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UNDERGRADUATE THESIS

Luck and Skill in Professional *League of Legends* (E-sports)

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"Luck is the residue of design."

Wesley "Branch" Rickey

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Abstract

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As professional gaming (e-sports) develops a greater global infrastructure, it will be critical to create league systems in which skill and luck balance to create competitive, exciting, and fair environments. This study uses the most developed e-sport leagues, found in the game *League of Legends (LoL)*, to examine early efforts at crafting such environments. The use of "winning persistence" and Bayesian statistical analyses reveal that best-of-one matches in *LoL* demonstrate an overall luck-skill ratio similar to professional baseball (MLB) and football (NFL). Best-of-three matches exhibit an understandably higher ratio of skill, similar to professional basketball (NBA). With both match lengths exhibiting viable but significantly different luck-skill ratios, *LoL* creator, Riot Games has the tools to control how much luck and skill exist in their matches and leagues, setting an important precedent for future leagues and organizations.

Thesis Supervisor: Anette Hosoi

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I owe Professor Hosoi and Christina Chase an infinite amount of gratitude for being such a great teachers, advisors, and friends. It has been an incredible four years at MIT and I am very happy to have had this last chance to produce novel research with Professor Hosoi. Thank you both very much for teaching me the ins and outs of the sports tech world and showing me how to be a successful thinker, leader, and person.

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List of Abbreviations

LoL	League of Legends
NA LCS	North American League Championship Series
EU LCS	EUropean League Championship Series
LCK	League Champions Korea
LPL	Legends Pro League
LMS	League Masters Series
MLB	Major League Baseball
NFL	National Football League
NHL	National Hockey League
NBA	National Basketball Association

For Mom, Dad, Madison, and Halley

Chapter 1

Introduction and Background

1.1 The Rise of Competitive Gaming

In recent years, an increasing number of people have become involved in the competitive play of video games, dubbed now as "e-sports." Hundreds of millions of people around the world play video games on a monthly basis, and the competitive scene has grown from inside this community as a natural evolution of competition. The traditional sports industry and the video game industry are both focusing large amounts of time and financial efforts on enhancing the e-sports experience. However, throughout this meteoric rise, few have taken a step back to examine the competitive viability of video games as sport. Is winning the millions of dollars now at stake in tournament prize pools as simple as flipping a coin or will the games be dominated by skilled teams and individuals?

1.1.1 Historical Context

To understand the dynamics of video games as sport, it is critical to understand the foundations upon which modern e-sports are built. As long as video games have existed, they have been designed to be competitive. Breaking the local arcade's *Galaga* record compared to the local track star beating the highschool long jump record. Winning a local *Street Fighter* tournament landed you in a similar realm as the tennis singles champion, but with a major caveat: there was never any direct person-person interaction between the video game players. The screen and the characters therein served as a proxy for how the players wanted to beat their opponent, whether the competition was real-time or based on some record left on the console. This mental barrier has long kept e-sports from being socially accepted, but the current young generation seems to have shed many mental distinctions between virtual and physical competition.

Many major changes such as equipment enhancements and the development of team-based games have brought competitive gaming from its arcade cabinet origins to the rising juggernaut it is today. Simply put, modern technology is reaching a point where communications between the players' actions and the games' actions are effectively instantaneous— a player is no longer limited by lag. When a player wants their character to swing a bat, the character swings the bat. This eliminates many luck-based elements of the game and any inconsistencies that artificially prevent players from succeeding (imagine breaking a stick every 5 shots in a hockey game).

The introduction of teams has produced leagues and expanded player base size. For single-player games such as *Super Smash Bros.*, *Starcraft*, and many others, early e-sport organizations have followed the style of traditional sports with a tournament format. Tournaments for various sports and games maintain positive correlations between skill and victory (the goal of competition).[17] While tournament points are kept across competitions in some cases (much like the ATP for professional tennis), each competition is a bracket-style tournament. However, as with traditional sports, team-based e-sports have tended to follow a season-based competition style. Examples include some of the more popular games of today: *League of Legends*, *Overwatch*, *Counter-Strike: GO*, and others.

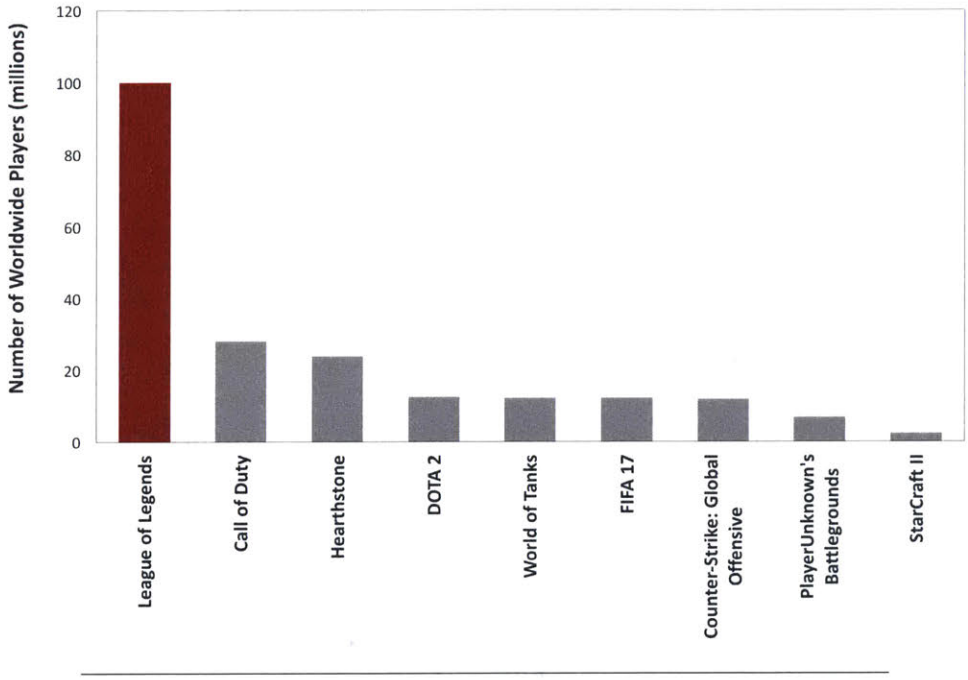

FIGURE 1.1: The number of players, in millions, of various popular games as of August, 2017. Of note is the extremely large player base of *League of Legends* compared to other popular games around the world. This large player base has bred a proportionally large e-sports scene that has been far more developed than any other e-sports organization.[18]

The overall popularity of team-based e-sports has reflected that of traditional sports like soccer, football, and basketball. With the increased popularity, the season-based e-sports have bred a more stable, analyzable platform for players, organizations, and viewers.

1.1.2 The Present and Future

Today, many of the results of e-sports' financial and social development are readily visible. Dozens of international sports organizations including the Golden State Warriors, Paris St. Germain, and the New England Patriots have purchased controlling stake in teams playing various games, namely *League of Legends*, *Overwatch*, and a few others. The resources that are being funneled towards competitive gaming

are immense, with hundreds of millions of dollars being invested annually around the world.[13] In almost every regard, this is an example of supply rising to meet demand, not an artificial demand response.

