models using the point-based approach, predicting serve probabilities with lower root mean squared error (0.077 vs. 0.082) and match outcomes with greater accuracy (68% vs. 66%) and lower log loss (0.60 vs. 0.64). The results are competitive with approaches modeling the match outcome directly, demonstrating the forecasting potential of the point-based modeling approach.

AUTOMATIC EVENT DETECTION IN BASKETBALL GAMES

Keshri, Suraj[†]; Oh, Min-hwan; Zhang, Sheng; Iyengar, Garud

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We propose a unsupervised machine learning framework for automatically tagging events in basketball games. Our framework uses the optical player tracking data made available for all NBA games since 2013. We take a two step approach: learn the time series of defensive assignment for each possession, which is then used as an input to detect events. We learn the defensive assignment using a novel player identity and court location dependent attraction based model which uses hidden Markov models (HMMs), Gaussian processes (GP), and “bond-breaking” based transition matrix. The GP uses a shared mean prior to pool information across both players and spatial locations on the court. The “bond energy” based transitions are used to learn a low-dimensional approximation for the full $(5^5) \times (5^5)$ dimensional transition matrix for the state space of all possible defensive assignments. The learned defensive assignments are used as an input to a set of HMMs that automatically detect events such as ball screens, drives and post-ups. We show that our models provide significant improvements over existing benchmarks both on defensive assignments and event detection.

A SHOT TAXONOMY IN THE ERA OF TRACKING DATA IN PROFESSIONAL TENNIS

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Shots are the vocabulary of tennis yet there has been limited quantitative study of the distinct types of shots at the professional level. In this study, we build a taxonomy of shots for elite tennis using

tracking data from five years of men’s and women’s matches at the Australian Open. Our taxonomy is constructed using model-based multi-stage functional data clustering, an unsupervised machine learning approach. Among 284,035 men’s and 194,091 women’s shots, we found 15 and 13 distinct first serves to the Ad and Deuce court for male players; 13 and 16 for female players. The distinct number of groundstroke shot types were notably higher, men having 25 and 30 distinct forehand serve return and forehand rally shot types, while women had 31 and 29 types, respectively. Both male and female players showed less variety on the backhand, with men having 20 distinct backhand serve returns and 14 backhand rally shots; women having 20 and 15 types. This dictionary provides a framework for investigating the vocabulary of tennis, characterizing playing style, and advancing the modeling and analysis of elite player performance.

HOW OFTEN DOES THE BEST TEAM WIN? A UNIFIED APPROACH TO UNDERSTANDING RANDOMNESS IN NORTH AMERICAN SPORT

Lopez, Michael (1); Matthews, Gregory (2), Baumer, Benjamin[†] (3)

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Statistical applications in sports have long centered on how to best separate signal (e.g. team talent), from random noise. However, most of this work has concentrated on a single sport, and the development of meaningful cross-sport comparisons has been impeded by the difficulty of translating luck from one sport to another. In this manuscript, we develop Bayesian state-space models using betting market data that can be uniformly applied across sporting organizations to better understand the role of randomness in game outcomes. These models can be used to extract estimates of team strength, the between-season, within-season, and game-to-game variability of team strengths, as well each team’s home advantage. Parameter estimates are validated by considering actual game outcomes. More generally, we use our framework to compare cumulative (across all weeks) and sequential (from all weeks prior) models. We implement our approach across a decade of play in each of the National Football League (NFL), National Hockey League (NHL), National Basketball Association (NBA), and Major League Baseball (MLB), finding that the NBA demonstrates both the largest dispersion in talent and the largest home advantage, while the NHL and MLB stand out for their relative randomness in game outcomes. We conclude by proposing a new metric for judging competitiveness across sports leagues. While we focus on sports, we discuss a number of other situations in which our generalizable models might be usefully applied.

USING DATA ANALYSIS TO PREDICT ATTENDANCE FOR NHL REGULAR SEASON GAMES

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We will discuss a data-driven approach to predicting the popularity of an NHL game for the purposes of informing business decisions within an NHL organization. We first describe a model for forecasting the popularity of a game that uses only publicly available information that is known before tickets go on sale, when we have no sales data available for individual games. Once single game tickets go on sale and we do have internal sales data, we describe a second model which uses this new data to update and improve the predictions. We discuss how those prediction models not only use different data, but also have slightly different purposes in mind at different stages of the pricing and ticketing process. Finally, we give a brief overview of the other kinds of data analysis and visualization we use in business operations, and how we combine both team data and business data to inform our business decisions.

PLAYER TRACKING IN AMERICAN FOOTBALL: SPATIO-TEMPORAL MODELING OF DEFENSIVE PLAYERS' INTENT

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Gaining separation is paramount to the success of an individual playing offense in many team sports. Conversely, the ability to collectively and continuously limit separation for all offensive players is often what defines a great defense. To truly understand the complex spatio-temporal patterns of offensive separation and defensive coverage, identification of defensive intent is necessary. While such methodology has become a staple of the analytics used in sports such as basketball, analogous methods for American football are limited. This presentation outlines methodology necessary to close this gap by estimating the probability that each defender is tracking each offensive player at predetermined intervals of time within a play using a hidden Markov model. Also, since trajectory differs between a defender in attack mode versus one in a surveillance motion, a secondary group of hidden states differentiating between these two behavioral patterns is included. The potential summary statistics that follow could revolutionize the sport, providing insight into aspects of player performance that have never been quantified, such as a player's instincts or their impact on the opposition's game plan. For illustration, both simulated data and data from NFL games obtained through the All-22 game film are used.

