Team vs. Team: Success Factors in a Multiplayer Online Battle Arena Game

JULIA NEIDHARDT

Vienna University of Technology, Austria

YUN HUANG

NOSHIR CONTRACTOR

Northwestern University, USA

ABSTRACT

There is a small but growing body of research investigating how teams form and how that affects how they perform. Much of that research focuses on teams that seek to accomplish certain tasks such as writing an article or performing a Broadway musical. There has been much less investigation of the relative performance of teams that form to directly compete against another team. In this study, we report on team-vs-team competitions in the multiplayer online battle arena game Dota 2. Here, the teams' overall goal is to beat the opponent. We use this setting to observe multilevel factors influence the relative performance of the teams. Those factors include compositional factors or attributes of the individuals comprising a team, relational factors or prior relations among individuals within a team and ecosystem factors or overlapping prior membership of team members with others within the ecosystem of teams. We also study how these multilevel factors affect the duration of a match. Our results show that advantages at the compositional, relational and ecosystem levels predict which team will succeed in short or medium duration matches. Relational and ecosystem factors are particularly helpful in predicting the winner in short duration matches, whereas compositional factors are more important predicting winners in medium duration matches. However, the two types of relations have opposite effects on the duration of winning. None of the three multilevel factors help explain which team will win in long matches.

Keywords:

Virtual teams, e-Sports, Online games, Team competition, Team performance.

INTRODUCTION

Most contemporary challenging tasks need to be addressed by teams. As a consequence, there is an increasing interest in studying how teams form and how that affects their performance. There is a small but growing body of work that aims at identifying team assembly factors that affect team performance in contexts as diverse as scientific collaborations and Broadway musicals (Guimera, Uzzi, Spiro, & Amaral, 2005). However, in many of these settings, the detailed process of team collaboration depends on the nature of the tasks.

In team-vs-team competitions, on the other hand, there are typically no pre-defined tasks; the overall objective is rather to defeat the opponent. Thus, in these settings, the winner is clearly identified but is based on relative performance vis-a-vis the loser. Furthermore, a team has to react constantly to the opponent's activities. This helps to reflect team internal dynamics from a more general perspective and provides the opportunity to study team performance in a comprehensive way.

Team-vs-team competitions often occur in sports but also in other areas such as business (e.g., the competition of two standards) and of course in military conflicts. However, by now these settings have drawn little attention from researchers, there are only very few articles explicitly modeling team-vs-team competitions. Klemperer (1992), for instance, studied head-to-head competitions between companies with similar product lines. With the help of a mathematical model he showed that matching product lines might lead to a less competitive market since using various suppliers is more costly for customers (e.g., extra effort) which they try to avoid. Duch, Waitzman, and Amaral (2010) examined the performance of soccer players in the Euro Cup 2008 tournament and applied a network approach to quantify both the performance of a team as well as the contributions of individual players. Furthermore, they illustrated how their method could be generalized to other setting such as scientific collaborations. Merritt and Clauset (2014) analyzed scoring dynamics in professional team-sports competitions. Only based on tempo and balance of scoring events, they developed a generative model that accurately predicts the outcome of a match.

Our research seeks to build on this tradition. In this study we use the multiplayer online battle arena game Dota 2 to study performance in a team-vs-team competition. In this game two teams of five members are competing against each other with the goal to defeat the opposing team. Our aim is to identify multi-level factors that influence the winner in this direct competition. These three categories of factors are related to the composition of a team, to relations within a team and to relations within the ecosystem of teams. Since, Dota 2 matches do not have a specific length we have the unique opportunity to explore if and how compositional, relational and ecosystem factors influence the duration of a match.

As a digital replica of real world scenarios, virtual communities and online games may provide an opportune environment to study human behavior and interactions (Williams, 2010; Williams, Contractor, Poole, Srivastava, & Cai, 2011). This research often studies players interacting with each other and collaborating in game teams in Massive Multiplayer Online Role Playing Games

(MMORPG). Most of the studies focus on in-game organizations or groups aiming to finish specific tasks, also call Player versus Environment (PvE). For example, Williams an colleagues (2006) analyzed social communities (so-called guilds) in World of Warcraft and showed that due to the game's design some interactions are encouraged whereas others are discouraged. Player versus Player (PvP) play style games show the advantage to directly measure the outcome of two teams competing with each other. Typically PvP games have no predetermined tasks and sometimes the game rules are flexible and changeable according to players' strategies. For the two popular online PvP games Texas Hold'em and Halo 2, Cheung and Huang (2012) examined dynamics how game rule develop and why new variants occur.