For the most recent League of Legends championship in China, an estimated peak of 95 million viewers tuned in to watch Royal Never Give Up defeat Edward Gaming in a best-of-five series to win the League Pro League (LPL).[6] For context, that competition falls just 8 million viewers shy of the 2018 Super Bowl between the Patriots and the Eagles.[16] Of course, League of Legends is the most popular e-sport in the world, but organizations such as Blizzard and Valve are beginning to launch their own efforts to match this popularity. Much like traditional sports, various e-sports will rise and develop their own fan bases and infrastructures.

1.2 Examining the *League of Legends E-Sports* Scene

Stepping back and focusing on the analysis of competition for e-sports, Riot Games' *League of Legends* offers a fantastic foundation to examine. *LoL* has the most developed e-sports system of any game both domestically and internationally. It has the most players, the most leagues, and a team of intelligent designers. Most importantly, the leagues that it has established are competitive and have changed significantly throughout the years, offering a solid platform for analysis.

1.2.1 Game Mechanics

In terms of abstract game mechanics, *LoL* plays very similarly to a traditional team sport. It should be noted that understanding every nuanced detail of the game does require significant reading and research, a common critique of e-sports. Accessibility can be difficult, and the activation energy for engaging as a viewer can be high. However, there are basic fundamental pillars for classifying games such as *LoL* that have shaped its competitive play and are relatable and graspable.

In LoL, players compete in a 5-versus-5 game where the main objective is to destroy the opponents' base. This goal is achieved by periodically engaging the opponents in combat, accruing both personal and team-wide resources, and destroying the opponents' structures throughout the game. There is no time limit on a match, and players cannot be substituted during a game. Coaches cannot communicate with the players during the game, and the team-based movements can be incredibly complicated and intricately linked to individual play.

The balance between individual prowess and team play in any sport is paramount. Recently, the professional *LoL* scene has seen a shift towards more team-based victories. In early seasons, a single player could lead a team to countless victories. Now, teams are much more reliant on inter-player interactions and plays to produce victories.

1.2.2 E-Sports History in Brief

League of Legends boasts one of the longest-running season-based e-sports, though the game's competitive scene began with grassroots local competitions (as with most

e-sports). The game is played in leagues around the world, with major regions in North America, Europe, China, Korea, and Taiwan. Other regions such as Brazil and Vietnam are constantly vying for global prominence as well. Very early on though, Riot Games acted in a nearly unprecedented way by involving the game designer with the e-sport development process. This intricate link has led to a burgeoning e-sports scene for *LoL*. The success of the game is now unconditionally linked to the success of the games' e-sports scene.

1.2.3 International Parity

Much like soccer, *League of Legends* and many other e-sports have regularly-spaced world championships and other international tournaments. Historically, e-sports have been more popular in Asian countries such as South Korea and China, and this has translated to consistent international victories for these two regions. Of the seven world championships that have been completed, South Korean teams have won five. Moreover, in its modern, more team-oriented form, South Korean teams have won every world-championship. Chinese teams consistently perform well at international events as well, and have typically performed second-best a region. North America, Taiwan, and Europe have never really competed for the spot as top region since the first season.

1.3 Luck and Skill in Sports

The intersection of luck and skill in sports has been studied by many with different approaches and for various purposes. Michael Mauboussin wrote and published *The Success Equation* on the topic with various methods of analysis, while statisticians such as Frederick Mosteller published work for the purpose of revealing to the MLB how luck-based the game was.[14][15] Even more recently, Daniel Getty, Professor Peko Hosoi, and others published research on the topic, with a comparative focus on daily fantasy sports competitions.[7] Traditionally, sports with well-established leagues or frequent competitions are analyzed for statistical reasons and due to personal interests. While tournament-based sports such as golf and tennis have been explored as well, research in these individual sports lags slightly behind the more well-explored team sports.[19]

1.3.1 Statistical Approaches

The main methods for analyzing the luck and skill for well-established leagues come from a persistence analysis and a Bayesian approach. Both of these methods do not apply as well to tournament-based sports, and so in most cases correlation analyses are examined for those tournaments. Both the persistence and Bayesian models are explored in this work. The persistence method generates a dimensionless, comparable value based on first- and second-half win percentages, while the Bayesian model provides an average number of win-loss records that are required to prove that a game is skill- or luck-based. Although the two methods vary in execution, both give a relative value for how luck- and skill-based a sport is.

1.3.2 A Spectrum of Luck and Skill

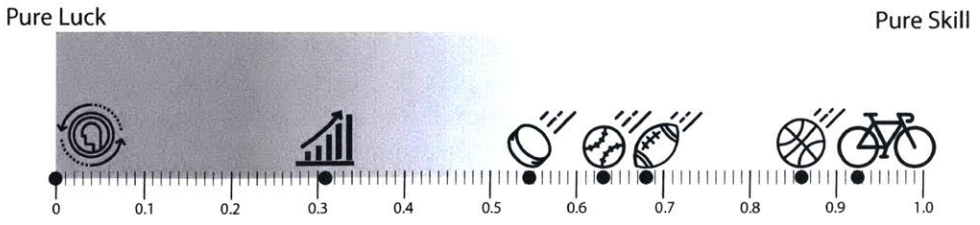

FIGURE 1.2: The spectrum of luck and skill for traditional sports. The balance of luck and skill for sports ranges from the more luck-based games such as hockey and baseball to the more skill-based sports such as basketball and cyclocross. All depicted sports exhibit a heavier reliance on skill than luck. Also pictured are the luck basis for flipping coins (far left), and trading stocks ($R^* = 0.31$). For any new sports or other competitions seeking to gain popularity, the balance of luck and skill therein might strive to be somewhere between hockey and cyclocross.[7]

After a persistence analysis of any given set of sports is completed, one can compare different sports by placing them on the spectrum of luck and skill. Figure 1.2 displays most of the major sports in the United States as well as coin-flipping, stock trading, and cyclocross. The data, analyzed by Getty Et. Al. demonstrates the existence of a wide variability in how luck- and skill-based common sports are. [7] However, a constant is that popular sports are more skill-based than luck-based. The goal for any new sport or e-sport should also be to fall on this skill-based end of the spectrum. Any competitions that are dominated by luck tend to be less engaging and entertaining over time.

1.3.3 Characteristics of Luck and Skill

The characteristics of a game that drive its placement on the spectrum of luck and skill are sometimes unknown, but more often can be hypothesized. One metric that appears to have a correlation to more skilled sports is the number of scoring chances created per game. As visible in figure 1.2, basketball is a more skill-driven game overall than hockey. This makes sense on the basis that in basketball there are hundreds of scoring chances a game, whereas in hockey, there are on the order of dozens per team per game, with even fewer goals. This means that one fluke goal has a much greater impact on any given hockey game than one incredibly lucky play in a basketball game. At the high end, you have cyclocross, in which points are effectively continually scored by bikers via their average speed. In an abstract way, every second of a race is a scoring opportunity.