LINNET: PROBABILISTIC LINEUP EVALUATION THROUGH NETWORK EMBEDDING

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Which of your team’s possible lineups has the best chances against each of your opponents’ possible lineups? In order to answer this question we develop LinNet. LinNet exploits the dynamics of a directed network that captures the performance of lineups at their matchups. The nodes of this network represent the different lineups, while an edge from node j to node i exists if lineup λ_i has outperformed lineup λ_j . We further annotate each edge with the corresponding performance margin (point margin per minute). We then utilize this structure to learn a set of latent features for each node (i.e., lineup) using the node2vec framework. Consequently, LinNet builds a model on this latent space for the probability of lineup λ_A beating lineup λ_B . We evaluate LinNet using NBA lineup data from the five seasons between 2007-08 and 2011-12. Our results indicate that our method has an out-of-sample accuracy of 69%. In comparison, utilizing the adjusted plus-minus of the players within a lineup for the same prediction problem provides an accuracy of 56%. More importantly, the probabilities are well-calibrated as shown by the probability validation curves. One of the benefits of LinNet – apart from its accuracy – is that it is generic and can be applied in different sports since the only input required is the lineups’ matchup performances, i.e., not sport-specific features are needed.

OPPOSITION ANALYSIS: METHODS FOR FORECASTING STYLE OF PLAY IN SOCCER

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Despite the exponential growth of granular performance data being collected in professional athletics, soccer, like other dynamic team-invasion sports, has resisted efforts aimed at identifying and quantifying the underlying attributes that inform team and player success. While all soccer teams have the same literal goals in mind, their methods of reaching those goals are necessarily diverse.

The pass is the most important on-ball event in the game of soccer, as it represents the most economical method of moving the ball around the field and manipulating play. In a recently studied professional soccer league that included over 300,000 individual passes, each team averaged over 400 passes attempted per game.

By applying various data mining and machine learning techniques to on-field passing coordinate data provided by Opta Sports, we have identified passing patterns that persist on a team-by-team basis. These passes are found to be spatially distributed across the field in a structured and relatively symmetrical manner. However, in practice, this distribution can become quite asymmetrical and unique on a per-team basis. These team-level deviations from the standard league cartography correlate strongly on a game-to-game basis.

This methodology has helped identify factors that commonly vary between teams but remain consistent for a single team over the course of a season. In an applied setting, this information has proven to be remarkably useful for opposition analysis, helping to streamline various coaching processes.

STRATEGY IMPLICATIONS OF THE NFL'S NEW PAT RULE

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The NFL has now completed two full seasons under the new PAT rule. The results of these last two seasons strongly suggest a phenomenon that could never have been firmly believed ever before. Namely, the probability of a successful 1-point conversion attempt is less than twice that of a successful 2-point conversion attempt. This dramatically impacts the results of any probabilistic approach to finding optimal PAT strategies. In the past, the 2-point attempt was essentially used to catch up when behind or protect the ability to reach overtime when ahead. Now the 2-point conversion attempt can be used as an offensive weapon to try to win in regulation time. This requires a different philosophy. We will discuss issues that need to be considered in this setting that were not of concern before the new rule.

REPLAYING THE NBA: USING MARKOV DECISION PROCESSES TO TEST DECISION-MAKING FROM THE 2015-2016 REGULAR SEASON

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Last year, the Cleveland Cavaliers took 329 contested mid-range jump shots with over 10 seconds remaining on the shot clock. What could have happened if they had taken these shots 20% less frequently over the season? We attempt to answer these types of questions by modeling possessions

from the 2015-2016 NBA regular season as Markov chains realized from team-specific Markov decision processes. To account for the dynamic nature of a basketball possession over the shot clock, we model the transition probabilities as a tensor exhibiting correlation in time. We assume the observed transition counts are multinomially distributed, governed by latent multivariate Gaussian distributions in order to explicitly impose a temporal covariance structure. We fit our model with STAN, using STATS SportVU optical tracking data. The draws from the transition probability tensor posterior distribution then serve as inputs in our regular season simulator.

We validate our simulation method by showing that we accurately recover the 2015-2016 transition counts for all intermediary and terminal states when simulating under the Cavs observed shot policy. To culminate, we simulate seasons under “alternate” shot policies proposed within the basketball analytics community and explore the net changes in production under these alternative policies.

REDUCING NFL OFFENSIVE PLAY-TYPE PREDICTIONS TO A PRACTICAL MODEL

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A great deal of past work and analyses have been conducted to try and predict with high accuracy whether an NFL offense will pass or rush the ball. Despite this past research, little has been done to effectively help defensive coordinators since all existing models require the use of a computer to perform the prediction. Since the NFL does not allow coaches to use any external technological devices, we set out to find the best way to help defensive coordinators gauge their opponent’s offense without the use of any such devices. We first used dozens of intricate attributes to train a neural network model on data from the 2012-2016 NFL regular seasons to achieve a prediction accuracy of 73.8%. We then analyzed passing predictability for each NFL team to inform coaches which teams deviate from expectation and which are more predictable. Finally, we created a more simplified model, using only a couple of feature variables that are easily observable by the defensive coach in real time, that predicts the opponent’s offensive play with 72.3% accuracy. Doing so, we have created a model that does not require a computer, but can instead be executed through a mental checklist of what a defensive coach can visualize on the field. Thus allowing for predictive analytics to leave the domain of theoretical research, to a more practical application in the NFL.