In recent years, Multiplayer Online Battle Arena (MOBA) games in which two teams combat in a standard battlefield have become very popular and further developed into a type of electronic sports (e-sports). Similar to other team sports such as basketball and soccer, more and more professional competitions are taking place and winning becomes increasingly lucrative. As a consequence, research has begun to focus on the competitive characteristic in online games. Carter and Gibbs (2013) studied EVE online which encourages ruthless play styles and unsocial behavior. They discussed how the e-sports version of the game could account for these unique features. Weiss and Schiele (2013) analyzed competitive virtual environments and customer needs. E-sports services are bringing cooperation and competition together. Results show that people are driven by competitive need gratifications (competition and challenge) mainly to use e-sports. Furthermore, e-sport use is also positively affected by hedonic need gratification. However, they found only escapism is a significant predictor; social relationship and fun do not have a significant effect in their study. Gao and colleagues (2013) utilized playing style and performance in the MOBA game Dota 2 to classify the role of a player within the team. Here, also the increasing popularity of e-sports events was discussed.

The rest of the paper is organized as follows: In section 2 we present related work and introduce our hypotheses and research question. In section 3 we provide more details about the game and the data, measurements, and methods that we use for the analysis. In section 4 we discuss models predicting how the multilevel factors influence outcome and in section 5 we discuss models predicting how multilevel factors explain winners based on the duration of matches. In section 6 we sum up the findings and present our conclusions.

THEORIES AND HYPOTHESES

A team can be described as a complex collection of individuals and their interactions. Therefore, many factors influence team processes and their outcomes. Guzzo and Dickson (1996) reviewed the research on groups and teams in organizations and examined factors that influence their effectiveness such as group composition, cohesiveness, leadership, and motivation. Furst and colleagues (1999) further proposed a set of social-psychological factors for effective virtual teams. Extending Hackman's Model of Group Effectiveness to teamwork in virtual environments these factors were classified into the general categories organizational context, group design, group synergy, group process and group material resources.

Based on the literature, we focus on three categories of factors when studying the performance of virtual teams in competitions: *compositional*, *relational* and *team ecosystem*.

Compositional factors represent a collection of attributes of the team members such as individual skills and expertise and lay the foundation for achieving team goals. Relational factors represent the social bonding among team members and facilitate a better collaboration among them. Team ecosystem factors measure inter-team relations and describe the external environment of teams.

The first two categories, i.e., compositional and relational factors, are clearly defined and well characterized in literature. The research on inter-team relations, on the other hand, is limited. To address relations between teams explicitly and to capture their impact on team performance in more detail, we propose team ecosystem factors as a separate category.

Compositional Factors

Considering a team as a collection of individuals, compositional factors measure team members' attributes such as their personal characteristics and their capabilities and knowledge related to team activities. The literature on virtual teams and team performance covers compositional factors in depth; many studies focus especially on task-related individual attributes such as skills or expertise of the team members to illustrate how compositional aspects influence the effectiveness of a team (Cohen & Bailey, 1997; Cooke & Kernaghan, 1987). The impact of task-related compositional factors is straightforward: teams with higher skilled members are more task-cohesive and therefore more likely to succeed than the teams with less competent members.

To form a virtual team in an online game, task-related factors are easier to observe and to verify than demographic information. Therefore, we propose the following hypothesis:

Hypothesis 1. Teams with higher players' skills are more likely to win.

Relational Factors

The importance of relational aspects within teams has been studied for several decades. Balkundi and Harrison (2006) conducted a meta-analysis based on 37 studies to find out whether and how network structure impacts team effectiveness (i.e., team viability and performance). The examinations of hypotheses related to density-performance, density-viability, match of tie content to team outcomes, centrality-performance, and moderating effects of time showed that teams with denser network structures tend to perform better. This is true for both instrumental ties (i.e., ties that emerge from formal relationships) and expressive ties (e.g., ties that reflect friendship); and both types of ties have similar predictive power. Furthermore, teams with denser networks tend to have greater team viability. Again, this is true for both instrumental and expressive ties. However, here expressive ties are a stronger predictor for team viability than instrumental ties. Further analysis considered two distinct aspects of the moderating effects of time. First, it is shown that there is a causal sequencing of network structure and team performance; network structure is antecedent to team performance rather than vice versa. Second, the impact of network structure on performance declines with time; the more the team members get familiar with each other and their tasks the weaker the effect of ties on performance. Thus, overall the meta-analysis showed that network relations clearly impact team performance and team viability.

Maznevski and Chudoba (2000) observed global virtual task teams, their dynamics and their effectiveness in a qualitative study over a period of 21 months. The study revealed that the effectiveness of a global virtual team is related to a series of adequate communication incidents among team members. In a longitudinal study, Lin and colleagues (2005) found a significant positive effect of group work-related relations on team performance at the late group working stage. Pobiedina and colleagues (2013) illustrated the positive effects of players' previous teaming relations and friendship on team's winning chances in the MOBA game Dota 2.