Moving away from something as concrete as scoring chances, the possibilities of what determine luck and skill can become vague. A hypothesis discussed later in this paper on the topic of luck and skill is the singularity of skill for a given sport, or role within a sport. For instance, a cyclist generally has one goal: generate a higher power-to-weight ratio than your opponents, which in effect means, travel faster than your opponents. For basketball, shooting ability (skill) is incredibly correlated to

victory/ Finally, for football, the skills required for each position, especially quarterback, are fairly singular and specialized. However, a game like hockey, has very fluid roles for nearly every player besides the goalie. Players complete such a wide array of responsibilities that the interaction between players may be more luck-based.

It becomes very difficult very quickly to qualify exactly what influences the balance of luck and skill in a given sport. This task becomes even more complicated for an e-sport like *League of Legends*, where not only are there a variety of responsibilities for each player to master, but there are also changing objectives. Each player must perform a variety of tasks, but each has a discretized role within the team, much like football, a more skill-based game. Even a metric such as scoring chances is obscured in a game such as League of Legends, mainly because it is hard to qualify the definition of a scoring chance. For *League of Legends* and all sports and e-sports, there is clearly a combination of many factors that contribute the luck and skill balance for a sport.

1.3.4 Implications and Impact

Many e-sports find themselves with unique opportunities in relation to the balance of luck and skill because of how easy it is to change certain parameters about the game. Firstly, minor- and medium-sized changes are constantly made to the various games through a patching system: a regular update that seeks to balance a game's structure. In *LoL* specifically, there are minor character and mechanic tweaks occurring about once every two weeks. Additionally, Riot Games makes significant changes to *LoL* approximately twice a year. The gaming community and its players are used to changes and adapting their play styles, which cannot necessarily be said for every sport. Therefore, the implications for the results of a luck-skill balance study are possibly more important for e-sports than for traditional sports as changes are more common and more easily implemented.

As with traditional sports, quantitative measures of luck and skill in *LoL* are important not only for balanced play, but also for fan experience, a critical piece of any competition. From a competitor standpoint, players must feel like they have agency within the game and within the league—their individual skill must contribute to victory and loss. The fans must also believe that this is true, and they also must be presented with a manageable amount of media in terms of time. Basketball games could become even more skill-based by playing for 3 hours, but viewership would almost certainly decline. In terms of the overall entertainment and longevity of competitive *League of Legends*, a balance between luck, skill, and consumability must be struck. This paper quantifies the balance between luck and skill for LoL in order to provide information on the creation of the e-sport as a whole.

1.4 Why *League of Legends?*

1.4.1 Determining League Viability

A primary reason for studying the relationship between luck and skill for any game or competition is to determine the game's basic viability as a sport. Luck-dominated

competitions could not produce reliable results for teams and would not be compelling as a player or observer. Specifically for professional gaming, there has been very strong anecdotal and qualitative evidence that most games are skill-based at the highest level, but it still requires proving. The games' creators must design the game such that it is not as luck-based as coin-flipping or stock-purchasing, and should probably not be more skill-based as cycling or other endurance sports.

As a model for many other e-sports to come, an analysis of *League of Legends* has implications not only for itself but also other e-sports as well. As more and more leagues pop up around the world, and more scrutiny falls upon *LoL's* e-sports scene, a sound foundation must exist.

1.4.2 Best-of-One vs. Best-of-Three

For any sport, the number of games in a match or playoff series is important. For a best-of-one series, the outcome may seem too luck-based, and with more games played, the more skilled team should more consistently win the overall match.[15] The same is true for *League of Legends*, and a large debate surrounds this topic. In the main professional North American league, the North American League Championship Series, (NA LCS) the format of regular season matches switched from best-of-one to best-of-three and then back to best-of-ones.

The changes could have been made for many reasons, but the predominant reasons appear to center around entertainment and competitiveness. Simply put, a best-of-three series can be too long for many viewers to watch— nearly three hours in length at times. In an effort to avoid baseball's game length problem, and following widespread community critique of long match-times, the NA LCS opted to return to best-of-ones. In addition to viewer experience, the overall competitiveness of the league appeared to drop when best-of-three series were implemented. Lower-tier teams were not able to win matches off of the top teams simply because they could not win two games in the same day without miracles. In this most recent season, which returned to best-of-ones, teams seemed much more competitive top-to-bottom within the league. However, as with many e-sports related debates, the perceived outcomes centered around qualitative analysis and observations.

This paper does not seek to challenge the idea that a best-of-one series will be more luck-based than a best-of-three series. For any game that is skill-based, the longer a series, the more likely it is that the more skilled team will win.[15] However, this paper does seek to examine the two different formats in order to verify that both are viable, as previously discussed and to examine the amount of change in the luck-skill balance between best-of-one and best-of-three series. Further, it seeks to explore the correlations between different leagues' match type and international success, if any.

Chapter 2

Persistence Approach

2.1 What is Persistence?

The idea of persistence takes many forms for different fields of research, but at base it is the continued or prolonged existence of a trend. Translated into an analysis of luck and skill in regards to a sport, persistence is essentially the prolonged existence of a team's winning percentage. In a sport or game driven nearly completely by skill, similar to chess, one finds a very high persistence for a given player or team. The world champion will nearly always beat all weaker opponents, and the opposite holds true for the weaker teams, which will very rarely beat more skilled opponents. Once any element of luck is introduced into the persistence model, however, noise is introduced. Weaker teams now have the chance to beat stronger teams through elements of chance.

For the purposes of quantifying a comparable universal metric of luck and skill, persistence can be simplified to the translation of a team's winning percentage from the first half of the season to the second half. For a fully skill-based system in which each team plays other teams twice (once in the first half of the season, once in the second half), each team should have the exact same record for the two halves of the season. Once luck is introduced, the first and second halves of the season may yield different win percentages for most teams, which is often case. This persistence model is advantageous for reasons ranging from data visualization and computational ease, to others that are explored later.

2.2 Visualizing Persistence

In many ways, persistence of winning can be more easily visualized than described. For a completely skill-based game, every team has the same exact record for the first and second half, and each team has a unique record. The result is a perfectly linear plot with win percentages varying from 0 to 1.000. For a completely luck-based league, any given team always has a 0.500 chance of winning, and therefore every team would end up with a .500 record in both the first and second halves with a long enough season. In reality, this is not likely, and so a more realistic vision of a luck-based system is the rounded, cloud-like plot in figure 2.1(a), where there appears to be little correlation between a team's first- and second-half win percentages.