NFLWAR: A REPRODUCIBLE METHOD FOR OFFENSIVE PLAYER EVALUATION IN FOOTBALL

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The NFL lacks comprehensive statistics for evaluating player performance. One answer to this need was Total Quarterback Rating (Total QBR; Oliver, 2014). However, Total QBR is built on proprietary data, is not defined on a scale convertible to wins, and is only available for the QB position. We introduce our reproducible method for calculating Wins Above Replacement (WAR) for offensive skill positions in football, nflWAR, based on publicly available NFL play-by-play data from 2009-2016 accessible with nflscrapR. First, using our novel multinomial logistic regression expected points model, we estimate the “true” value for each play with expected points added (EPA; Burke et al., 2015). Then, similar to work measuring pitcher and catcher value in baseball (Judge et al., 2015), we extend a mixed model approach to isolate the EPA contribution made by individual offensive players and the opponent’s defense as random effects while accounting for variables relating to the game situation as fixed effects. Next, we establish a robust way to define “replacement” level for each offensive skill given the historical play-by-play data. Finally, the expected points above replacement is converted to WAR (which we provide for all skill position players dating back to 2009) based on the observed relationship between points scored and wins. We emphasize that our reproducible nflWAR framework can be extended to estimate WAR for non-skill position players (e.g. linemen, linebackers, etc.) if provided with data specifying which players are on the field for both teams every play.

Poster Presentation Abstracts

MODELING NCAA TOURNAMENT BRACKET POOL MULTIPLE ENTRY STRATEGY

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Single entry strategies for the NCAA tournament bracket pool have been explored in the statistical literature, but in-depth analysis has never been extended to multiple entry strategies. Modeling suggests the favorability of certain single entry strategies, but the estimated profits have never been directly confirmed in the most common real-world bracket pools: those that lack upset incentives.

It is difficult to design a single-entry hypothesis test with high statistical power. Multiple entries represent one way to increase the statistical power.

A multiple entry strategy is developed and back-tested on 10 years of data from a real bracket pool. The strategy uses the following methods: a Markov model based on pre-tournament Sagarin ratings to estimate win probabilities, an opponent model based on contemporaneous opponent pick distribution data that is publicly available from large bracket contests (ESPN, Yahoo) before the tournament, Monte Carlo estimation of profit, hill-climbing optimization of profits. All these methods have been used in the literature to optimize brackets, but never in combination, and never to mutually optimize multiple brackets.

The profits or losses that would have accrued for 10 consecutive years (2008-2017) from entering 100 mutually optimized brackets in a real bracket pool with 200 opposing brackets are measured and used to test the hypothesis that this strategy would have been profitable. The 10 year back-test yielded a 53% average yearly profit on exposed capital, with a one-tailed t -test p -value = 0.032.

IT'S A TOSS-UP: AN ANALYSIS OF COIN TOSS STRATEGY IN T20 CRICKET

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As a quicker form of cricket than Test matches and One Day International (ODI) matches, the T20 format has emerged as a marketable form of the game in the 21st century. This format largely owes its popularity to the flashy, big money, and relatively recent Indian Premier League (IPL), considered the flagship tournament for T20 cricket. This study quantifies the effects of (1) winning the coin toss and (2) the decision to bat or field made once a team wins the coin toss on the result of T20 games. This paper extends Dawson, et al.'s (Journal of the Operational Research Society, 2009) analysis of ODI matches to the very different T20 format. Data on 636 games from the first ten seasons (2008-2017) of the IPL were used in this analysis. Using linear probability and probit models, we analyzed home field advantage, pitch condition, and team quality metrics as determinants of the outcome of the game in addition to the coin toss. Results suggest that although the winner of the coin toss initially appears insignificant in determining the outcome of the given IPL game, at the 99% confidence level, the team that bats second (chasing team) has a significantly higher probability of winning. These results indicate that winning the coin toss could potentially prove a significant advantage, should captains improve their strategy in choosing whether to bat or chase.

BUMP, SET, SPIKE: USING ANALYTICS TO RATE VOLLEYBALL TEAMS AND PLAYERS

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In the international arena, volleyball is one of the world's most popular sports. However, in U.S. collegiate volleyball, they don't get the resources as some of the other major sports, including football and basketball. As such, the methods used to analyze volleyball have been relegated to methods bordering on archaic. We have developed a system to rate teams and players based on their ability in various fundamentals within volleyball. Our initial goal was to provide a new way to grade passing other than the traditional three-or-four point scales that are currently used by most teams. This expanded to include similar analysis for the fundamentals of serving, attacking, blocking, and digging. By applying statistical methods to data provided by VolleyMetrics, we have developed an unbiased way to rate teams and individual players in each of these fundamentals. Our findings matched the actual results for men's collegiate volleyball last year. We also used these ratings to create a head-to-head model to predict the outcomes of matches with high accuracy. During two weeks of the 2016 men's season in which there were 52 matches played, our models predicted the winner with 87% accuracy. While these results are encouraging, we hope to improve our model with additional data that will allow us to be even more accurate in our ratings and, by result, our predictions.