Among social relations, team collaboration history, i.e. previous collaboration relations, was particularly important to explain team performance (Joshi & Roh, 2009). When forming new teams, people often prefer partners they are familiar with from previous work or joint projects. Furthermore, as explained by the "performance-outcome learning" perspective (Schwab & Miner, 2008), previous performance outcomes also influence the chances of future collaboration. Individuals with successful previous collaboration are more likely to team up again in future activities. Prior knowledge reduces uncertainty; prior success increases the social capital of the team members, which in turn enhances the outcome of new collaboration (Amaral & Uzzi, 2007).

Based on this, we propose the following hypothesis to test the effects of intra-team relations on team performance:

> *Hypothesis 2. Teams with players with more previous collaboration ties are more likely to win.*

Team Ecosystem Factors

Teams are not standalone entities in an organization (Ancona & Caldwell, 1992). Teams learn from both internal and external sources (Bresman, 2009) and are influenced by team members' external experiences and relations.

When members of different teams work together, their collaborations establish relationships between these teams, which in turn results in a complex team ecosystem. De Montjoya and colleagues (2014) studied within-team and between-team relationships and their impact on the performance of teams of students. Two types of relations are considered: expressive ties (represented by friendship relations) and instrumental ties (defined by the time collaborators spend in physical proximity). Results show that only the strong ties (expressive as well as instrumental ties) have an impact on the performance of the team and the impact is significant for both within-team and between-team relations. The positive effects of inter-team relations on team performance were also observed for further students' teams (Baldwin, Bedell, & Johnson, 1997), R&D project teams (Wurst, Hoegl, & Gemuenden, 2001), and work groups in organizations (Oh, Chung, & Labianca, 2004).

In a team ecosystem, membership overlap between teams ("structural folding") might significantly contribute to higher performance of a team and creative success (de Vaan, Stark, & Vedres, 2014). Similarly, Burt and Merluzzi (2014) used the concept "network oscillation", defined as an iterative process of deep engagement in a group and brokering across groups, to characterize the network advantage on performance. Inter-team connections form social capital (Burt, 2000) and bring in new knowledge for the teams' benefits (Ramanadhan, Wiecha, Emmons, Gortmaker, & Viswanath, 2009).

If team members have played in many teams with different combination of other players they had the opportunity to learn different approaches and tricks. We propose the following hypothesis:

> *Hypothesis 3. Teams with players who played in many different teams are more likely to win.*

Team Process and Duration

When applying the traditional input-process-output model of team performance, the three categories of factors outlined above refer to the "inputs" to this model. They characterize the essential team attributes and relation patterns. However, to understand how these attributes and patterns actually interact and influence team performance we need to understand the dynamics of the "process" as this phase directly affects the "output".

In previous work, when studying teaming and how different factors influence the outcome, the detailed process of team collaboration has typically depended on the nature of the tasks. We, on the other hand, are focusing on a team-vs-team setting to separate the different processes. In a team-vs-team competition, the overall objective is to defeat the opponent and there is typically no pre-defined task.

The duration of a competition provides an approximate measure of complex interactions during the whole teaming process. We will use this duration to isolate the basic mechanisms of compositional, relational and team ecosystem factors in team collaboration. Therefore, we propose the following research question:

> *RQ1: How do different performance factors change the amount of time a team takes to win?*

METHODS

Dota 2 Game Setting

Dota 2 is a MOBA Game produced by Valve (Valve Corporation, 2014), where two teams, named the Radiant and the Dire, compete against each other. Each of the teams consists of five players and they are located at the opposite corners of the gaming map: Team Radiant at its lower left and team Dire at its upper right (see Figure 1). To win a match, a team has to destroy the opponents' *Ancient*, i.e., a massive structure within a team's stronghold that is guarded by two towers. Although the Radiant side and the Dire side are conceptually the same, there are a number of design differences between them. The environment of team Radiant, for example, is brighter and friendlier than the dark and gloomy environment of team Dire.

Each player controls a character called *hero*. These characters evolve during a match. They acquire experience, which helps them to level up, as well as gold, which can be used for buying items. There exist more than 100 hero characters in Dota 2, each of them with different attributes and abilities and different ways to evolve. This opens up many possibilities and makes the game very complex.

Heroes can die, but revive after a certain period. The length of this respawn time in seconds is computed by *4 x hero level* but can be decreased with gold. Each match starts from scratch and takes on average about 45 minutes. However, there is no fixed length.

In order to ensure a fair match, Dota 2 utilizes a matchmaking system 1) to assign players to a team and 2) to match the opposing teams. Although the detailed algorithm has not been disclosed by Valve, it is known that the matchmaking mechanism strives to match players of similar skills and experiences against each other. The experience of a player is defined by the number of matches the player has played before and the skill measure is related to the performance of the player in those previous matches. However, also other hidden variables are taken into account when assigning the players into the opposing teams (Curse Inc., 2014).

Dota 2 was officially released in July 2013, but before that it had been available as a beta version with limited access since 2011. Dota 2 is a very popular and high-paying e-sports game; already in its beta phase, professional Dota 2 tournaments were taking place.

FIGURE 1

Dota 2 Gaming Environment

Note: Team Radiant is located at the bottom-left; team Dire at the top-right.