Now, examining data from League of Legends in figure 2.1 more in depth, one can see the traces of both skill and luck, even in a simple scatter plot. Comparing the

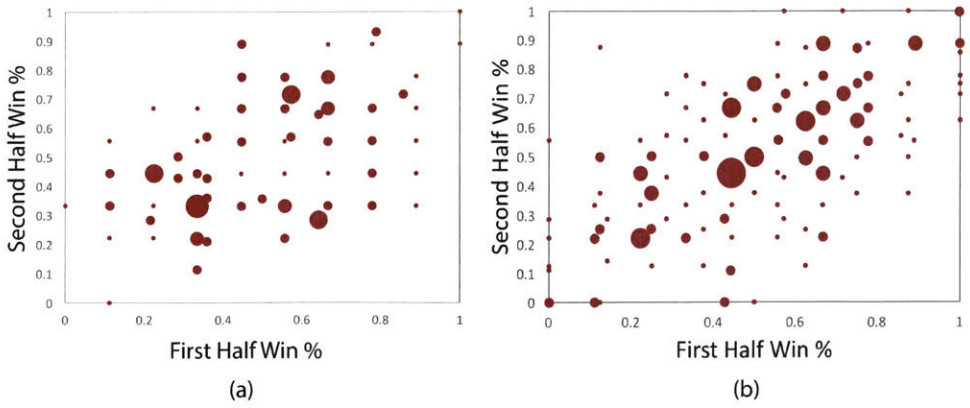

FIGURE 2.1: On the left in (a) is a scatter plot visualizing the win-loss records for teams competing in best-of-one leagues from around the world. On the right in (b) is a scatter plot depicting the win-loss of teams competing in best-of-three leagues. For both plots, the size of a dot is proportional to the number of win-loss records corresponding to the value shown. Although both plots demonstrate substantial noise, a signal of skill visible in a diagonal linear progression is more visible for best-of-three leagues.

scatter plots between seasons with best-of-one and best-of-three matches reveals the artifacts of both skill and luck. There is clear evidence of skill in that certain teams have gone undefeated in certain seasons of best-of-one and best-of-three matches. There also appears to be an underlying linear trajectory across the diagonal, more clearly visible in (b), the best-of-three matches. However, there are also clear signs of a luck-based system. The cloud-like noise spread is clearly present as well, as most teams did not exactly replicate their first-half winning percentage in the second half.

Even though the scatter plots can demonstrate a difference between the best-of-one and best-of-three match systems, further distillations of the data can help demonstrate the differenceeven further. In the heat map found in figure 2.2, a random set of 120 win-loss records have been mapped from both the best-of-one and best-of-three match systems. This is done in order to visually represent the best-of-one and best-of-three heatmaps most equally given data set limits. In figure 2.2, the best-of-three heat map does more clearly show the linear progression along the diagonal of the plot, while the best-of-one chart appears to have a more random assortment of records. This is visible in the wide spread of lighter colors in figure 2.2(a), and the high presence of consistently low winning percentages in 2.2(b) for best-of-three matches.

Taking the visualization process one step further, one can use these heat maps, and set thresholds for colorization in order to better visualize trends. In figure 2.3, such thresholds have been set, and the underlying patterns become even more clear. Here, the linear trend of the best-of-three system and the randomness of the best-of-one system are most clearly visualized. With a random selection of 120 data points from various leagues, these trends hold very consistent throughout various data selections. Even with these simple visualizations, it is clear that best-of-one series are more luck-based than best-of-three series, but by how much exactly?

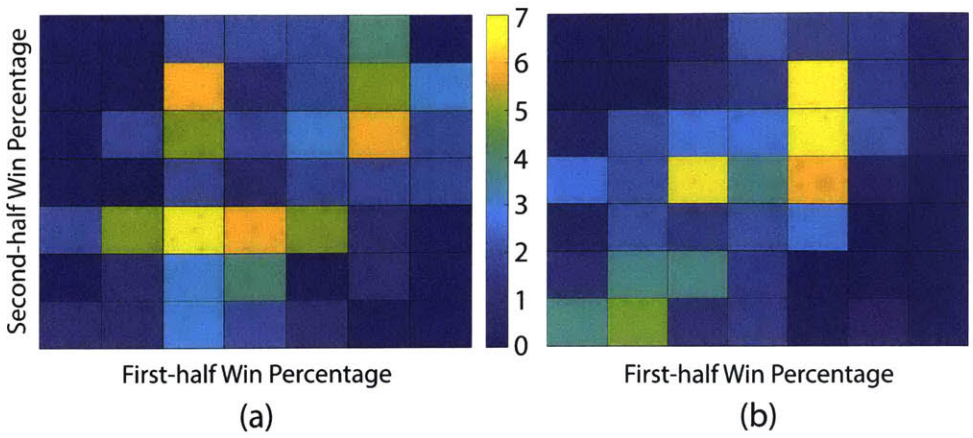

FIGURE 2.2: The heatmap visualization for a random subset of 120 win-loss records for both best-of-one (a) and best-of-three series (b). Although the differences between (a) and (b) are again subtle, the heatmap reveals a more clear visualization of the increased width distribution of the best-of-one series. Specifically, the presence of heatmap buckets that contain 5 and 6 data points far removed from the diagonal axis from (0,0) to (1,1) indicate the more luck-based system of best-of-one matches.

2.3 Quantifying Persistence

Having visualized what luck-based and skill-based systems look like, one can go a step further to quantify exactly how luck- and skill-based they are. In essence, the qualitative visual comparisons of different systems rely upon the variance along the two diagonals of the first and second half win percentage plot. For the purpose of analysis, p_i represents the first half win fraction for a given team, i. Likewise, q_i represents the second half win fraction for the same team, i.

In order to easier quantify the desired variance across the diagonals, rotating the (p,q) coordinate system simplifies calculations, and introduces two new variables:

$$s_i = \frac{1}{\sqrt{2}}(p_i + q_i + 1)$$

$$t_i = \frac{1}{\sqrt{2}}(q_i - p_i)$$

Now, for a given team, s_i represents the variation of p_i and q_i from a value of $1/2$. t_i now represents the discrepancy in win fraction difference between the first and second halves of a given season for the same team, i.

Taking the standard variance of the values s_i and t_i helps to characterize the balance of luck and skill for a game. Note that in previous analyses, weighted variance has been taken into account given varied confidence in each data point. As no such confidence lag exists for the used data, a standard variance is used:

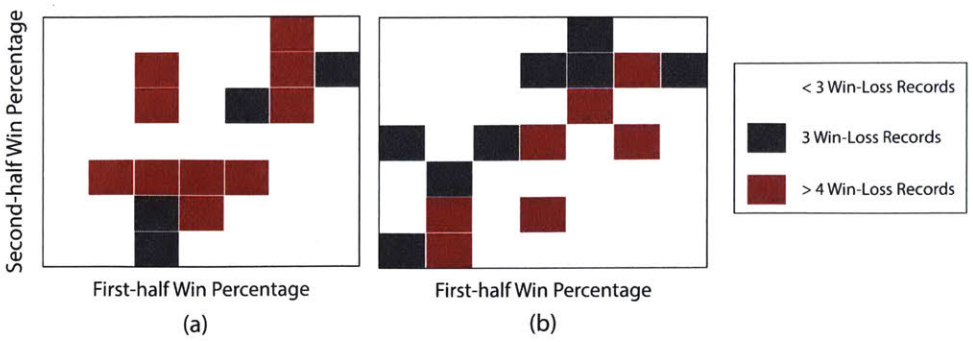

FIGURE 2.3: A tiered (threshold) heatmap of both best-of-one (a) and best-of-three series (b). For the heatmap depicted in figure 2.2, this figure applies threshold values for coloring the heatmap. For containers with fewer than three data points, no color is applied. For containers that contain three win-loss records, a grey shade is applied, and for containers with more than 3 data points, a red color is applied. These plots reinforce previous explorations by more starkly revealing the linear nature of the best-of-three system (b), and the more chaotic, random distribution of data points generated from best-of-one series (a).

$$A = \sigma_s^2$$

$$B = \sigma_t^2$$

Finally, A and B can be combined to create a single variable capable of defining sports on the spectrum of luck and skill:

$$R^* = 1 - \frac{B}{A}$$

R^* produces large comparative value based upon its intuitive limits. A completely luck-based system will yield a value of $R^* = 0$, while a completely skill-based system will yield a value of $R^* = 1$. This simple scale provides a powerful spectrum for ranking and comparing the luck-skill basis of different sports and other competitions.