USING SURVIVAL ANALYSIS TO ESTIMATE INJURY RECOVERY TIMES AND POSITIONAL VARIATION IN THE NFL

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Hammond, Kyle E (2)

(1) *Department of Epidemiology, Rollins School of Public Health, Emory University, Atlanta, GA, USA;* (2) *Department of Orthopedics, Emory University School of Medicine, Atlanta, GA, USA*

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When an NFL athlete is injured the public relies on team-provided recovery time estimates. We sought instead to estimate recovery times for common NFL injuries, overall and by position, from historical injury report data. We defined time to injury recovery as the difference in weeks between an injury's initial appearance on and its removal from weekly injury reports. We studied 5 common injuries from the 2007-2015 regular seasons using the Football Outsiders Injury Database. We built Kaplan-Meier (KM) curves for each position and injury category, with athletes censored at regular season's end. The interquartile range (IQR) from each KM curve represents the time within which the middle half of injuries can be expected to resolve. In 17,310 player-seasons there were

2,334 ankle, 756 groin, 1,463 hamstring, 2,966 non-ACL knee, and 1,473 shoulder injuries. Median recovery was 2 weeks for all injuries. The proportion of injuries lasting ≤ 3 weeks ranged from 63% (knee, 95% confidence interval (CI) 61-65%) to 72% (groin, 95% CI 68-75%). IQR was 1-4 weeks for ankle, groin, and hamstring and 1-5 weeks for knee and shoulder injuries. Positional variation was greatest with shoulders: most positions had IQRs of 1-4 or 5 weeks, but defensive backs were 1-8 weeks, and there was insufficient follow-up to observe 75% of quarterbacks recovering. In summary, a majority of injuries resolved after 2 weeks, but recovery profiles varied by injury type and position. Limitations include heterogeneous injury categories and variable team injury reporting practices.

OPTIMIZING PRE-SEASON TRAINING LOADS IN AUSTRALIAN FOOTBALL

Carey, David L[†] (1); Crow, Justin (1,2); Ong, Kok-Leong (1); Blanch, Peter (3); Morris, Meg E (1); Dascombe, Ben J (1); Crossley, Kay M (1)

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This study investigated whether pre-season training plans for Australian football can be computer generated using current training load guidelines to optimize injury risk reduction and performance improvement. A constrained optimization problem was defined for daily training loads in the pre-season phase of an elite Australian football team. Maximizing total training volume and Banister model projected performance were considered as optimization objectives. Cumulative workload and acute:chronic workload ratio constraints were placed on training programs to reflect current guidelines on relative and absolute training loads for injury risk reduction. Optimization software was then used to generate pre-season training plans. The optimization framework was able to generate training plans that satisfied relative and absolute workload constraints. Increasing the off-season chronic training loads enabled prescription of higher amounts of ‘safe’ training and higher projected performance levels. Simulations showed that using a Banister model objective led to plans that included a taper in training load prior to competition in order to minimize fatigue and maximize projected performance. In contrast, when the objective was to maximize total training volume, more frequent training were prescribed in order to accumulate as much load as possible. An optimization approach provides an adaptable framework for physical preparation staff to quickly create athletic training plans that objectively optimize training goals whilst satisfying injury risk constraints, without exposing their plans to subjective bias. The method allows for individualized training plan design and the ability to adapt to changing training objectives and training load metrics.

USING A TENNIS RATING SYSTEM TO DETERMINE HANDICAPS IN AMATEUR MATCHES

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This paper builds on a recently developed Markov Decision Process-based (MDP) handicap system for tennis, which aims to make amateur/social matches more competitive. The system “gives” points to the weaker player based on skill difference, which is measured by the point-win probability. However, estimating point-win probabilities at the amateur level is challenging since point-by-point data is generally only available at the professional level. On the other hand, tennis rating systems are widely used and provide an estimate of the difference in ability between players, but a rigorous determination of handicap using rating systems is lacking. Therefore, our goal in this paper is to develop a mapping between the increasingly popular Universal Tennis Rating (UTR) system and the MDP-based handicaps, so that two amateur players can determine an appropriate handicap for their match based only on their UTRs. Using data from over 2500 ATP and WTA matches from 2015, we first develop and validate an approach to extract server-independent point-win probabilities from game-level data using the Markov chain model for a single game of tennis. Given the lack of point-level data for amateurs, we believe estimation of point-win probabilities from game-level data is important. Then, we show how to map server-independent point-win probabilities to server-specific point-win probabilities using Bayesian logistic regression. Finally, we use the estimated probabilities to produce handicaps via the MDP model, which are regressed (Bayesian linear regression) against UTR differences between pairs of players. We conclude with thoughts on how a handicap system could be implemented in practice.

WHAT FACTORS IMPACTS A SUPERSTAR’S PERFORMANCE IN NBA?

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Nowadays, many sports superstars perform unbelievably well in their own fields. For example, NBA player Stephen Curry made 402 three pointers in the regular season 2015-16, obliterating the previous record of 286 three pointers in the regular season 2014-15. In addition, he had the second highest 3-point percentage in NBA with an accuracy of 44.4%. In this study, we explore the factors that may significantly impact the sports superstars’ performances across multiple regular seasons. Variables include social media, team support, competitive opponents, etc. This study aims to support the superstar’s team to mitigate the risk of a superstar’s performance being fluctuated.