Data Samples and Measurements

Based on a game log of all Dota 2 matches in year 2011, we select 64,643 sample matches that were played in the second week of December 2011 (December 8th to 14th). In these matches, moreover, no hero is computer-controlled, each team consists of five human players. Since one central goal of our analysis is to study the impact of different factors on the performance of teams, we want to make sure that the sample matches are completed with a clear winner. As described previously, a match is completed if one team destroys the Ancient of the other team. The two towers guarding this Ancient have to be demolished before the Ancient can be attacked. Thus, we exclude matches where one team wins because the other team abandons the game. Both Ancient towers of the losing team have to be destroyed. With these criteria, we obtain 62,034 matches with a clear winning/losing situation.

For all players and teams in the 62,034 sample matches, we use their activities before December 8th to construct their game statistics and measure their skills, relations and team interactions.

The performance of a team is related to the skills of its members. In the complex and competitive setting of Dota 2 it is important for a team to have the abilities to attack, to defend, and to apply certain strategies to win a match. We relate these abilities to the in-game statistics in the following way: The number of enemy heroes a player kills in a match represents his or her attacking skill. Having a high number of *kills* is relevant since a player gains experience and gold from kills, which increases the chance of winning. The number of times a player's hero gets killed in a match captures his or her defending skill. A player usually strives for having a low number of *deaths* since the player loses a certain amount of gold and has to wait some time to revive. In Dota 2, denying is regarded as a complex cooperation strategy. A player gets a *deny* point if he or

she kills an allied unit before the opponent is able to do so. The deny strategy prevents the enemies from gaining experience and gold.
To capture the skill statistics for each team, we first calculate individual player statistics based on the matches in the previous week and then aggregate at the team level. For example, individual player's kill statistics is the mean of the numbers of kills in his or her previous matches. For each team, the *team kills statistics* (abbreviated as "team kills") is the average of the individual kill statistics of all five team members and measures the overall attack skill of a team. To capture the defence skill, we compute individual player's death rate as the mean of the death-to-kill ratios in his or her previous matches. For each team, the *team death rate* (abbreviated as "death rate") is the average of the individual death rates of all five team members and measures the overall defense skill of a team. Similarly, the *team deny rate* (abbreviated as "deny rate") is the average of the individual deny-to-kill ratios of all five team members and measures the team's ability to apply complex deny strategies.

The *number of previous co-play relations* (abbreviated as "co-play") measures the previous relations among players in a team. A co-play relation between two players is given if they have played together at least twice in all previous matches. The range of the co-play measure is from 0 to 10 in a team of five and more co-play relations imply that the team members are more familiar with each other.

The *number of unique partners* (abbreviated as "partners") measures the overall experience of playing in other teams for all members in a team. For each team we compute the total number of unique co-play partners (other than the current teammates) the five members have played together with in all previous matches; i.e., all unique players that are not in the team to whom the five members have co-play relations.

Note that the skill measures are constructed based on the matches of the previous week to get a more accurate estimation of a player's performance, whereas the co-play and partners measurements are constructed based on all previous matches to detect their potential interactions in the past.

MODELING RELATIVE OUTCOME

Match Categories

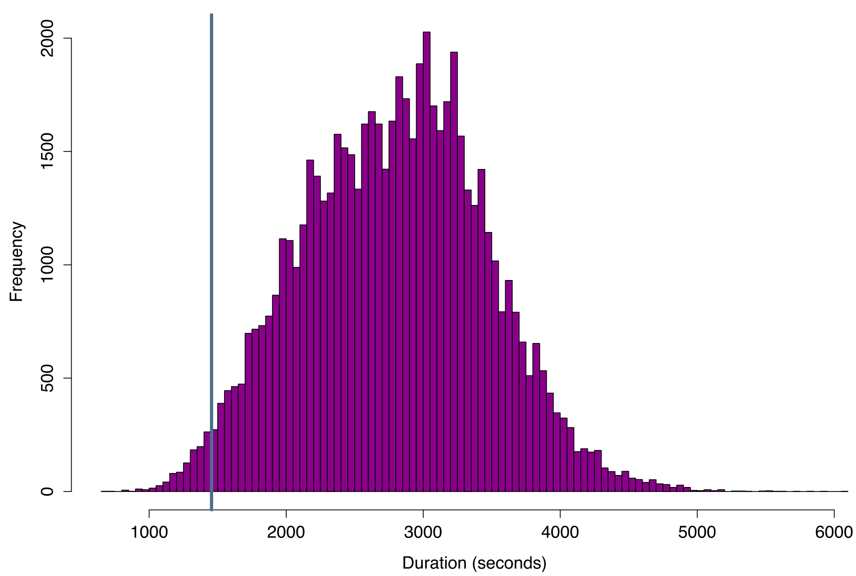
To capture the impact of the compositional, relational and team ecosystem factors on the outcome of a match in this team-vs-team setting, we develop models of relative performance. Therefore, we take the perspective of one team. Thus, the dependent variable shows whether team Radiant beats team Dire in a match. The independent variables capture relative advantages by taking the differences (Δ) in team measurements, i.e., team Radiant minus team Dire. To model the relative outcome, we use binary logistic regression.

