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The Influence of Communication and Support Networks on Leadership and Team Dynamics in Massively Multiplayer Online Games

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Abstract

Observing the interactions that take place between group members teaches much about the dynamics that occur in teams. Social network analysis (SNA) provides the tools that help scientists to better understand how teams function internally and reveal how these patterns influence the effectiveness and success of groups. Communication, leadership, and support networks play a particularly important role in network based team research. Measures of density, centrality, and centralization have been found to be the most relevant patterns in this field. However, as leadership patterns are considered, core-periphery structures are increasingly coming into focus. How best to apply and combine these network patterns to make predictions about team outcomes and leadership structures is the central question addressed in this thesis. The second central question of this thesis is whether the behavior of players in the virtual worlds of MMOGs is able to reflect human behavior in the real world (mapping principle). Drawing on two extensive datasets from the game Travian, we are able to show that it is possible to predict team success and identify leadership structures with a network-based machine learning approach. Based on an extensive literature review, we are also able to show that the relationships between intra-team interaction patterns and team success observed in our case study are consistent with the interdependencies identified in meta-studies of real-world work teams. Due to the small number of studies conducted to date, the question of whether findings from MMOG-based research can be generalized to real-world settings has remained largely unanswered. Thus, our study provides further scientific evidence that human behavior in a virtual online gaming context does not necessarily differ from behavior in traditional offline contexts. However, our case study also confirms once again that it is imperative to take into account the circumstances and incentive structures of the respective virtual world when conceiving the research design. Given these limitations, we conclude that MMOGs should continue to be used as useful research environments for the study of human behavior. In addition, our two proofs of concept for potentially predicting team success and identifying the best performing players laid the groundwork for future work in this area. In summary, the results and case studies of this dissertation show the possibilities, as well as the restrictions, that MMOG game worlds like Travian, with their large amounts of interaction data, are able to offer to the research community. So far, no reliable trend has emerged to indicate whether these new research environments will be widely applied in all kinds of research disciplines in the long run, or whether research in MMOGs will remain a niche for the particularly technology-savvy field of computer science.

Zusammenfassung

Die Beobachtung der Interaktionen zwischen Gruppenmitgliedern gibt Aufschluss über die Dynamik, die in Teams herrscht. Die Analyse sozialer Netzwerke (SNA) liefert die Instrumente, die Wissenschaftlern helfen, besser zu verstehen, wie Teams intern funktionieren, und aufzuzeigen, wie diese Muster die Effektivität und den Erfolg von Gruppen beeinflussen. Kommunikations-, Führungs- und Unterstützungsnetzwerke spielen in der netzwerkbasierten Teamforschung eine besonders wichtige Rolle. Messungen der Dichte, Zentralität und Zentralisierung haben sich als die relevantesten Muster in diesem Bereich erwiesen. Bei der Betrachtung von Führungsmustern rücken jedoch zunehmend Kern-Peripherie-Strukturen in den Fokus. Wie diese Netzwerkmuster am besten angewendet und kombiniert werden können, um Vorhersagen über Teamergebnisse und Führungsstrukturen zu treffen, ist die zentrale Frage dieser Arbeit. Die zweite zentrale Frage dieser Arbeit ist, ob das Verhalten von Spielern in den virtuellen Welten von MMOGs in der Lage ist, menschliches Verhalten in der realen Welt zu reflektieren (Mapping-Prinzip). Anhand von zwei umfangreichen Datensätzen aus dem Spiel Travian können wir zeigen, dass es möglich ist, mit einem netzwerkbasierten maschinellen Lernansatz Teamerfolg vorherzusagen und Führungsstrukturen zu identifizieren. Basierend auf einer umfangreichen Literaturrecherche können wir zudem zeigen, dass die in unserer Fallstudie beobachteten Zusammenhänge zwischen teaminternen Interaktionsmustern und Teamerfolg mit den in Metastudien zu realen Arbeitsteams identifizierten Interdependenzen übereinstimmen. Aufgrund der geringen Anzahl der bisher durchgeführten Studien blieb die Frage, ob sich die Erkenntnisse aus der MMOG-basierten Forschung auf reale Situationen verallgemeinern lassen, bisher weitgehend unbeantwortet. Unsere Studie liefert daher weitere wissenschaftliche Belege dafür, dass sich menschliches Verhalten in einem virtuellen Online-Gaming-Kontext nicht unbedingt von dem Verhalten in traditionellen Offline-Kontexten unterscheidet. Allerdings bestätigt unsere Fallstudie auch einmal mehr, dass es unabdingbar ist, die Umstände und Anreizstrukturen der jeweiligen virtuellen Welt bei der Konzeption des Forschungsdesigns zu berücksichtigen. In Anbetracht dieser Einschränkungen kommen wir zu dem Schluss, dass MMOGs weiterhin als nützliche Forschungsumgebungen für die Untersuchung menschlichen Verhaltens genutzt werden sollten. Darüber hinaus haben unsere beiden Konzeptnachweise für die potenzielle Vorhersage des Teamerfolgs und die Identifizierung der leistungsstärksten Spieler den Grundstein für zukünftige Arbeiten in diesem Bereich gelegt. Zusammenfassend lässt sich sagen, dass die Ergebnisse und Fallstudien dieser Dissertation die Möglichkeiten Möglichkeiten, aber auch die Einschränkungen, die MMOG-

Spielwelten wie Travian mit ihren Spielwelten wie Travian mit ihren großen Mengen an Interaktionsdaten der Forschungsgemeinschaft zur Verfügung stehen. Bislang hat sich noch kein verlässlicher Trend abgezeichnet, ob diese neuen Forschungsumgebungen langfristig in allen möglichen Forschungsdisziplinen eingesetzt werden, oder ob die Forschung in MMOGs eine Nische für den besonders technikaffinen Bereich der Computerwissenschaften bleiben wird.