Furthermore, opposing teams can leverage this study to predict a player’s performance in upcoming games and strategize appropriately.

In this project, we take Stephen Curry as an example and analyze what impacts his 3-point performance, with regards to both quantity and accuracy. Data collected includes the overall performance of the Golden State Warriors (excluding Curry) per game, the opponent’s overall performance of each game, Curry’s performance per game, and Twitter data about him during the season 2015-16, etc. We applied Principal Component Analysis to identify key factors. Sentiment Analysis was also involved in order to understand the impact of social media on the player’s performance. By implementing the Generalized Linear Model, we are able to identify significant factors on Curry’s 3-point quantity and accuracy.

RAO-BLACKWELLIZING FIELD GOAL PERCENTAGE FOR NBA PLAYERS

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Shooting skill in the NBA is almost exclusively defined by field-goal percentage – the number of makes out of the total number of shots. Even advanced metrics like true shooting percentage still rely on counting the makes and misses of individual players. Here we attempt to better quantify a player’s shooting skill by using optical tracking data and shot trajectory characteristics to reduce the variability in predicting player field-goal percentages. Using tracking data, we model the trajectory of individual shots and use this to estimate shooting factors such as entry angle, shot depth, and left-right accuracy. We use these shooting factors to predict the probability of making a shot as well as measure shot accuracy bias and variation for individual players over the 2015-16 season. We then use these individual player measurements to stabilize inference of their field-goal percentage, allowing us to estimate metrics such as corner 3 shooting percentage earlier in a season than was previously possible. Finally, we present results on the effect of defense and minutes played on shot trajectory bias and variability, as well as differences in shooting factors for players over periods of hot and cold shooting.

A SURVEY OF ADVANCED MODELING TECHNIQUES FOR FORECASTING COLLEGE FOOTBALL GAME OUTCOMES

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There are many motives why data scientists and fans of college football would want to forecast the outcome of games – gambling, game prep (e.g. analyzing which factors a team should focus on), academic research, and so forth. As advanced statistical methods become more readily accessible, so do the opportunities to develop more robust forecasting models. Using data from the 2011 to 2015 seasons, we are implementing a variety of advanced modeling techniques to determine which best forecasts the outcome of games. These methods include ridge regression, the lasso, the elastic net, neural networks, random forests, k-nearest neighbors, gradient boosting machines and different Bayesian regression models. To evaluate the efficacy of the proposed models, we are testing them on data from the 2016 season; with all models accurately predicting the outcome at least 2/3 of the time, with the top performer – a Bayesian regression with team-specific variances – predicting the correct outcome 75.3% of the time.

PERFORMANCE VS. OBSERVATION: ARE EXPERTS AND ANALYSTS WATCHING THE SAME GAME?

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Baseball’s longstanding history of conflict between scouts and analysts came to light in popular culture with the successful 2003 release of Michael Lewis’ Moneyball. The argument presented in this project is that scouting feedback is not necessarily indicative of performance on the baseball field. To test this, we examined performance of pitchers from recent Babson College seasons, then assigned pairs of pitchers a “similarity score” of the type popularized by Bill James. This measure was based on the distance between the pair in terms of a standardized FIP-like measurement. We also designed a more qualitative approach in which three “scouts” (Babson Coaches) described the pitchers by choosing their outstanding attributes from a list of traditional baseball terms (i.e. command, control, velocity.) Pairs of pitchers were again ranked by similarity using a scoring system based on common attributes. In this initial study we did not find a strong association between performance similarity and scouting similarity, but the work does suggest ways we might find connections between scouts and analysts in professional data.

THE FIRST-PITCH GAME: STRATEGIES AND SIGNIFICANCE OF THE FIRST PITCH IN THE MLB

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There has been an immense amount of work achieved in better quantifying baseball players according to their contributions in almost every imaginable facet of the game. This has helped create a fairer market in the profession. However, there is less in-depth, publicly available research using newer, more detailed data, which lends itself to evaluating player strategies and the consequences thereof. Analysts have broken down the general importance of the first pitch and demonstrated the corresponding value of a first-pitch strike for a pitcher and first-pitch ball for batter. Similar research has revealed above-average results on first-pitch contact. And though other work has manifested strike- and swing-based tendencies that certain pitchers and hitters exhibit on 0-0 counts, there remains room to dig deeper into complex and motivating interaction-based analyses. Fluctuations in first-pitch strike and swing rates over the past few years have hinted at an equilibrium point, making this the perfect time to address the crucial 0-0 count. Previous studies are referenced and reanalyzed to give context to questions surrounding first-pitch significance and tactics. Hypotheses are formed and experimented on substantial data from TruMedia Networks, Inc., rejecting the notion of optimal mixed strategy equilibrium in 0-0 counts and demonstrating the opportunity for differing areas of strategical exploitation and improvement on the first pitch. We find that pitchers should be throwing more first-pitch strikes and batters should swing more at first pitches over the heart of the plate.