2.4 League of Legends Analysis

Of course, the goal of this paper is to use these methods to analyze luck and skill in *League of Legends*. As such, analyses using the persistence method were broken apart into a few different categories: a comparison with traditional sports, the difference between best-of-one and best-of-three matches, and finally the discrepancy between different regions.

2.4.1 Comparison to Traditional Sports

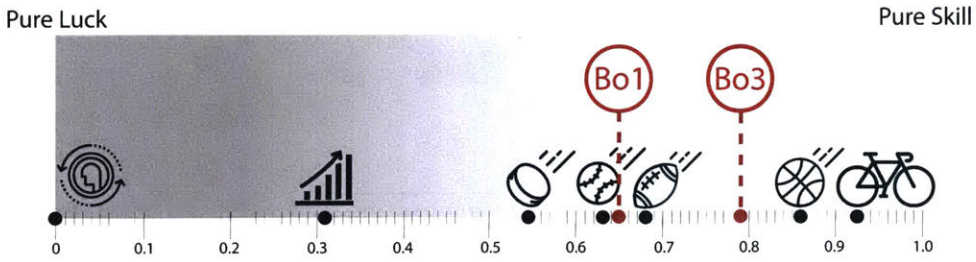

FIGURE 2.4: A spectrum including previously explored traditional sports as well as the breakdown of best-of-one (Bo1) and best-of-three (Bo3) series in League of Legends. The data reveal that both best-of-one and best-of-three series offer a viable balance of luck and skill, and that best-of-three series tend to be more significantly skill-based than best-of-one series, reinforcing previous explorations of the topic.[7]

A combined analysis of best-of-one and best-of-three series for *LoL* was not applied because of the large difference between the two match types, and so they are plotted separately. In line with previous research, the skill basis for victory becomes greater when transitioning from best-of-one to best-of-three series.

However, the fact that both best-of-one and best-of-three series fall well within the range for standard team sports is important. Best-of-one series fall at a value of $R^* = 0.65$, between baseball ($R^* = 0.63$) and football ($R^* = 0.69$), while best-of-three series generated a value of $R^* = 0.79$, slightly lower than the most skill-based team game, basketball ($R^* = 0.86$). The fact that both match types are bounded by traditional sports is certainly a positive result, and is discussed further Chapter 4: Results and Discussion.

2.4.2 Best-of-One Regional Breakdown

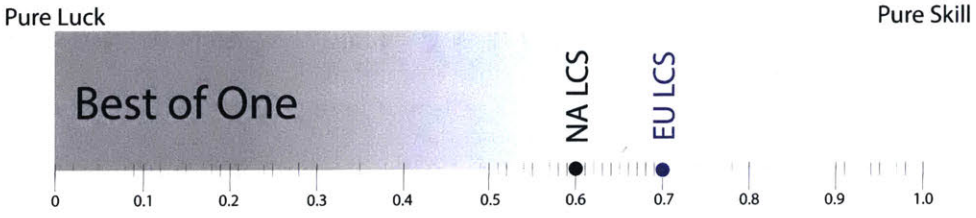

FIGURE 2.5: A spectrum displaying the differences between the two major regions that have played best-of-one matches for multiple seasons. Only Europe's EU LCS and North America's NA LCS have historically played in best-of-one series. The EU LCS exhibits a substantially greater skill-basis than the NA LCS across multiple seasons, by about 17 percent. The results of this analysis are discussed in Chapter 4.

Examination of the breakdown of best-of-one by the contributions of the various regions provides further insight into the global picture of *LoL* as an e-sport. Interestingly, the North American League Championship Series (NA LCS) and the European Championship Series (EU LCS) vary significantly in how luck and skill based they have been since their inception. The difference from a comparative perspective is that the NA LCS ($R^* = 0.60$) has a luck-skill ratio similar to the MLB ($R^* = 0.63$), and that the EU LCS ($R^* = 0.70$) is most similar to the NFL ($R^* = 0.69$). The implications of this phenomena and its discovery and their relation to international tournament results are discussed further later.

2.4.3 Best-of-Three Regional Breakdown

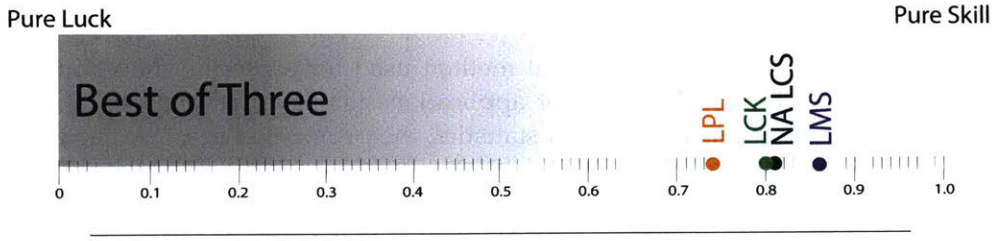

FIGURE 2.6: A spectrum displaying the differences between the various major regions in League of Legends that have competed in multiple seasons with best-of-three matches. Of note is a familiar spread between the most luck-based and skill-based major leagues from around the world. China's LPL ($R^* = 0.74$) exhibits a significantly more luck-based system than Taiwain's LMS ($R^* = 0.86$), a similar discrepancy to that found for best-of-one series.

Transitioning to a further analysis of the regional breakdown for best-of-three series provides more interesting results. As visible in figure 2.6, a similar difference exists between the most skill-based and luck-based leagues. With Taiwan's LMS being the most skill-based ($R^* = 0.86$) and the LPL being the most luck-based ($R^* = 0.74$), the NA LCS and Korea's LCK fall around the average skill-basis of $R^* = 0.8$. The causes of this spread and the implications of this phenomena and its discovery and their relation to international tournament results are discussed further in Chapter 4.

Chapter 3

Bayesian Approach

3.1 Purpose of Bayesian Analysis

Bayesian analysis is a strong statistical method used for exploring the validity of a prior belief. Although the range of applications for Bayesian analysis is large, in successful applications of Bayesian statistics, the prior belief must be capable of being probabilistically quantified. Evidence suggesting the probability of different outcomes must also be quantifiable via known distributions. For the most basic Bayesian analysis, three quantifiable pieces of knowledge must be available:

p(prior)	The probability that the belief is true, which can begin anywhere between 0 and 1.
p(result | prior)	The probability of observing a result given the probability distribution of p(prior)
p(evidence)	The probability of the underlying data. Specifically, this value is determined by integrating or summing possible p(prior) values modified by a probability of their occurrence.
p(belief)	The probability that the belief is true, which is quantified at the end of analysis

The resulting equation for which one can iteratively solve is:

$$p(belief) = \frac{p(result|prior) * p(prior)}{p(evidence)}$$

With enough iterations, one can quantify the validity of the initial hypothesis by updating the results for each iteration. Eventually, the probability of the belief will converge to a value of zero or one, at which point the analysis ends, and the outcome has been determined. From this analysis, the overall result of the convergence and the speed at which the analysis converges to a given point (time to convergence) are important. The rate at which different systems converge can provide a comparative metric if the systems are still similar enough to compare.