Publications

Table 1: Peer-reviewed core publication basis of this dissertation

No.	Year	Authors	Title	Venue/Journal
1	2020	Siegfried Müller, Raji Ghawi and Jürgen Pfeffer	Using Communication Networks to Predict Team Performance in Massively Multiplayer Online Games	ASONAM
2	2022	Siegfried Müller, Raji Ghawi and Jürgen Pfeffer	Identifying Power Elites in Massively Multiplayer Online Games by Applying Machine Learning to Communication and Support Networks	ASONAM
3	2023	Siegfried Müller, Raji Ghawi and Jürgen Pfeffer	Reviewing the potentials of MMOGs as research environments: A case study from the strategy game Travian	PLoS ONE

Table 2: Other peer-reviewed publication basis of this dissertation

No.	Year	Authors	Title	Venue/Journal
1	2021	Raji Ghawi, Siegfried Müller and Jürgen Pfeffer	Improving team performance prediction in MMOGs with temporal communication networks	Social Network Analysis and Mining

Table 3: Talks and Presentations

Date	Title	Venue
February 21, 2020	Performance Prediction in MMOGs	TUM Course: Presenting Papers and Posters
November 17, 2020	Social Networks in MMOGs	TUM Course: Präsentieren von Konzepten in digitaler Landschaft
December 9, 2020	Using Communication Networks to Predict Team Performance in Massively Multiplayer Online Games	The 2020 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining
November 12, 2022	Identifying Power Elites in Massively Multiplayer Online Games by Applying Machine Learning to Communication and Support Networks	The 2022 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining

Contents

Chapter 1

Introduction

"Networks are at the core of all organizational life" (Nohria and Eccles 1992). It is with this statement that Nohria and Eccles introduce their book "Networks and Organizations". The reason they attribute this great importance to networks is that these, formed by the connections between individual actors, create patterns that both drive and constrain group action. These patterns can reveal whether a group or organization is working together effectively, making it possible to predict whether it will succeed or fail. The basis for the identification of these patterns is network data, which is the result of interactions between group members.

In particular, communication and support networks are powerful in unveiling "how work really gets done in organizations" (Cross and Parker 2004). They help us to answer the question of what the optimal interaction network of a high-performing team looks like (Bavelas 1950; Monge and Contractor 2003; Zenk et al. 2010). For this purpose, a large number of different approaches have been investigated over the past few decades (Borgatti and Foster 2003). The most common view is that effective collaboration in a group is characterized by two factors: (1) The way the group is led and capable of coordinating itself, and (2) the way resources flow within the group.

The first aspect, the leadership structure within a group, can be best represented by a continuum from hierarchical to distributed leadership (Pearce and Conger 2003a). This concept stands in stark contrast to the traditional view of leadership (Lord et al. 2017). "Historically, leadership has been conceived around a single individual - the leader - and the relationship of that individual to subordinates or followers. [...] This relationship between the leader and the led has been a vertical one of top-down influence. As a result, the leadership field has focused attention on the behaviours, mind-sets, and actions of "the leader" in a team or organisation"(Pearce and Conger 2003a).

In contrast to this, the concept of *shared leadership* defines it as "a dynamic, interactive influence process among individuals in groups for which the objective is to lead one another to the achievement of group or organizational goals" (Pearce and Conger 2003a). The exercise of shared leadership is reflected in a number of activities carried out by the various members of the team. The decisive factor here is that shared leadership means interacting with others in the group. It manifests itself in behaviors such as communicating, influencing, making suggestions, and holding people accountable (Aime et al. 2014). From this perspective, "shared leadership entails a simultaneous, ongoing, mutual influence process within a team that is characterized by "serial emergence" of official as well as unofficial leaders" (Pearce and Barkus 2004). In order to take into account this new approach to the distribution of the leadership task within the team, it is necessary to be able to operationalize it.

For this purpose, Mayo et al. 2003 developed a network-based model that allows us to map the extent to which leadership within a team is concentrated in a single central actor (decentralization). Simultaneously, they take into account the density of leadership relationships within the group. This combination has made it possible for the first time to apply network data to the identification of (shared) leadership structures. The model was originally based on leadership networks, which can only be collected through traditional surveys. Since these were difficult to operationalize, communication networks were introduced as an alternative (Monge and Contractor 2003). Researchers have noted that by applying various relational theories, leadership can be viewed as socially constructed through the exchange of communication (Cullen-Lester et al. 2017). This is especially important because leadership is inextricably linked to communication among group members (Ahuja et al. 2003). This is particularly of relevance since communication has always been understood as the core element of any group (Sarker et al. 2011). In addition, there is another very practical reason for using communication networks. Unlike the traditional collection of network data via surveys, communication networks can be collected very easily and non-obstrusively via the use of electronic communications such as email (trace data). The studies that are part of this dissertation have also taken advantage of this.

Support networks, on the other hand, are particularly well suited to represent the results of these coordination processes, and therefore allow us to track whether a group has been able to achieve the desired goals. However, they have been used in very few cases in network-based team research (White et al. 2016). Therefore, in this dissertation, we have developed a number of concepts and tested them in the context of the prediction of team success. The combination of communication networks with support networks seems to have particular potential (multiplexity) (Contractor et al. 2012). The same applies to the time-sensitivity analysis of cause and effect of the above-mentioned network patterns on the success of team collaboration. However, there is still a lot of ground work to be done here, which means that these areas are primarily of interest for future work.

As a new innovative experimental laboratory for the above-described possibilities of analyzing team structures, Massively Multiplayer Online Games (MMOGs) have increasingly come into focus in recent years (Castronova 2005; Ducheneaut 2010; Assmann et al. 2010b; Wigand 2018). Especially in the field of network analysis, quite a number of studies have been published demonstrating the potentials of MMOGs as research environments (Shim et al. 2010; Szell and Thurner 2010; M. Zhu et al. 2013; Fuchs and Thurner 2014; Corominas-Murtra et al. 2014; Hajibagheri et al. 2018). The two predominant research questions of these mostly exploratory studies were: (1) How best to apply and transform the vast amounts of raw data (secondary data) so that they can be used in appropriate research designs? (2) Do the behavioral patterns observed in trace data of MMOGs correspond to those of human behavior in the real world? This dissertation is also devoted to these two sets of issues.

The structure of this work is therefore as follows: The theoretical foundations of the interplay between social dynamics in teams and the influence of leadership on team performance are discussed in section 2. Section 3 looks at different ways of mapping these dynamics using the toolbox of social network analysis. The use of MMOGs for this type of research will be the subject of a discussion in Section 4. In addition, the history of the emergence of this relatively new field is discussed in detail. Further, this section provides insight into how the research used in this paper came to exist. In addition to describing data collection, this section also discusses the extraction and processing of raw data from game database. For a better understanding of this data, a short introduction to the game world of the MMOG Travian is also given here. Section 5 provides a list of the published peer-reviewed publications that form the basis of this dissertation. Section 6 concludes with a summary of achievements and contributions. In addition, there will be a discussion of the obstacles and limitations which have become apparent in the course of the work. An outlook for future work and a conclusion conclude this paper.