One main objective of our analysis is to study the impact of the different factors with regard to the duration of a match. Thus, as a first step we introduce different duration categories to find out whether or not we can find associations between the impacts of the factors and the length of a match.

The distribution of the durations of the 62,034 matches shows that on average a match lasts 2,791 seconds with a standard deviation (SD) of 668 seconds. We define five categories (see Figure 2): short, medium low, medium, medium high, and long duration matches using cut-off points 1455, 2123, 3459, and 4127 seconds (i.e., two SD below the mean, one SD below the mean, one SD above the mean, and two SD above the mean respectively).

FIGURE 2

Five Sample Categories with Different Match Durations



Descriptive Statistics

The correlations between the variables for all matches (N=62,034) are listed in Table 1. We see that the skill measures of a team are all weakly correlated with *Radiant wins*. Teams that have more kills than their opponents also tend to have a higher death rate and a higher deny rate respectively. Furthermore, the number of co-play relations is weakly correlated with the skill measures.

When studying the correlations for the single match categories, the results are quite similar (not shown). This is particularly true for medium low matches and for medium matches. For longer matches, the correlations between *Radiant wins* and the other measures are not significant. Furthermore, the correlation between *Δ co-play* and *Δ partners* is not significant for short and long duration matches.

TABLE 1

Correlations of Variables in Relative Outcome Models

	Radiant wins	**Δ Team kills**	**Δ Death rate**	**Δ Deny rate**	**Δ Co-play**	**Δ Partners**
Radiant wins	1.00					
Δ Team kills	0.02**	1.00				
Δ Death rate	-0.02**	0.31**	1.00			
Δ Deny rate	0.04**	0.20**	0.43**	1.00		
Δ Co-play	0.03**	0.26**	0.23**	0.16**	1.00	
Δ Partners	0.05**	0.13**	0.13**	0.13**	-0.10**	1.00

*Note: N=62,034; * p<0.01; ** p<0.001.*

Table 2 shows the descriptive statistics including means and standard deviations for all team matches as well as the breakdowns of Radiant/Dire teams and winning/losing teams. The average *team kills* are slightly higher for Radiant and for winning teams than for Dire and for losing teams. For winning and losing teams *co-play* is quite balanced. Dire has more co-play relations on average than Radiant. Radiant and winning teams have on average a higher number of unique partners than Dire and losing teams.

TABLE 2

Means and Standard Deviations of Team Statistics

	All Teams	**Team Radiant**	**Team Dire**	**Winning Teams**	**Losing Teams**
Team kills	4.78 (2.52)	4.81 (2.51)	4.75 (2.54)	4.81 (2.52)	4.76 (2.52)
Death rate	1.27 (0.73)	1.28 (0.72)	1.27 (0.73)	1.26 (0.72)	1.28 (0.73)
Deny rate	0.81 (0.63)	0.81 (0.62)	0.81 (0.63)	0.82 (0.63)	0.8 (0.62)
Co-play	1.32 (1.81)	1.09 (1.50)	1.56 (2.04)	1.36 (1.84)	1.29 (1.77)
Partners	12.31 (16.24)	12.74 (16.74)	11.88 (15.72)	12.63 (16.75)	11.98 (15.71)
N	124,068	62,034	62,034	62,034	62,034

The descriptive statistics for the differences in team measures by match category are listed in Table 3. In short and medium low duration matches, team Radiant wins more often than Dire. In medium duration matches it is balanced; and for longer durations Dire predominately wins. Thus the longer the match duration, the fewer matches are won by Radiant. Although it is not known what causes this effect, this early game Radiant advantage is well known by the community (LiquidDota, 2014)

Especially in short duration matches, Radiant has a higher average *team kills* than Dire: in every 3.7 matches, Radiant has one *team kills* more than Dire. For the other duration categories, this measure is more balanced. For *Δ death rate* and *Δ deny rate* there are no big discrepancies between the duration categories. The number of average *co-play* relations is higher for Dire for all durations; however, the longer the duration the bigger the differences. In short duration matches, Dire has on average one more *co-play* than Radiant in one out of three matches. In long duration matches, on the other hand this is the case in one out of two matches. Radiant has more average *partners* in all categories. Here, the differences vary even stronger. For short duration matches, Radiant has on average one more unique partner than Dire in every 0.6 match. For long duration matches it is only one more unique partner every 1.6 matches.