3.2 Application in Sports

The application of a Bayesian method to historical data for *League of Legends* and all sports serves predominantly as a consistency check for results from persistence analysis. While knowledge about the skill/luck convergence rates of different sports is valuable on its own, it also serves to reinforce the statistical explorations of the persistence method with an entirely different approach. Additionally, the Bayesian method provides an extreme lower-bound value for the number of win-loss records required to complete a viable persistence analysis.

In order to apply use a Bayesian approach to measure the balance between luck and skill in sports, one must first assign the variable states. For this analysis, there are four variables, and the prior belief is that *League of Legends* exhibits an even balance of luck and skill ($p(skill) = p(luck) = 0.50$):

p(skill)	The probability that the game is skill-based. This is also the p(belief and in updated throughout the analysis.
p(luck)	The probability that the game is completely luck-based
p(record | skill)	The probability that a given record is skill-based
p(record | luck)	The probability that a given record is luck-based

Which generates the resulting Bayesian equation:

$$p(skill) = \frac{p(record|skill) * p(skill)}{p(record|skill) * p(skill) + p(record|luck) * p(luck)}$$

For the purposes of this study, and with most Bayesian analysis, it is important to accrue a large number of trials and calculate an average convergence speed. As such, this work bases the results of its Bayesian analysis on the average results from 500 trials with the full set of data for both best-of-one and best-of-three matches. Each result on its own is not necessarily useful except to verify that the game is skill based, but the convergence times provide a valuable metric.

3.3 Analyzing *League of Legends*

Performing an iterative analysis of *LoL* isolated in best-of-one and best-of-three systems replicates the results found with the persistence method. Plotted below are the resulting visuals for 500 iterations of Bayesian analysis for both best-of-one and best-of-three series.

In this instance, the visualization of the data in its raw form is not necessarily useful except in terms of picking out the presence of extreme outliers. Clearly visible are a more significant amount of Bayesian analyses that exceed more than seven iterations for best-of-one series. Although these outliers are striking, they may not represent the trends of the underlying data. In order to account for this possible discrepancy,

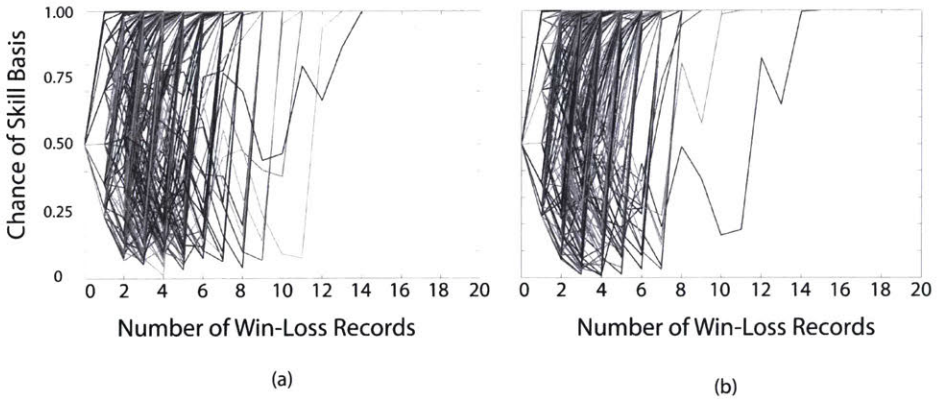

FIGURE 3.1: A plot showing 500 iterations of a Bayesian analysis for best-of-one (a) and best-of-three matches (b). Qualitatively, it appears that a larger number of outliers tend to have a large number of win-loss records until convergence for best-of-one series (a). This observation can be quantified: for best-of-one series, the average analysis converged to a skill basis after 3.8700 win-loss records. For best-of-one series, the average analysis required 3.334 win-loss records to converge to a 100 percent chance of a skill basis.

it is important to analyze the overall distribution and average of the number of iterations that it takes for best-of-one and best-of-three series to converge. In this way, the movement from qualitative visualization to quantitative analysis mirrors that of the persistence method.

For best-of-one series, the Bayesian analysis yielded an average number of 3.8700 win-loss records until the system converged to 100 percent probability of a skill basis. Similarly, best-of-three analysis yielded a convergence length of 3.3340 games. These results clearly reinforce the qualitative findings of the persistence method. As visible in figure 3.2, the distribution of point around this average more closely resembled a Rayleigh distribution rather than a normal distribution, a fact discussed in Chapter 4.

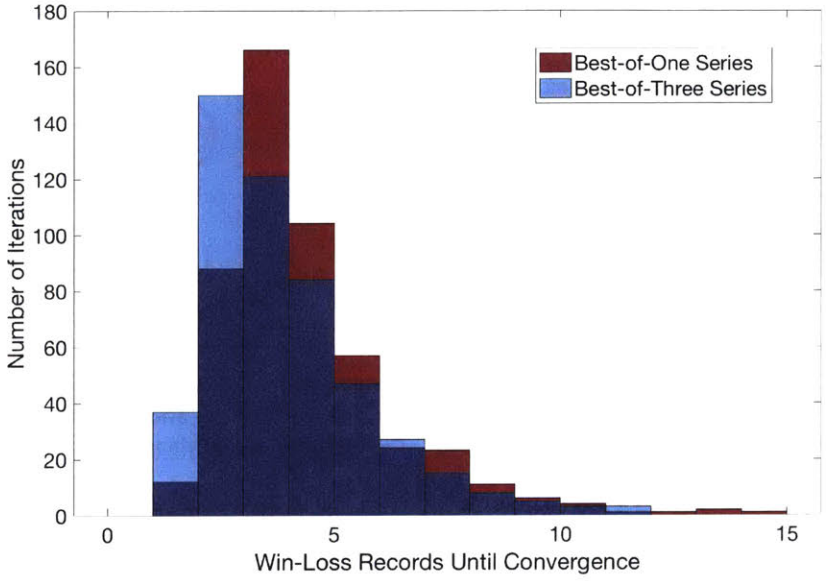

FIGURE 3.2: A histogram showing the distribution of convergence time for 500 iterations of a Bayesian analysis of best-of-one and best-of-three matches. In this plot, the higher average of the best-of-one series (3.8700 win-loss records) is more clearly visible in maroon, reinforcing the qualitative observations from figure 3.1. The average of 3.3340 win-loss records until convergence for the best-of-three series is slightly lower. Of note, the distribution of convergence time resembles that of a Rayleigh distribution rather than a normal distribution.