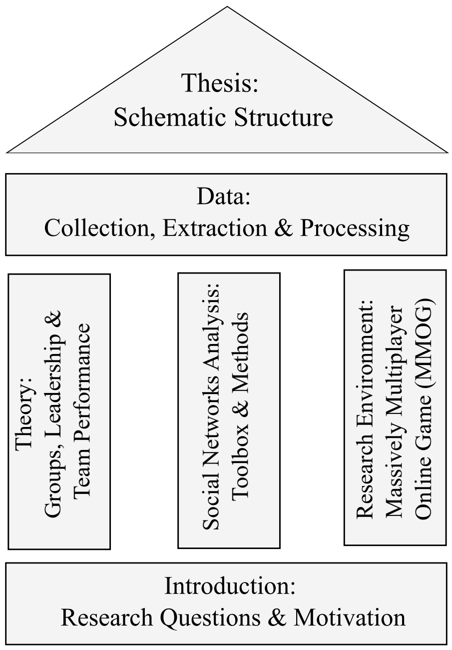

Figure 1.1: Schematic diagram of the dissertation

Chapter 2

Intra-team dynamics and team performance

2.1 Performance: Exploring what makes teams successful

The question of what distinguishes an average team from those that achieve the extraordinary has always been one of the central questions in research on groups and organizations (Goodman et al. 1997; Hackman 1987; Shea and Guzzo 1987; Bettenhausen 1991). Therefore, an important goal throughout the history of organizational research has been "to identify the factors and processes that give rise to increased group performance" (Beal et al. 2003). It is therefore no coincidence that "performance is the most widely studied criterion variable in the organizational behavior and human resource management literatures" (Bommer et al. 1995) and thus the construct validity of performance measures is of high importance. However, a look at the theoretical literature shows that a "global conceptualization" of the construct performance is hard to find (Campbell et al. 1993). Starting with a basic consensus, scholars therefore proposed the view that "teams exist to perform tasks" (Mathieu et al. 2008) by regarding a "task" as "virtually any task that the culture views as having value" (Campbell et al. 1993). This shift in view led to a new perspective in which performance can alternatively be seen as a *behavior* (Campbell et al. 1993; Beal et al. 2003; Mathieu et al. 2008; Kozlowski and Bell 2012). Along these lines, Campbell et al. introduced the construct of *performance as behavior* whose measure is an evaluation of actions or behaviors relevant to the achievement of group goals (Beal et al. 2003). Simultaneously, they considered *performance as an outcome* when the measure represents the consequences or results of performance behavior. This split of the construct of *performance* into *behavior* (performance as doing) and *outcome* (results of actions) laid the foundation for the development of the concept of *team effectiveness* that became "the core focus of theory and research on teams and all topics addressed" (Kozlowski and Bell 2012). *Performance efficiency* was thus defined as "the effectiveness of a group with some consideration of the cost of achieving that level of effectiveness, that is, a ratio or factoring of inputs relative to outputs" (Beal et al. 2003). Potential inputs are usually interpreted in a very broad way (Gist et al. 1987; Mcgrath 1991; Beal et al. 2003), "including time, effort, and other resources expended, as well as number of errors made and relative size of the group" (Beal et al. 2003).

A pioneering work in this respect has been the review articles written in recent years by Koslowski and Bell. At the time of their original review in 2003, “most models of team effectiveness were loosely formulated around the Input–Process–Outcome (IPO) framework posited by McGrath (1964)” (Kozlowski and Bell 2012).

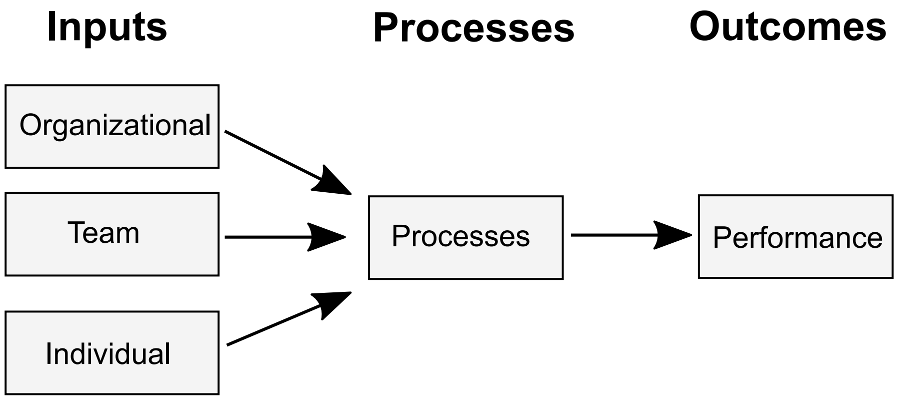

Figure 2.1: Input-Process-Outcome (IPO) Team Effectiveness Framework - adopted model by Mathieu et al. 2008

Other researchers have built on this work. In this respect, Mathieu et al. 2008 conclude that the IPO model “has served as a valuable guide for researchers over the years, but it has also been modified and extended in several ways”. Others emphasize that IPO models have been critiqued for failing to differentiate between different types of processes and outcomes (Ilgen et al. 2005). These team processes are of importance because they describe the interactions of team members focused on task accomplishment and thus represent how the team’s input is transformed into results. Some examples for those processes are: cooperation, relationships and task conflicts (Mathieu et al. 2008). Earlier work again classifies these processes into the categories: *influence* (facilitation, social impact, loafing), *development* (identification, team development), and *decision making* (participation, information generation, alternative evaluation, consensus building) (Gist et al. 1987). Or more generally: “Processes represent mechanisms that inhibit or enable the ability of team members to combine their capabilities and behavior” (Kozlowski and Bell 2012).