TABLE 3

Means and Standard Deviations of Differences of Team Measures by Duration Category

	Short	**Medium Low**	**Medium**	**Medium High**	**Long**
Radiant Wins	0.56	0.53	0.50	0.47	0.46
Δ Team kills	0.27 (2.38)	0.07 (2.25)	0.06 (2.30)	0.02 (2.39)	-0.03 (2.45)
Δ Death rate	0.03 (0.84)	0.01 (0.82)	0.01 (0.84)	0.01 (0.85)	0.01 (0.87)
Δ Deny rate	0.00 (0.61)	0.01 (0.63)	0.00 (0.63)	-0.01 (0.64)	0.01 (0.64)
Δ Co-play	-0.33 (2.2)	-0.44 (2.25)	-0.48 (2.2)	-0.46 (2.25)	-0.49 (2.25)
Δ Partners	1.68 (16.69)	1.41 (16.05)	0.77 (13.38)	0.55 (11.65)	0.64 (10.77)
N	1,078	9,489	41,830	8,285	1,352

Models and Results

Table 4 shows three models for short duration matches with different sets of measures in order to illustrate the prediction power of compositional, relational and team ecosystem factors. The first model includes compositional measures and studies the impact of player skills on the team outcome. Here, *Δ death rate* and *Δ deny rate* are significant. Teams with a higher death rate than their opponents are less likely to win. A difference of one in the team *death rate* leads to a 70% odds ratio to win in a short duration match. On the other hand, teams with a higher *deny rate* than their opponents, are more likely to win. Here, a difference of one in the team deny rate leads to a 168% odds ratio to win. The second model in Table 4 contains in addition the relational measure *co-play*. This measure is significant; teams with more co-play relations than their opponents are more likely to win. One more *co-play* leads to a 109% odds ratio to win. Both *Δ death rate* and *Δ deny rate* are still significant; and the coefficients of these measures are almost the same as in the first model. The third model comprises all three types of measures, i.e., compositional, relational and ecosystem. We see that *Δ partners* is significant. Teams with more outside partners than their opponents are more likely to win in a short duration match. One more partner in one team leads to a 102% odds ratio to win. However, also *Δ death rate, Δ deny rate* and *Δ partners* are still significant; and the coefficients of these measures do not change a lot. For all three models the intercept term is positive and significant whereas *Δ team kills* is not significant in any of these models. The variance that is explained increases from 4% in the first model to 5.1% in the second and 7.8% in the third model.

TABLE 4
Relative Outcome Models for Short Duration Matches

Hypotheses	**Measures**	**Compositional**	**Compositional + Relations**	**Compositional + Relations + Eco-system**
H1: Skills (attack)	Δ Team kills	0.01 (.03)	0.00 (.03)	-0.02 (.03)
H1: Skills (defense)	Δ Death rate	-0.44** (.09)	-0.47** (.09)	-0.50** (.09)
H1: Skills (strate-gy)	Δ Deny rate	0.52** (.12)	0.51** (.12)	0.47** (.12)
H2: Relations	Δ Co-play		0.09* (.03)	0.10** (.03)
H3: Team	Δ Partners			0.02** (.00)
	Intercept	0.26** (.06)	0.29** (.06)	0.28** (.06)
	R^2	**0.040**	**0.051**	**0.078**
	N	**1,078**	**1,078**	**1,078**

*Note: * p<0.01; ** p<0.001.*

In summary, to win quickly (i.e., in a short duration match), it is an advantage for a team to consist of players who have better defense skills than their opponents, are able to apply complex strategies, have co-play experience within the team and a higher number of outside partners. In terms of variance explained, relational and the team ecosystem measures are as important as the compositional measures.

For all the other duration categories we applied the same stepwise procedure and compared the three types of models (here, we only list the results of the third models comprising compositional, relational and team ecosystem measurements – see Table 5).

The variable *Δ team kills* is not significant in most of the cases. Only in medium duration matches a small advantage can be observed; one more average *team kills* leads to a 101% odds ratio to win. The measure *Δ death rate* has a significant negative impact for medium duration matches and below. The shorter the duration, moreover, the higher this impact: a difference of one in the average *death rate* leads to a 61%, 73% and 88% odds ratio advantage to win in short, medium low and medium duration matches respectively. The measure *Δ deny rate* has a positive impact for all but long duration matches. Also here, the impact is strongest for short durations and decreases with duration category: a difference of one in the average team *deny rate* leads to a 160%, 138%, 117% and 112% odds ratio to win in short, medium low, medium and medium high duration respectively.

The measure *Δ co-play* has a significant positive impact in medium and shorter duration matches: One more co-play relation than the opponent leads to a 111% (short duration), 109% (medium low duration) and 102% (medium duration) odds ratio to win. Further, the measure *Δ partners* has a significant positive impact in short, medium low and medium duration matches; one more unique partner than the opponent leads to a 102% (short duration), 101% (medium low duration) and 101% (medium duration) odds ratio to win. The intercept term is significant for short, medium low and medium high duration matches; in the first two cases it is positive and in the latter it is negative. The amount of variance that is explained by the models is very modest: 7.8% for short duration, 4.4% for medium low duration, 0.7% for medium duration, 0.3% for medium high duration and 0.5% for long duration matches.