COMPARING GOLF ERAS: AN ANALYSIS OF GOLF'S BEST TO DETERMINE THE GREATEST PROFESSIONAL GOLFER OF ALL TIME

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Competition can be found in a schoolyard baseball game, a retirement home shuffleboard match, an NBA championship final, and anywhere in between. It is through this competition that the motivation to best one's opponent is found, and underlying that motivation, is the desire to be the greatest. But in sports, this theme of greatness does not simply extend to just one match, or a single season, but rather, it reaches throughout all of time. For a sport such as golf, like many others, the debate of determining the greatest player of all time appears hopelessly divided. This paper aims to close that division by analyzing several of the major statistical categories for professional golfers, in which total event wins and win percentage is ranked for both PGA and Major Tournaments. In addition, two new categories will be evaluated, comparing the elite golfers amongst one another by equating their respective results for every Major Tournament event participated in as a professional. This allows for a direct comparison between golfers of different eras as it will be assumed that the first time playing in an event is of equal difficulty for each player, regardless of the year. Each distinct categorical assessment is given a weighted value which corresponds to the respective category's level of importance. These evaluations, combined with their weighted values, produce an overall score in which the golfers are then ranked in descending order to yield the final results.

PROJECTING COLLEGE BASKETBALL FRESHMAN PERFORMANCE USING GRASSROOTS BASKETBALL STATISTICS

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Basketball recruiting relies largely, if not solely, on the opinions of scouts who travel the country to see and evaluate as many players as they can. Logistically, it is impossible for scouts to see every player that will play National Collegiate Athletic Association (NCAA) Division 1 basketball, and there is a bias towards evaluating the best players and teams with more exposure. With the rise of Grassroots leagues sponsored by athletic apparel companies, prospective basketball recruits now play in organized leagues that level the playing field and provide consistent statistics. Using available box scores statistics, this paper will create Box Plus/Minus ratings for the players in those Grassroots leagues and perform polynomial regression between the Grassroots and College Box Plus/Minus ratings for all players who participated at both levels. This paper will then summarize the results by evaluating the utility of forecasting the performance of NCAA Division 1 freshman basketball players given their Grassroots Box/Plus Minus ratings.

NEW WAYS TO EVALUATE PITCHERS USING WEIGHTED OFFENSIVE AVERAGE AND PENALIZING EARNED RUNS

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For measuring a pitcher's performance Earned run average (ERA) has been a dominant statistic to along with number of wins (W), walks plus hits per inning pitched (WHIP), and opponents' batting average (OBA). ERA is the mean of earned runs given up by a pitcher per nine innings pitched. Weighted offensive average (WOA), explains a batter's overall performance to generate runs and introduced by Kim (2013), is used to develop the opponents' batting average (oWOA) as an alternative of ERA.

ERA roles differently between starting and relief pitchers. If a relief pitcher enters the game with scoring position and allows a hit which scores runs, he is not charged with those runs. Also relief pitchers typically pitch for short innings so they can more concentrate on each pitch, unlike starters who need to save their energy over 6 or 7 innings. This may lead the relievers keep their ERAs down. We modify the current ERA by penalizing relief pitchers' earned runs even they enter the games already with scoring positions. We propose allocating earned runs based on where runners

were left on base when a pitcher is relieved. We allocate $1/4$, $2/4$, and $3/4$ of an earned run to the starter for runners left on the 1st, 2nd, and 3rd base, respectively, that score while the reliever is pitching. The remaining of the earned run goes to the reliever. We evaluate the top five ‘oWOA’ MLB pitchers in 2016 using this new ERA.

EXPERIENCED VETERAN OR PROMISING ROOKIE: THE EFFECTS OF MLB MANAGERS’ SALARY AND EXPERIENCE ON TEAM SUCCESS

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Based on a 2007 article in Sport Business Daily, MLB managers averaged a \$1.4 M salary in 2007. For the 2017 season, an average salary of the top-five highest-paid managers is a \$4.5 M. Unsurprisingly, four out of five managers are employed with teams located in large cities such as New York, L.A., Chicago, and San Francisco. Also, the five managers have many years of experience as a manager. It is no doubt that a manager’s job responsibilities and duties are quite significant and their salary is considered an expense from the team’s perspective. Thus, hiring a new manager could be a more difficult decision to teams in small markets than to those in big markets. Teams in small markets may want to consider hiring a more affordable and less experienced but promising young manager to save money to hire good players, rather than an expensive and experienced one. Given the MLB managers’ salaries and its business challenge, we offer the following research questions: 1) Do teams with experienced managers perform better? 2) Do teams with high-paid managers perform better? To answer the questions above, we will examine the effects of MLB managers’ salaries and their experiences on their teams’ success. We will come up with different ways to measure the team’s success and explore manager-related factors that might be positively or negatively related to the team’s performance.

A TIMEOUT IS A TIMEOUT? EFFECTS OF A RULE CHANGE IN THE NATIONAL HOCKEY LEAGUE (NHL)

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Starting with the 2015-16 National Hockey League (NHL) season, coaches have been able to risk their one timeout allocated per game to challenge goals if they contended the other team either

interfered with the goalie or were offside en route to the goal. In order to examine the impact of this rule change, we analyzed play-by-play records for the two seasons before and the two seasons after the rule change. We find that when timeouts can be used by coaches to challenge a scoring play, there are (1) significantly fewer timeouts called and (2) those timeouts that are used tend to be called later in games. In addition, we find that (3) the odds of a timeout being called immediately after an opponent scores have approximately doubled since the adoption of the rule change, presumably because it is the main window of time when a timeout can now be put on the line to challenge a goal. Our study contributes to a better understanding of the effects of rule changes in sports as well as why coaches use timeouts.