Chapter 4

Results and Discussion

4.1 Best-of-One and Best-of-Three Series

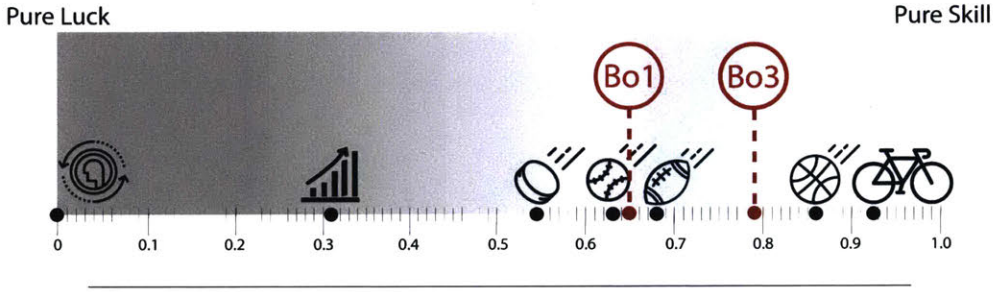

FIGURE 4.1: A spectrum including many traditional sports from the United States as well as the breakdown of best-of-one and best-of-three series in League of Legends. *This figure is a repetition of figure 2.4.*[7]

4.1.1 Traditional Sport Context

Reiterating, a main purpose of this work is to analyze professional *League of Legends* in order to determine if the luck-skill basis for the overall game and they way the leagues function compares to traditional sports. Different leagues employ different match systems around the world, and most opt for either a best-of-one or a best-of-three approach. The support for both forms is divisive, and quite often skill expression is a topic when discussing their differences.

As such, the result that best-of-one series and best-of-three series exhibit R^* values of 0.65 and 0.79 respectively bodes well for the competitive nature of professional *League of Legends*. Both best-of-one and best-of-three series exhibit a dominant skill basis that falls well within the bounds of traditionally popular and competitive sports. So even though the debate about balancing luck and skill may continue, both systems do fall into a sort of competitive "sweet spot."

4.1.2 Causes

As with the analysis of results for other sports, it is important to hypothesize the underlying sport and league mechanics that produce these results. Borrowing from

traditional sports, a few prominent causes that emerge are season length, number of points scored, and diversity of skillset, both mental and physical.

For season length, it is interesting to note that all professional *LoL* leagues have relatively short seasons, about 16 to 30 games. This puts *LoL*in a similar category to football in terms of season length, and in that they have a similar balance of luck and skill, especially for best-of-one matches. Although the total number of games in a season is different for different teams in a best-of-three system, teams play about 30 to 60 games, which is closer to basketball and hockey. A longer season traditionally supports a more skill-based system as teams regress to the mean if given enough games.

The value of number of points scored in a game is significantly obscured when considering a game like *League of Legends*. Number of shots is an important factor in basketball's skill basis, but what exactly is a "shot" or "point" in *LoL*? If one considers kills of opponents or objective destruction as metrics for points, a typical game of *LoL* contains around "25" scores total. This is significantly more than any of baseball, hockey, or football, which may boost the skill-reliance in the game. Further work is certainly required to explore this potential cause.

Finally and similarly, the diversity of skills contributing to wins may be a factor, but a difficult one to quantify for *LoL*. At some point, one has to parse the physical and mental aspects of the game in order to get a better understanding of the underlying mechanics. Mechanically and physically, e-sports are incredibly focused, which may contribute to their heavier reliance on skill than many traditional sports. The physical skills required for e-sports are nearly as singular as a quarterback's or a motorsport racer. This is reinforced by the fact that some professional *LoL* players have left the game to play competitively in other e-sports.[10]

However, despite the heavy reliance on consistent finger and wrist movements, the mental skills it takes to excel at the various phases of a *LoL* game are quite astounding. The micro and macro movements that players must execute in tandem with their teammates are more akin to chess or other strategy games, but played in real-time. This parsing and analysis of the mental and physical tasks required to play a sport and their relation to a skill-luck basis demands further insight, and may prove important for not only other e-sports but also traditional sports.

4.1.3 Implications

These results carry implications from the two important overall discoveries of traditional sport context and the difference between best-of-one and best-of-three series. Primarily, at the very least, the base game of *League of Legends* can perform viably as a competitive sport, with skill reliance ranging from baseball to basketball levels. Additionally, they can safely assume that a league composed of best-of-one or best-of-three matches will perform similarly to traditional sports leagues in terms of parity.

However, the difference between the way in which best-of-one and best-of-three matches carry out is significant. Firstly, this means that each league has the ability to twist this simple dial and make their league significantly more luck or skill based if they so desire. This has implications for the player and viewer engagement, and carries implications for major tournaments.

Most leagues employ simple double-round-robin systems for play, but international tournaments are typically different. A pool system similar to the world cup is usually based on best-of-one matches and the ensuing bracket stage usually contains best-of-three or even best-of-five matches. In the context of this study, it might become even more important for Riot Games to examine the structure of their tournament styles. Is it desired to have a more luck-based bracket entry system and a more skill-based bracket? How does this affect global parity and excitement?

4.2 Regional Differences

Finally, this study reveals significant differences in the luck and skill balance between major regions both for best-of-one and best-of-three matches.

4.2.1 Implications

The implications of variation in the balance of luck and skill across global leagues is unclear. Korea's LCK has a similar balance to the NA LCS, but a Korean team has won the past five world championships while a North American team hasn't made the semifinals in the same amount of time. There has always been a debate about the skill-level in the different major regions for *LoL*, and discerning the balance between luck and skill for each of those leagues does not seem to answer any major questions. These results secondarily examine the variance of skill within a league, but does not quantify an average skill for a given league.

4.2.2 Perceived Variance

One interesting qualitative area of exploration is perceived variance of skill within the different leagues around the world. Examining table 4.1 and comparing the perceived variance of the different leagues to the persistence analysis regional breakdown (found in figures 2.5 and 2.6) reveals some discrepancies in how the skill gap is perceived across different *LoL* leagues. It should be noted that this is a single example of perceived variance across various leagues, but it still serves as a poignant example, and is not dissimilar to rankings from the current 2018 season.[3]

At the most simple level, if a league has more variance in overall team skill, the league should be more skill-based, and visa-versa. However, this is not how many analysts perceive the various leagues across the globe. Taiwan's LMS has the smallest perceived gap between its teams, but the league is predominantly skill-based in reality. Likewise, the NA LCS was perceived to have the most variance from top-to-bottom, but that is not actually the case, as it balances an average amount of luck and skill in comparison to other leagues for best-of-threes. It's not quite clear right now what this means for analysts in terms of how they should rank teams globally, but it might mean that unexplored statistics coming from the various leagues might provide insight into this discrepancy. Conducting longer-term analysis may be very helpful in this regard.[8]

League	Average Rank	Standard Deviation
LCK (Korea)	13.6	12.4
LPL (China)	27.8	12.2
NA LCS (North America)	27.7	15.1
EU LCS (Europe)	29.6	13.6
LMS (Taiwan)	29.1	12.1

TABLE 4.1: A table displaying the average team rank from leagues around the world and the standard deviation of their ranking with data taken from ESPN's weekly "power rankings." This specific data set is taken from the final ranking before the world championship of 2017 (season 7). Power Rankings such as this serve as an estimation for both the average skill level of a region (league) as well as a perception of the variance in skill across the region. Comparing these estimations to quantitative measures of luck and skill provides one basis for evaluating power rankings.[8]

Chapter 5

Conclusions and Future Work

As the world of e-sports continues to rapidly expand, the arena for analysis likewise expands. As statistical analysis and other quantified studies of traditional sports have increased in recent years, the same will eventually occur for e-sports. With critical similarities and differences between e-sports and traditional sports, quantifying the nature of e-sports will bring important data for players, teams, leagues, and game creators. The e-sports industry is largely based upon traditional sports models, and the possibilities for challenging this association are great.