Clearly the outcome is harder to predict the longer the duration of the match. Especially for medium high and long duration matches the outcome is highly unpredictable. As the duration gets longer, it appears that random effects (or at least effects not accounted for in our model) determine who will win.

TABLE 5

Relative Outcome Models for All Duration Categories

Hypotheses	**Measures**	**Short**	**Medium Low**	**Medium**	**Medium High**	**Long**
H1: Skills (attack)	Δ Team kills	-0.02 (.03)	0.02 (.01)	0.01* (.00)	-0.01 (.01)	0.00 (.02)
H1: Skills (defense)	Δ Death rate	-0.50** (.09)	-0.31** (.03)	-0.13** (.01)	-0.07 (.03)	-0.07 (.07)
H1: Skills (strategy)	Δ Deny rate	0.47** (.12)	0.32** (.04)	0.16** (.02)	0.11* (.04)	-0.03 (.10)
H2: Relations	Δ Co-play	0.10** (.03)	0.09** (.01)	0.02** (.00)	0.02 (.01)	0.06 (.03)
H3: Team	Δ Partners	0.02** (.00)	0.01** (.00)	0.01** (.00)	0.00 (.00)	0.00 (.01)
	Intercept	0.28** (.06)	0.16** (.02)	0.00 (.01)	-0.12** (.02)	-0.13(.06)
	R^2	**0.078**	**0.044**	**0.007**	**0.003**	**0.005**
	N	**1,078**	**9,489**	**41,830**	**8,285**	**1,352**

*Note: * p<0.01; ** p<0.001.*

A stepwise regression for medium low duration matches shows that the explained variance increases from 2% for a model that contains only compositional measures, to 2.8% for a model with compositional and relational measures to 4.4% for the full model which includes also ecosystem effects. As in the case of short duration matches, the two sides – compositional measures on the one side and relations plus team ecosystem measures on the other side – have similar contributions. For medium duration models the explained variance equals 0.5% for a model with only compositional measures and does not increase when adding the co-play measure. However, in the full model it increases to 0.7%

Summing up, hypotheses H1 (defense and strategy), H2 and H3 are confirmed for short duration matches, medium low duration matches and medium duration matches. In order to win, a team should have the skills to protect itself and to apply complex strategies. Furthermore, it is a clear advantage if the members share prior co-playing experiences and if they have played in the past on other teams with more unique other partners. Hypothesis H1 (attack) is only significant in medium duration matches.

Relations and team ecosystem have a slightly higher impact in short duration than longer duration matches. That is, they are more likely to help teams win more quickly. However, if a team does not win quickly, the skills differential between the teams gains increasing importance. This is consistent with (Balkundi & Harrison, 2006) since results of their meta-analysis showed that the impact of relations on performance decreases as the team members get familiar with each other and their tasks.

For matches that last very long, none of the factors are significant and predicting the outcome is not possible.

MODELING DURATION

Performance and Duration

In previous section we show that compositional, relational and team ecosystem factors influence the outcome of a match in each duration category in a different way. Now we want to establish the association between the factors and the duration of a match more explicitly to understand the mechanisms and dynamics of the teaming process better.

We choose the duration of a match in seconds as the dependent variable. The independent variables are the metrics associated with whichever team won as well as the differences (Δ_W) in metrics between the winning team and the losing team. We use linear regression to estimate the effects of these metrics on the duration of the game.

Insert Table 6 (Page 20) about here

Descriptive Statistics

The correlations between all dependent and independent variables are listed in Table 6. The skill measures of a winning team are moderately correlated. Also the number of co-play relations is moderately correlated with the skill measures. The number of unique partners of a winning team is moderately correlated with the winning team kills and deny rate and weakly correlated with its death rate and the number of co-play relations. The differential measures are all moderately correlated with the corresponding main effect measure, i.e., *winner team kills* with *Δ_W team kills*, *winner death rate* with *Δ_W death rate*, *winner deny rate* with *Δ_W deny rate*, *winner co-play* with *Δ_W co-play*, and *winner partners* with *Δ_W partners*. The duration of a match is weakly correlated with most of the variables. Whether or not Radiant wins is weakly negatively correlated to the difference in the number of co-play relations of the winning team and the losing team; i.e., if the winning team has more co-play relations than the losing team it is less likely that Radiant won.

Models and Results

Table 7 shows the two Models. In Model 1 we include the compositional, relational and team ecosystem metrics of the winning team. We also add *Radiant wins* as a control variable, to capture which team succeeded. In Model 2, we include the differences in the metrics for the difference in compositional, relational and ecosystem factors between the winning and losing team.