Regarding inputs, a common classification is following the different organizational levels: *organization*, *team* and *individual*. Further, inputs are typically divided into *internal* and *external* input factors (Kozlowski and Bell 2012). Some examples of internal input factors are: skills, abilities, personalities, composition of knowledge, group structure and team design. Examples for external input factors are: rewards, training, or organizational climate. Beyond that, later works have introduced other input factors as *psychological safety* (Edmondson 1999; Zohar 2000; Gilson et al. 2015), *emergent states* (Wang et al. 2014; Mathieu et al. 2017), *shared mental models* (Mathieu et al. 2000; Levesque et al. 2001; DeChurch and Mesmer-Magnus 2015; Lungeanu et al. 2022), *trust* (Mayer et al. 1995; Colquitt et al. 2007; Costa et al. 2018), and *leadership* (Goodman et al. 1997; Hoch and Kozlowski 2014; Lord et al. 2017).

2.2 Processes: The interaction of team members

Team processes are of particular importance, as they describe the interactions between members that are geared towards the fulfillment of tasks. They can therefore be seen as interdependent actions of members that transform inputs into outcomes through cognitive, verbal, and behavioral activities aimed at organizing work to achieve collective goals (Marks et al. 2001). These individual socio-psychological processes can manifest as group, subunit, and organizational phenomena and are reflected in models of organizational behavior (Kozlowski and Klein 2000).

Historically, team processes have been categorized as either *task work* or *teamwork*. Essentially, taskwork refers to the functions that individuals perform to accomplish the team's task, while teamwork refers to the interactions between team members (Mathieu et al. 2008). Further, "taskwork communication involves exchanging task-related information and developing team solutions to problems. Teamwork communication focuses on establishing patterns of interaction and enhancing their quality" (Kozlowski and Bell 2012).

In their original 2003 review, Kozlowski et al. identified three broad, observable process mechanisms that influence team effectiveness: (a) coordination, (b) cooperation and (c) communication. They differ in that coordination involves a temporal component that is not an essential part of cooperation or collaboration, and that communication is a means of enabling coordination or cooperation (Kozlowski and Bell 2012).

These three main mechanisms play a central role in this dissertation's investigation of individual interaction patterns. Above all, the flow of communication within the group proved to have a major impact on the success of the team and its predictability (Müller et al. 2020). In turn, the patterns showing how mutual support took place in the team proved to be suitable for representing the success and thus the result of the coordination measures (Müller et al. 2023).

2.3 Input factor: Organizational

"Organizations are multilevel systems". This axiom, which can be considered as the foundation of "virtually all contemporary theories of organizational behavior" (Kozlowski and Klein 2000), is of great importance in understanding how human collaboration works. The system is divided into *organizational*, *group*, and *individual* levels, with each level falling under the purview of different disciplines, theories, and approaches (Kozlowski and Klein 2000). In their updated review of working groups and organizations Kozlowski and Bell summarize: "*Teams don't behave, individuals do; but they do so in ways that create team-level phenomena. Individuals are nested within teams, and teams in turn are linked to and nested in a larger multilevel system. This hierarchical* *nesting and coupling, which is characteristic of organizational systems, necessitates the use of multiple levels — individual, team, and the higher level context*" (Kozlowski and Bell 2012). Figure 2.2 depicts the multi-level approach proposed by Scott-Young et al. that simultaneously considers all three nested levels of functioning: Micro (individual), Meso (team and project), and Macro (organization).

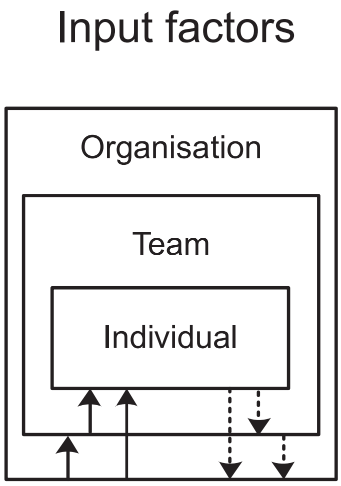

Figure 2.2: Illustration of input factors from multi-level systems model in work teams proposed by Scott-Young et al. 2019

Kozlowski and Klein 2000 go on to conclude that this broader system imposes top-down constraints on how well teams perform. At the same time, team reactions are complex bottom-up phenomena that emerge over time from individual perceptions, affect, behavior, and interactions among members in the team context.

In the context of this dissertation, the organizational perspective, which in this model is hierarchically subordinate to the team perspective, plays only a minor role. This is due to the limitations of the research environment used rather than the lack of relevance. In our applied virtual research environment, collaboration between individuals plays a critical role at the team level, while collaboration and interdependence between groups is more peripheral.

2.4 Input factor: Team

The most frequently studied input level, and the focus of this dissertation, is that of *teams* or *groups*. They are the vital link between individuals and organizations (Mathieu et al. 2017). Therefore, researchers refer to teams as the central building blocks of organizations, embedded in an open but bounded system of multiple, nested levels (Kozlowski and Bell 2012). Systematic research in this area goes back at least as far as the Hawthorne studies of the 1920's and 1930's. From the 1990s to the present, the scope of research and the types of topics addressed by the research on groups have expanded significantly. During this period, the focus shifted from individuals within teams or comparisons between individuals to a focus on the team itself and larger team systems (Mathieu et al. 2017).

Over time, various definitions of work groups or teams have emerged.[1] An established definition is that of Kozlowski and Bell 2012. According to them, work teams and groups are defined by the collection of the following characteristics: They (a) consist of two or more individuals, (b) who exist to perform organizationally relevant tasks, (c) share one or more common goals, (d) have task interdependencies (i.e., workflow, goals, knowledge, and performance), (e) interact socially (face-to-face, virtually), (f) maintain and manage boundaries, and (g) are embedded in an organizational context that sets boundaries, constrains to the team, and influences interactions with other units in the larger entity. These individual points are discussed in more detail below.

2.4.1 Membership and team size

Teams vary greatly in nature, depending on the number of members (Caplow 1957). It is therefore impossible to examine the membership and the size of the team separately. This creates a compelling need to account for variable team size when designing a study dealing with teams or groups (Kozlowski and Klein 2000). Two appropriate options here are to include team size as a control variable or to compare only groups of similar size.