GRIP IT AND RIP IT: A FURTHER EXPLORATION OF PREDICTING SUCCESS FOR MALE PROFESSIONAL GOLFERS ON THE PGA TOUR

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Success in golf is hypothesized to be influenced by the ability to be a long ball hitter, having command of one's irons, and having a feathery touch around the greens. Prior studies have explored these common beliefs in order to predict golf success. This study continued with the trend of most previous work (Berry 1999, Nero 2001, Rishe 2001, Alexander and Kern 2005, Kahan 2010, Baugher 2016), which used earnings as the metric to measure golf success; however, we also explored salary rank by year. Data were obtained from ESPN, CBS Sports, and the PGA Tour, and incorporated traditional shot measures in the modeling process. This study expanded upon previous studies by considering a wider range of covariate transformations, using more specific shot measures, exploring data over a greater time frame (2003 to 2016), and incorporating longitudinal analysis into the modeling process. While our results were consistent with prior studies, finding scoring average to be a major contributor to success, we were also able to find more specific predictors of golfers' earnings over time.

FROM NOOB TO SMURF: ADVANCED ANALYTICS FOR LEAGUE OF LEGENDS

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Standard metrics for multiplayer online battle arena (MOBA) games like League of Legends (LoL) are very simple: kills, deaths, and the like. At Vantage Sports, we use a proprietary method

to generate unique metrics that are more useful for professional players. These metrics are then calculated for hundreds of thousands of amateur player games, and the results used to determine which ones most contribute to winning. Some of the most important ones are worthless deaths and smart kills, which refine the standard metrics based on whether the team overall benefited from the activity. A new player rating model described here correlates strongly with winning even though it is essentially based on just one individual’s contribution to a five-on-five game.

FROM MARKOV MODELS TO POISSON POINT PROCESSES: UNDERSTANDING PLAYER MOVEMENT IN THE NBA

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When considering movement in space, a useful tool is a Markov model, where the position of the agent at time $t + 1$ depends only on their position at time t . In this paper we build on existing theory to show that as the number of spatial locations in a bounded region approaches infinity, a Markov model can be represented by a Poisson point process, a popular type of spatial model that accounts for correlation between nearby locations. Using SportVu player tracking data provided by the National Basketball Association we show how this relationship can be leveraged to produce distinct maps of player movement for each team in the NBA. By comparing these maps, we can understand the tendencies of each team and how teams utilize court space differently.

ISLANDS IN THE SEA ARE CONNECTED IN THE DEEP: PROFESSIONAL SOCCER PLAYER TRANSFERS IN BIG 5 EUROPEAN LEAGUES USING EXPONENTIAL RANDOM GRAPH MODEL (ERGM)

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The 2016 revenue of the Big 5 European soccer leagues (England, France, Spain, Italy, and Germany) was £ 12.89 Billion (compared to NFL’s annual revenue of £ 12.27 Billion). Combined valuation of players in just one league (England) was £ 4.98 Billion. Player transfers amongst these clubs are strongly inter-related, thus making transfer market a clear case of violation of the ‘independent observations’ assumption of conventional regression models. For instance, Pogba’s move from Juventus to Manchester United in 2015 is clearly related to Higuain’s move from Napoli to Juventus

amongst other player purchases of Juventus. Extant literature of player transfers does not address this serious issue. Grounded in Strategic Management literature, we use Resource Dependence Theory to investigate tie-formation in player transfer network involving European Big 5 Soccer Leagues, using ERGM. ERGM captures the dynamic evolution of a network in combination with nodal (club) attributes and network structural elements. 2015 Player transfer data for this study is obtained from transfermarkt.com, fifaindex.com, and Deloitte Football Money League. Clubs' previous season standings, network status, resource richness (financial), squad rating (FIFA player rating), and squad size are significant explanatory variables under the 'independent observations' assumption. However, after incorporating network dynamics and interrelationships in ERGM, only previous season standing remain to be significant. Network properties such as edges, cyclical ties and popularity are significant determinants of professional soccer player transfers. Network perspective using ERGM is a more realistic framework to understand drivers of soccer player transfers as compared to conventional regression models.

WHAT DOES IT MEAN TO DRAFT PERFECTLY? A GAME THEORETIC FRAMEWORK FOR THE NHL ENTRY DRAFT

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This project defines what it means for a team to be successful in drafting and determines if any NHL teams exhibited a sustained competitive edge in drafting from 2000 to 2009. At a high level, we compare actual draft outcomes to teams' perfect draft outcomes. A perfect draft can be thought of as what would happen if a GM could redo a draft with complete knowledge of prospects' career values as well as other teams' choices, which remain unchanged. In this scenario, it is optimal to select good players just before other teams do.

We use this as a benchmark for a draft efficiency metric, which retrospectively analyzes how well teams drafted relative to their best case scenario in each year. This allows us to compare draft outcomes fairly, and we find that no NHL team had a statistically significant advantage in extracting value from the draft over the ten-year period. However, teams like the Blackhawks set themselves up for success with many high-value picks.

Teams can prospectively utilize this framework by modeling two inputs for every eligible player: expected NHL value as well as a probability distribution of possible draft positions. They can then algorithmically define and order a series of selections that maximizes total expected NHL value. The advantage of this approach over simply drafting the best player available at each pick fades in later rounds. Still, there are notable recent instances where teams would have theoretically benefited from waiting longer to pick their preferred prospects.