TABLE 7

Models for Duration

Measures	**Duration Model 1**	**Duration Model 2**
Radiant wins	-51.54** (5.37)	-60.13** (5.43)
Winner Team kills	5.60** (1.48)	8.99** (1.94)
Winner Death rate	44.60** (4.77)	28.38** (6.10)
Winner Deny rate	-19.35* (5.92)	-0.91 (8.01)
Winner Co-play	-0.42 (1.66)	12.20** (2.27)
Winner Partners	-5.97** (0.19)	-7.51** (0.24)
Δ_W Team kills		-5.86** (1.58)
Δ_W Death rate		14.60* (4.64)
Δ_W Deny rate		-25.20** (6.22)
Δ_W Co-play		-13.86** (1.74)
Δ_W Partners		2.23** (0.24)
Intercept	2825.88** (6.65)	2822.19** (7.40)
R^2	**0.023**	**0.027**
N	**62,034**	**62,034**

*Note: * p<0.01; ** p<0.001.*

The results for Model 1 indicate that overall team Radiant tends to spend 51.54 seconds less to win than team Dire; according to Model 2 it is 60.13 seconds. Teams with higher *team kills* spend more time to win and a higher team kills of one in both teams leads to an 8.99 seconds longer match when the difference between the teams remains constant (i.e., *winner team kills* is increased by one and Δ_W *team kills* remains the same). On other hand, the differential advantage over the opposing team reduces the winning time and one kills advantage leads to a 5.86 seconds shorter match. Teams with a higher *death rate* spend more time to win. A higher *death rate* of one in both teams (i.e., *winner death rate* is increased by one and Δ_W *death rate* remains the same) in a match leads to a 28.38 seconds longer match; if *death rate* of a team increases by one compared to the other team (i.e., Δ_W *death rate* is increased by one and *winner death rate* remains the same), the team needs 14.60 seconds more to win. Teams with a higher *deny rate* spend less time to win. A team that has a higher *deny rate* of one compared to the other team spends 19.35 seconds less to win. In the second model, only the differential effect is significant, not the main effect. Each additional co-play relation on the winning team (i.e., *winner co-play*) leads to a 12.20 seconds longer match; Each additional co-play relation the winning team has more than the losing team (i.e., Δ_W *co-play*) results in 13.86 seconds less to win. Winning teams with external unique partners spend less time to win but the differential advantage increases the time it takes to win.

FINDINGS AND CONCLUSIONS

In this study we explored the impacts of different types of team factors on performance and duration of matches in a team-vs-team setting. These factors were related to players' skills (compositional), co-play relations (relational) and partnerships with players on prior teams (team ecosystem). We proposed that teams are more likely to win if they have higher players' skills (H1), if they share more previous co-playing experiences (H2) and if they comprise players who played in many different teams before (H3). To test these hypotheses we introduced five match categories. These categories were based on the distribution of the duration of the matches. For short, medium low and medium duration matches all hypotheses were supported. However, relations tend to have a stronger impact for short duration matches whereas skills are especially important for medium duration matches. For longer matches the outcome is basically unpredictable. They might represent tie situations where random effects decide on winning and losing. Alternatively, they might be explained by additional variables not included in our model.

We find different patterns of impact mechanisms of the three performance factors on the time it takes for a team to win. The compositional and relational factors have the same patterns: high levels of skills and previous collaboration in the winning team lead to a longer match and differential advantages of one team over the other lead to a shorter match. On the other hand, the team ecosystem factor has an opposite pattern: when members of the winning team played in many different teams, they tend to finish the game faster; matches where the winning team has a higher differential of external partners will take a bit longer to win.

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TABLE 6

Correlation of Variables in Duration Models

	1	2	3	4	5	6	7	8	9	10	11
1 Duration	1.00										
2 Radiant Wins	-0.04**	1.00									
3 W Team kills	-0.03**	0.02**	1.00								
4 W Death rate	0.01*	0.01**	0.56**	1.00							
5 W Deny rate	-0.06**	0.02**	0.59**	0.55**	1.00						
6 W Co-play	0.00	-0.13**	0.43**	0.35**	0.38**	1.00					
7 W Partners	-0.14**	0.05**	0.46**	0.25**	0.50**	0.17**	1.00				
8 Δ_W Team kills	-0.01*	0.03**	0.46**	0.18**	0.09**	0.15**	0.05**	1.00			
9 Δ_W Death rate	0.01*	0.01**	0.15**	0.56**	0.23**	0.14**	0.06**	0.31**	1.00		
10 Δ_W Deny rate	-0.02**	0.00	0.10**	0.25**	0.52**	0.10**	0.05**	0.20**	0.43**	1.00	
11 Δ_W Co-play	-0.01	-0.21**	0.13**	0.14**	0.09**	0.64**	-0.04**	0.25**	0.23**	0.15**	1.00
12 Δ_W Partners	-0.04**	0.06**	0.09**	0.09**	0.10**	-0.04**	0.48**	0.13**	0.13**	0.13**	-0.11**

*Note: N=62,034; *p<0.01; **p<0.001; "Winner" is abbreviated as "W".*