This is especially important because small groups and large groups have very different characteristics, strengths, and weaknesses (Slater 1958). Larger teams, for example, draw on more resources such as time, energy, money, and expertise that can facilitate team performance on more difficult tasks (Hill 1982). They also tend to survive longer (Gist et al. 1987). Other researchers have clearly shown that larger teams tend to be more dysfunctional than smaller teams. Further they found differences in leadership patterns, conflict resolution, and engagement across teams of different sizes (Pearce and Barkus 2004; Slater 1958; Gist et al. 1987). Due to these existing trade-offs, the prevailing opinion in the literature is that it is impossible to define the one optimal team size, as it always depends on the appropriate type and purpose of the team (Pearce and Barkus 2004).

In the context of this work, the wide variety of group sizes in the already existing dataset posed a major challenge. It included group sizes ranging from 2 members (very small teams) to 60 members (large teams), representing the full range normally used in team research (Müller et al. 2023). Thus, it became apparent that the possibility of using group size as a control variable quickly reached its limits. In contrast, combining groups of similar size and sub-datasets proved to be more helpful. However, it should be noted that data point sizes were often very small, limiting the ability to perform some

1. While these two terms were initially used differently, in recent years the consensus has developed to use these two terms symonymously (Sundstrom et al. 2000; Mathieu et al. 2017).

types of analysis.

2.4.2 Performing tasks

"Teams exist to perform tasks" (Mathieu et al. 2008). This simple statement, combined with the fact that the performance of these tasks must be important to the organization, lays the foundation for the raison d'être of any workgroup. The nature of these tasks varies widely, depending on the goals of the group (Hackman and Walton 1985). One of the most important classifications in the literature of organizational behavior is that of *creative tasks* versus *routine tasks* (Mathieu et al. 2017). This distinction is important because there is evidence that task heterogeneity in work teams is more desirable in the creative environment of project teams than in the routine environment (Stewart 2006).

An extended classification of team tasks comes from Sundstrom et al. 2000, who lists several categories, including:

- Generating solutions versus Executing action plans (McGrath 1984)
- Technical versus Interpersonal demands (Herold 1978)
- Difficulty (Shaw 1981)
- Number of desired outcomes and trade-offs between them (Campbell 1988)
- Intermember communications (Naylor and Dickinson 1969)
- Fulfilling coordination requirements (Nieva et al. 1983)
- Task divisibility (Steiner 1972)
- Subtask demands (Roby and Lanzetta 1958)

Keeping these different dimensions in mind is important because maximizing the combination of capabilities of group members as a whole is a key leadership task and central to maximizing the performance of the group (Zajonc and Smoke 1959).

In the context of this dissertation, there are a number of standardized tasks that must be completed by study participants (players). In addition, there are a number of game specific tasks that relate to communication, as well as leadership and coordination of the group. Participants in the MMOG environment are free to perform these tasks as desired. In the same way, the groups can decide for themselves how to distribute the pre-defined tasks among themselves.

2.4.3 Shared goals

The role that shared goals play in the formation of a group can best be understood by looking at the stages of Tuckman's theoretical model of team development (Tuckman 1965). The idea behind this is that a group's efforts to create a structure to govern its interpersonal interactions are motivated by progress toward the goal (Kozlowski and Bell 2012). Tuckman describes this in terms that goal setting can be seen as a phase in which the group unites and is characterized by a common goal and group spirit (Tuckman 1965). In the theoretical model of the team life cycle, this is reflected in the goal-setting phase, which involves clarifying the team's goals (general and specific), defining subtasks, and establishing schedules (Sundstrom et al. 1990).

In the research environment of this thesis, goals also play a central role in forming alliances. On the one hand, groups protect their members from external threats (especially other groups and individuals); on the other hand, the game environment specifies goals and tasks that can only be achieved collectively.

2.4.4 Task interdependence

A key characteristic of a team is that its members have different skills. Especially when executing the more demanding, non-routine tasks, the combination and coordination of these skills is one of the most important prerequisites for mastering complex tasks. A central assumption is that the individual contributions of the specialized team members (accomplished tasks) cannot be performed in parallel or independently of each other (Sundstrom et al. 2000). This interdependence of group members distinguishes a collection of individuals from a work group. Therefore, scholars note that the "recognition of the central importance of the team workflow, and the task interdependence it entails, to team structure and process is a [...] key characteristic of the organizational perspective on work groups and teams" (Kozlowski and Bell 2012).

In the MMOG research environment, which is the data base for this work, there are a number of clearly defined tasks to be performed by each participant. In principle, the tasks that the participants have to accomplish are the same for all of the participants. However, each participant has the opportunity to specialize in the tasks that best suit his or her personality and preferences. This results in a specialization and thus a task-related dependence of the individual group members on each other. Coordinating these well is ultimately the job of the leaders of each team.

2.4.5 Social interaction and virtuality

The social interaction among team members is an important feature of teams, as normative expectations, shared perceptions, and compatible knowledge emerge and are created through them (Kozlowski and Bell 2012). Conversely, the interactions between members of a work team are significantly influenced by the resulting workflow structures that link individual contributions, outcomes, and goals (Steiner 1972). McGrath 1984 summarizes this dual relationship as follows: "The group interaction process itself is both the result of these shaping forces and the source of some additional forces".

Interactions can occur in a variety of ways. Kozlowski and Bell 2012 define three types of interactions that are of particular relevant in the context of this work: (a) determining the flow of activities, (b) exchange activities, and (c) communication (Kozlowski and Bell 2012).

Communication plays a central role here, as it can take place both virtually and in person. This is especially important since *team virtuality* plays a crucial role in the context of this dissertation. While traditional organizational research has generally assumed that members interact in direct face-to-face exchanges, technological developments in recent years have significantly changed this.

To better distinguish these new types of collaboration (especially virtual team collaboration) from traditional ways of working, Bell and Kozlowski 2002 developed a framework. The core of this classification that is (a) spatial distance and (b) information, data, and personal communication is shown in Figure 2.3.

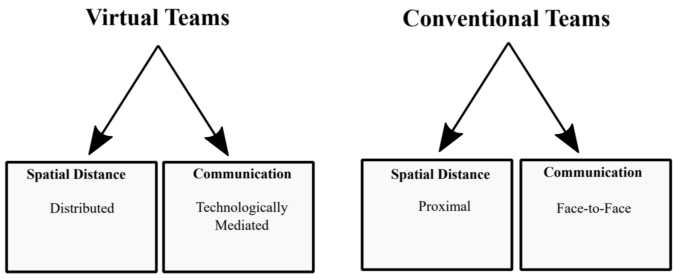

Figure 2.3: Characteristics that differentiate virtual teams from conventional teams taken from Bell and Kozlowski 2002

With this theoretical background, the research environment used for this thesis can be classified as a virtual environment.