SCHEDULING EFFECTS IN THE NBA AND NHL AND THEIR BETTING MARKETS

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Teams in the NBA have are giving increasing consideration to the issue of fatigue, recognizing that without rest, performance might be compromised. Using generalized linear mixed models we estimate effects of schedule conditions, whether home/road teams were idle, home or away the day prior to a regular season contest in professional hockey and basketball. We attempt to control for team strengths with factorial effects for home and visiting teams. On the scale of win probabilities, we find the magnitude of the estimated effects of one day of rest for the home team and the away team to be highly significant, additive and comparable across the two sports. The relative change in estimated win probability from the least to the most favorable schedule conditions is as large as 17% (NHL) or 18% (NBA).

We also find evidence that bettors are taking schedules into consideration. Published point spreads and over/under (o/u) lines in the NBA differ significantly across schedule conditions, achieving an ordering that is consistent with the conventional wisdom that having to play the day before a contest and then travel has a negative effect on performance. Interestingly, the observed game totals do not differ significantly across scheduling conditions, nor reflect this conventional wisdom. Lastly, inclusion of an overtime effect can “debias” factorial team effect estimates and improve predictions made prospectively (without knowledge of whether wagered-upon games went into overtime), identifying a potential market inefficiency.

RISK FACTORS AND PREDICTIVE MODELING OF THE UCL INJURY USING PITCHF/X DATA IN MLB

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Ulnar collateral ligament (UCL) reconstruction surgeries, also known as Tommy John surgeries (TJS), for baseball pitchers have increased in recent decades. The UCL injury can be caused by in the iterative stress to the UCL in the medial elbow. In spite of the importance of preventing UCL injuries, the scientific consensus of the risk factors for the injuries has never been obtained yet. In this presentation, we reconsider candidates of risk factors for the injuries referring to some experts’ opinions, and then obtain adjusted odds ratios for selected risk factors by a logistic regression model. As a result, for starter pitchers, a smaller repertoire of pitch types, a farther horizontal

release location away from the body, and a greater mean pitch count per game are selected risk factors. Also, for relief pitchers, a smaller repertoire of pitch types, a farther horizontal release location away from the body, a greater mean pitch speed of fast balls, and fewer days between consecutive games are selected. Also, we consider some predictive modeling methods to predict the UCL injuries.

AN ANALYSIS OF SHOT QUALITY IN MAJOR LEAGUE LACROSSE (MLL)

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Analytics in the game of professional field lacrosse is very much in its infancy. This paper analyzes spatial and visual tendencies as means to enhance lacrosse expertise. We introduce analytical techniques designed to quantify, visualize, and communicate spatial aspects of Major League Lacrosse (MLL) performance. We propose mixed effects modeling to quantify shooting quality of MLL players and present practices that differentiate MLL players' shooting ability. We conduct a case study to inspect shot site performances for every player in Major League Lacrosse and determine which players exhibit the most potent offensive behaviors. We conclude by proposing that visual and spatial analysis represent new methodologies for analysis of professional field lacrosse.

PREDICTING SHOT SUCCESS USING REAL ESTATE

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Neural networks have been used in myriad prediction tasks and outperform other non neural network based models. One area where learning tasks, in general, have not been extensively used is in adversarial multi-agent trajectory domains. Traditionally, there has not been a natural way to represent trajectory inputs which are continuous and spatially correlated that are amenable to existing machine learning techniques. For the problem of predicting whether a basketball shot is a make or a miss in the National Basketball Association (NBA), different methods have been used in representing players trajectories for prediction tasks. We investigate exploiting the temporal information in trajectories for purposes of shot prediction. Further exploring trajectory representations and player movement, we leverage additional information to represent as spatial features within

polygons that represent space that is owned by a player. For offensive spatial features present in the polygons, channel shading can represent shooting ability over the space that is owned by the shooter. We also present a framework to identify and quantify defensive congestion during a shot to create value behind defensive positioning. Finally we assign player roles through channels formed from encoded player representations. By representing different spatial features of player movement during a possession, we aim to provide increased accuracy when determining if a basketball shot is a make or a miss.

QUANTIFYING THE CAUSAL EFFECTS OF CONSERVATIVE FOURTH DOWN DECISION MAKING IN THE NATIONAL FOOTBALL LEAGUE

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It is often argued that football coaches are too conservative in attempting fourth down conversions. However, coaches' decisions are not randomized, and because teams going for it do so by choice, traditional research into team decision-making may be confounded by extraneous factors. For example, teams going for it generally do so because they are trailing, and thus inference on how all teams should behave has required unjustifiable extrapolations. Using the National Football League (NFL), we attempt to estimate the causal effects of implementing a more aggressive fourth down strategy by approximating the additional number of wins that any one NFL team could have gained. Utilizing a nearest neighbor matching algorithm, teams that went for it are paired to those who did not go for it based on their probability of going for it, defined as the propensity score, as well as other game-level factors. By looking at outcomes within the cohort of matched plays, we find that, on average, imposing a simple, more aggressive fourth down strategy would have added an estimated 3.3 wins across 13 seasons. Our results better inform decision-making in a high-stakes environment where standard statistical tools are informative but, to date, limited.