5.1 Further *League of Legends* Analyses

5.1.1 Best-of-Two Analysis

Although a best-of-two analysis is omitted from this work as the system is now generally outdated for *LoL*, there is clear value in examining the luck-skill balance for best-of-two series. Interestingly, this system was tested predominantly in regions of the world where soccer is more prevalent such as Europe and Brazil. The matches either end in a win, a loss, or a tie for the two competing teams, which adds a another dimension to the gameplay and theoretically the standings. Although it is unlikely that this system will become prominent again in e-sports, further analysis may prove interesting.

5.1.2 Skill and Luck Progression

One of the more interesting pieces of future work will focus on how the balance of luck and skill in *LoL* changes over time. As teamwork continues to become a more integral part of the game, it is very likely to bring changes in the luck-skill balance. Additionally, as teams begin to understand how to more optimally play *LoL* and player bases and rosters expand, the dynamics of chance and skill will change further. Any changes have large implications for the viewing and playing experiences of fans and players. Additionally, Riot Games may be able to take a veritable timeline of data to better understand how certain gameplay changes or tweaks affected the balance in order to refine their future modifications.

5.1.3 "Early League" Comparison

Although the major leagues in competitive *League of Legends* appear to have an appropriate balance of luck and skill, questions still linger surrounding the sustained dominance of certain teams. The Korean team SK Telecom T1 has won three of the previous five World Championships and has exerted a dominance over their local region as well. But is this dominance typical for a new sport or league?

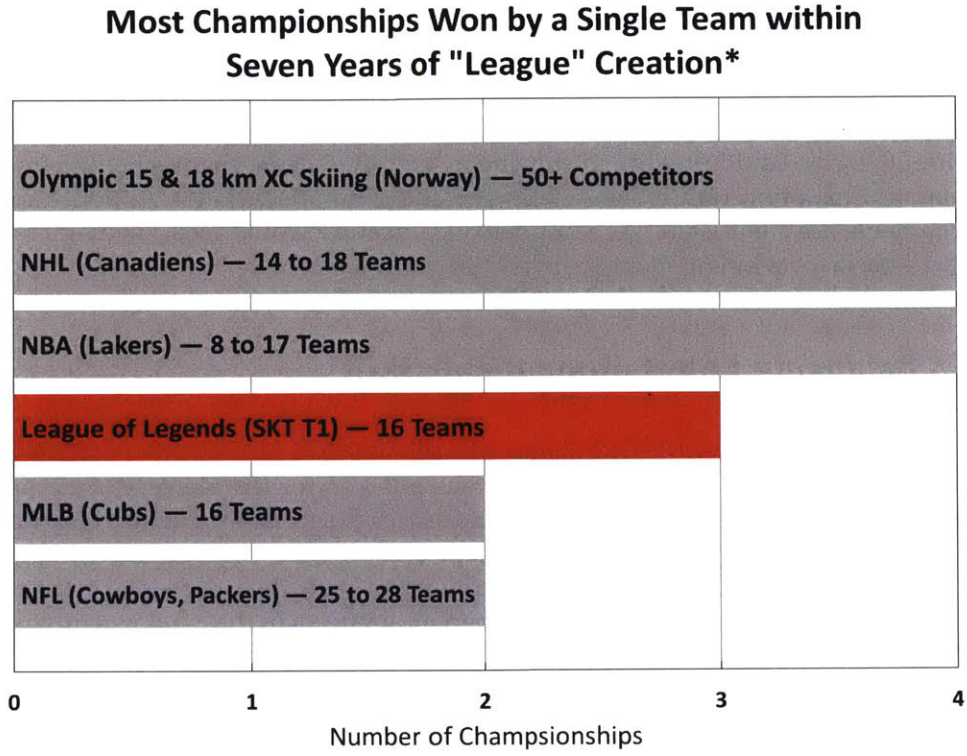

FIGURE 5.1: A comparison of the number of championships won by the most dominant team within the first seven years of league creation. For most sports, even with a wide range of skill and luck balance, a single team tends to dominate in the early stages of league creation, and *League of Legends* is no different. The world's most dominant team, SKT T1, has won the most *LOL* world championships with 3, but this dominance is quite average for a new sport or league. *Within League Creation is defined as the range in which the league first eclipsed 16 teams in order to more aptly make comparisons with *LoL*.[9, 11, 1, 5, 4, 12]

Examining a range of sports along the skill-luck spectrum, it is clear that the dominance of SK Telecom is not an aberration. Many "young" sports exhibit a single-team dominance within the first years of establishment. Interestingly, this holds true for significantly skill-based sports such as cross country skiing and sports that exhibit a more luck reliance such as hockey in the NHL. For the most part, this finding simply reinforces the idea that *LoL* exhibits an appropriate balance of luck and skill. It may also help skeptical fans and analysts believe that eventually, the dominance of Korean teams will wane, as has happened in other sports.

5.2 Tournament-Based E-sport Analysis

Although this paper focuses on the analysis of the predominant season-based e-sport, *League of Legends*, there still exists many opportunities to study other games. Many popular games such as *DOTA 2* and *CS:GO* operate on tournament-style models. Even though analysis of tournaments is less-explored, many have studied the balance of luck and skill in sports such as golf and even poker. Measuring correlations between prior placements within tournaments gives a strong idea of how much skill is involved in winning.[17] [19]

Finally, tournament-based e-sports offer another interesting field of study in that many operate with a "losers" bracket, where players and teams who lose have a second chance to make it to the finals. Analyzing the theoretical results of tournaments without this rule could provide interesting insight into the mechanics behind its excitement. This opportunity also wields the ability to affect how traditional sport tournaments are conducted. A "second-chance" feature would most likely increase the skill-basis for winning in any competition.

5.3 Balancing Entertainment and Skill

As was iterated previously, the balance of luck and skill in a given sport has implications not only for the players and teams but also for the viewers. One must remind oneself that most modern sports industries exist mainly due to viewer and consumer engagement. It's a strange concept that provides different incentives for game designers and league managers, as the majority of their decisions must take viewer experience into account. This has had clear affects in the MLB recently with their new pacing rule changes, and for e-sports the balance is crucial as well.[2] A proper balance of luck and skill brings excitement and parity to a league. It's exciting when teams go undefeated, but only because the occurrence is so rare.

In this regard, e-sports maintain a strong advantage over traditional sports. The adaptability of designers, players and viewers far outstretches that of traditional sports. Very few sports have seen major gameplay changes in the past ten years, and the changes are often received poorly. In e-sports however, the patch system introduces frequent changes in order to balance the game and shake things up. The fact that all of the games' assets are digital also removes many financial hurdles to major changes. For e-sports the ability to change quickly is essentially an evolutionary advantage over traditional sports, leading way for a very bright future.

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