2.4.6 Team boundaries

Team boundaries are essential to the team formation process for a variety of reasons. The most important aspect is that from an ecological perspective, boundaries both separate and connect work teams within their organizations (Sundstrom et al. 2000). Further, clarity and stability of boundaries play an important role in distinguishing members from non-members and in defining the scope of a team (Wageman et al. 2012). Sundstrom et al. 2000 state that “group boundaries are difficult to describe concisely, because they subsume so many aspects of the relationship of group and organization”. Therefore, they propose the definition that boundaries (a) differentiate a work unit from others (Cherns 1976), (b) pose real or symbolic barriers to access or transfer of informarion, goods, or people (Katz 1978), (c) serve as points of external exchange with other teams, customers, peers, competitors, or other entities (Friedlander 1987).

Alderfer notes that boundaries are, at least in part, a definition of how a group must operate in its context in order to be effective. If the boundary is too open or unclear, the team runs the risk of becoming overwhelmed and losing its identity (Alderfer 1987).

Boundaries help define what constitutes team effectiveness in a particular context (Sundstrom et al. 2000). Finally, boundaries are essential for research in teams because they often change their composition over time for a variety of reasons (Mathieu et al. 2017). This can include changes in team size as well as in member characteristics.

In the context of this work, boundaries play a crucial role as they allow us to capture the individuals involved as they interact within the alliances. Two key challenges play a role in this: One is the fact that team members can join or leave an alliance at any time. Second, for reasons of practicality, data must be aggregated over specific time periods. These two aspects imply that the observed groups are not stable in their composition (no clear demarcation), resulting in smaller - but not negligible - biasing effects.

2.4.7 Organizational context

A final characteristic of work teams is that they do not operate in isolation, but that the context (organizational ecosystem) in which they operate plays a formative role. In this sense, Sundstrom et al. write: “Besides doing its task, a work team has to satisfy requirements of the larger system and maintain enough independence to perform specialized functions (Berrien 1983). So one key aspect of the group-organization boundary is integration into the larger system” (Sundstrom et al. 2000).

This larger system is characterized by a number of dimensions. In their *ecological framework for the analysis of work team effectiveness*, they specify the following elements that shape such an organizational context:

- Organizational Culture
- Task design/technology
- Mission clarity
- Autonomy
- Performance feedback
- Reward/recognition
- Training & consultation
- Physical environment

Within the game environment, which is the basis of this work, there are always clusters of alliances, which form so-called meta-alliances. In absolute terms, however, this is the exception rather than the rule and therefore only represents a marginal aspect. In terms of how they are organized, most teams operate completely independently. Thus, the framework conditions described here and the integration into higher-level organizational structures do not play a relevant role in the data used here.

2.5 Input factor: Individual

When it comes to the role of individuals in organizations, scholars distinguish between the *micro* and *macro* perspectives. The *macro perspective* is rooted in its origins in the sociological sciences. “It assumes that there are substantial regularities in social behavior that transcend the apparent differences among social actors. Given a particular set of situational constraints and demographics, people will behave similar” (Kozlowski and Klein 2000). It is therefore possible to focus on aggregate responses and ignore individual differences. The *micro-perspective*, on the other hand, is rooted in psychology. “It assumes that there are variations in individual behavior, and that a focus on aggregates will mask important individual differences that are meaningful in their own right” (Kozlowski and Klein 2000). The focus, therefore, is on the variations in individual traits that affect the responses of individuals.

The levels approach creates a more integrated view by combining micro and macro perspectives. In this context, House et al. 1995 suggest the term *meso* to capture this alternative perspective.

Another question that a theoretical multilevel model needs to address is how the phenomena at the different levels are related to each other. These connections can be made from *top down* or from *bottom up.* Kozlowski and Klein 2000 point out that a variety of the theories will include both top-down and bottom-up processes:

(1) Top-down processes: Each level of an organizational system has a higher-level context, or is part of a higher-level context. Top-down processes show how higher contextual factors influence lower levels of the system.

(2) Bottom-up processes: Many organizational phenomena have their theoretical origins in how individuals perceive, affect, behave, and act. Through social interaction, exchange, and reinforcement those emergent properties manifest at higher levels.

The data set that was used for this thesis contained almost no data at the individual level. Only the interactions between individuals were available. Demographic or psychological profiles of individual actors were not available at all. For this reason, the analyses of this dissertation were primarily focused on the *macro view. Bottom-up processes* have also been studied. Network analysis proved to be an excellent tool for this purpose. This is explained in more detail in the following chapter.

Chapter 3

Organizational Network Analysis

3.1 Social Network Analysis (SNA): An alternative approach toward understanding team processes and success

Beginning with early work by authors such as Stogdill and Shartle 1948, Bavelas 1950, or Shaw 1955, researchers started to explore the potential of the emerging field of social network analysis (SNA) to learn more about how work groups function and succeed. Since these early days, interest in the application of SNA to team research has grown consistently. To illustrate this, Figure 3.1 shows how the number of publications in this area has developed in past years.

Building on this rapidly growing body of research, a number of metastudies (Mullen et al. 1991; Balkundi and Harrison 2006; Burke et al. 2006; Wang et al. 2014; Nicolaides et al. 2014; D'Innocenzo et al. 2016) and conceptual reviews (Krackhardt and Hanson 1993; Monge and Contractor 2003; Borgatti and Foster 2003; Carter et al. 2015; J. Zhu et al. 2018) have demonstrated that network structures have a significant influence on the functioning and success of teams.

The initial conceptional idea behind the SNA approach is that "actors, whether they are individuals, groups, or organizations, do not exist in isolation. Rather, individuals are embedded in networks of relationships that likely affect important outcomes" (Brass 2018). "In particular, social network structures, or the patterns of informal connections (ties) among individuals, can have important implications for teams because they have the potential to facilitate and constrain the flow of resources between and within teams" (Balkundi and Harrison 2006).

The social network approach offers a number of advantages to traditional approaches of analysis. Cross and Parker 2004 for example point out that researchers focusing on the informal social contexts (i.e. social networks) can examine "how work really gets done in organizations" because those informal networks tend to shadow formal required interactions (Brass 2011).

Technically, research on teams has focused on a set of network indices that are supposed to reflect important group characteristics affecting performance. A special role thereby play, the three most frequently used network indices: (1) node *centrality*, (2) network *density*, and (3) network *centralization* (Grosser et al. 2019).

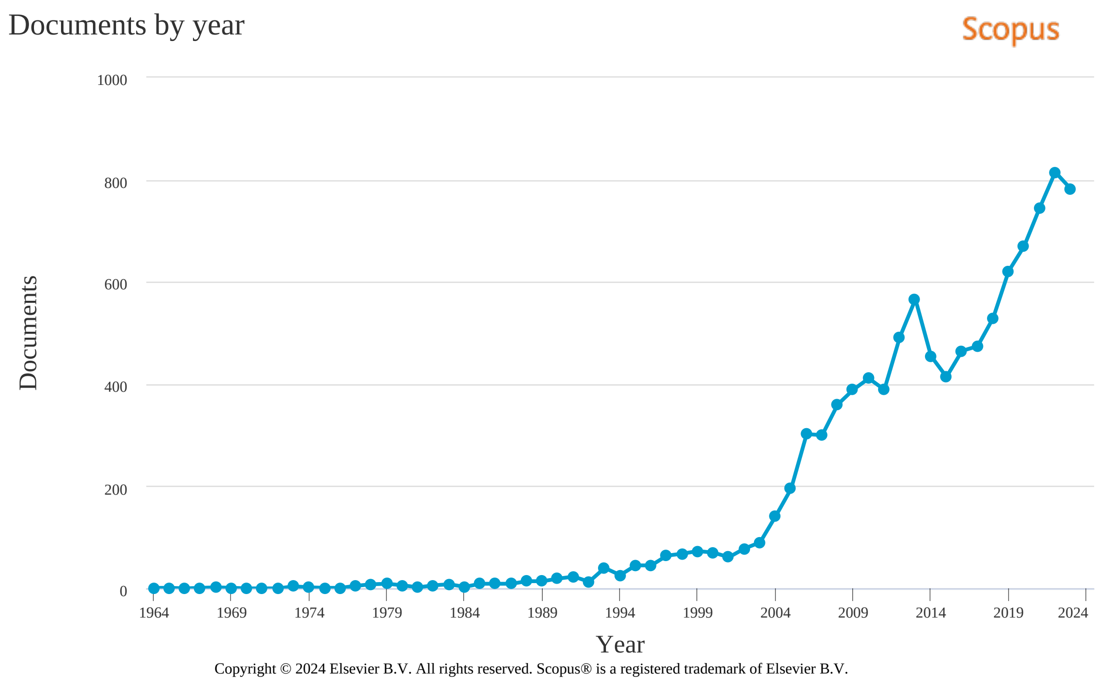

Figure 3.1: **Publications in social network research on team performance**: Keyword search in Scopus covering the period from 1964 to 2023, using the keywords: network, team or group, and performance or effectiveness from the domains social science, psychology and business.

The most popular network measure, applied in 26.9% of the studies, is *centrality*, "with indegree centrality being the specific measure most often examined" (Grosser et al. 2019). In summary, research has found that team members with high indegree centrality (e.g., in advice networks) tend to have higher levels of individual performance (Sparrowe et al. 2001). Furthermore, a meta-analysis has shown that "centrality of a team's formal leader in a team's informal social network is positively associated with team task performance" (Balkundi and Harrison 2006). Others have found that central team members (indegree) who show high levels of helping behavior are associated with better team processes and higher team performance (Li et al. 2015). However, several findings also show that a high indegree centrality in negative tie networks leads to a reduction in the influence and acceptance of a leader and thus indirectly causes a negative effect on group performance (Chiu et al. 2017; Balkundi et al. 2011).

The network feature with the second highest popularity in network-based team studies (17.9%) is *density* (Grosser et al. 2019). Again, meta-analytic results indicate that network density is in general positively related to team performance (Balkundi and Harrison 2006). Tie content plays an important role in the effect of density. While the density of positive ties (e.g., advice, communication, friendship, or workflow) is generally regarded as having a positive effect on performance (Balkundi and Harrison 2006; Cross et al. 2008), negative ties (e.g., avoidance, obstruction, or hostility) are associated with a negative effect on team outcomes (Sparrowe et al. 2001; Chiu et al. 2017). Cross et al. 2008 therefore conclude that "from a pure performance perspective, strengthening networks isn't about simply increasing interactions; it's a product of increasing productive interactions and reducing unproductive ones". These general principles are contrasted with some exceptions. One such example is that a high level of social relationships in work groups (group cohesion) can lead to a certain degree of insularity, as members of densely networked teams are less inclined to seek knowledge from external sources (Oh et al. 2004). Such effects then in turn tend to have a negative influence on group outcomes. Finally, leadership plays an increasingly important role when it comes to dense relationships in teams. For example, Zhang and Peterson 2011 found that the team leader's transformational leadership exerts a significant effect on team density in advice networks. This mediation mechanism in turn positively influences the team's performance.

Although with 7.9% of the published studies (Grosser et al. 2019) the network measure *centralization* plays an important role, the results of the numerous works are notably contradictory. The reason for the varying effects of centralization on team performance seems to have its origin in the different nature of the ties. Researchers have therefore opted to use multilevel models to combine and explore how each level may relate to each other (Monge and Contractor 2003). Further, it appears that team member turnover, team composition, knowledge distribution, and situational demands factors seem to influence this relationship (Grosser et al. 2019). Therefore, the results of the mentioned studies are more consistent when considering the influence of the centralization of the network as that of a moderator. An interesting example of this is the role of generalists. Huang and Cummings 2011 compared the performance of teams composed of generalists (i.e., having the same broad knowledge) with the performance of teams that had unique knowledge distributed among specialists. They found that in teams composed of specialists, performance was higher in the case of decentralized networks. In the case of teams consisting of generalists, however, the degree of network centralization had almost no influence on team performance.

3.2 Structural patterns in the study of leadership and elites

The idea of what it means to lead a group or an organization has constantly changed in past years. In their conceptual review about the evolution of leadership research, Lord et al. 2017 identify various waves. Initial areas of interest were general leadership problems and the personality of the leader. In particular, analyses were carried out to determine whether certain groups of characteristics are associated with leadership qualities (Flemming 1935). Other researchers focused on intelligence and individual differences. Of particular note here is the work of Terman 1916, who was the developer of the Stanford-Binet intelligence test, which was used to test officers in the Army Alpha project. Based on this, procedures were developed to classify personnel and define leadership duties as well as responsibilities for various positions (Lord et al. 2017).

An important shift in focus was introduced by Stogdill and Shartle 1948, who proclaim that "leadership is not a unitary human trait, but is rather a function of a complex of individual, group, and organizational factors in interaction". They further argue that "leadership must, therefore, be studied as a relationship between persons" (Stogdill and Shartle 1948). This expanded view is reflected in Yukl's leadership model, which considers the reciprocal effects of leader and follower behavior (Yukl 2012a). The model also takes into account the character traits of both the leader and the followers, as well as the context in which the leadership takes place. Figure 3.2 illustrates these relationships by means of a slightly modified model.

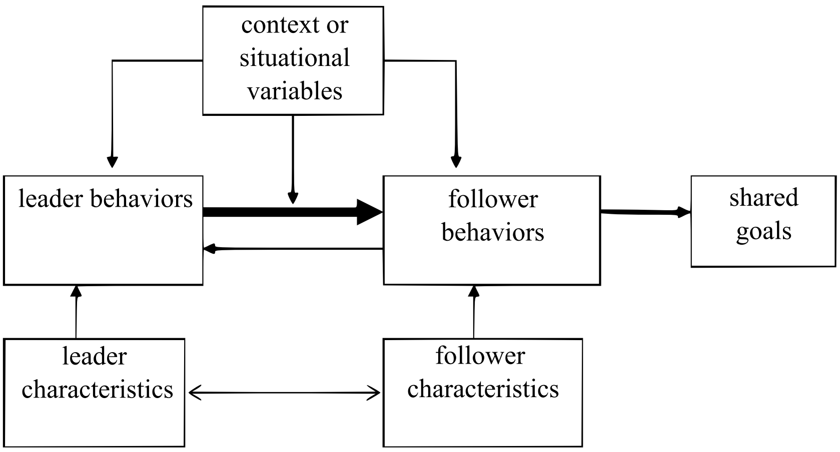

Figure 3.2: Causal relationships among the primary types of leadership variables - adopted model by Drath et al. 2008

This alternative view increasingly put in the spotlight on *what leaders do* instead of *who they are* (Lord et al. 2017). As a consequence, this raised the question of what should be the specific tasks that leaders should perform. Cullen-Lester et al. 2017, for instance, consider it as an important aspect of leaders' tasks "to understand, leverage, and modify the structures of relationships surrounding themselves and connecting members of the groups they lead in order to meet organizational needs".

It was this more contextual approach that brought social network analysis into play in the study of leadership. The idea behind this "network perspective" is that the traces of the activities performed by leaders and their followers (social ties) can be found as unique patterns in the team (leadership) networks (Carter et al. 2015). In turn, leadership ties shape social ties. White et al. 2016 therefore point out that "it is important to recognize that leadership influence and [social] ties are unlikely to occur independently of each other". To better illustrate this interdependence, the theoretical framework introduced by Carter et al. 2015 on "*Leadership in and as Networks*" is quite helpful."

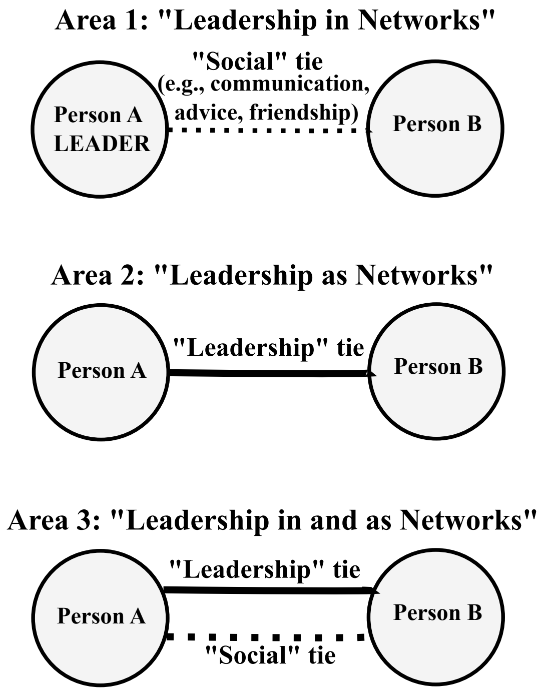

Figure 3.3: **Framework by Carter et al. 2015**: The role of dyadic building blocks of networks in leadership emergence.

With this structural approach they offer a "distinction between research that positions social network ties in the foreground, using them to explain individuals' emergence and effectiveness as leaders, and research that positions leadership network ties (distinct from other social network ties) in the foreground to understand leadership network emergence and effectiveness" (Carter et al. 2015).

Given this theoretical background, the question arises which specific structural patterns can be best applied to identify leadership influence. A look at the SNA-based leadership literature shows that the most extensive body of research deals with *leader's centrality*, followed by the concept of *shared leadership* (Balkundi and Harrison 2006; Grosser et al. 2019). Another promising, but far from popular, approach to identify leadership in teams is that of core-periphery structures (Borgatti and Everett 1999).

According to Yukl 2012b, one way to approach the construct of leadership is to conceptualize it in terms of *influence*. Following this approach, a leader's influence within their organization can be best represented through the concept of *centrality*. Brass 1984 notes in this regard that actors "occupying central positions in a network are viewed as potentially powerful because of their greater access to and possible control over relevant resources". Further, several scholars have demonstrated that taking central positions in social networks predicts later occupancy of a formal leadership position (Collier and

Kraut 2012; Parker and Welch 2013; Cullen-Lester et al. 2017). In addition, research has shown that it is related to group effectiveness (Mehra et al. 2006; Balkundi and Harrison 2006). A variety of ways of measuring centrality have emerged. The three most prominent metrics are: (1) degree, (2) betweenness centrality, and (3) closeness centrality (Brass 1984).

"Degree centrality refers to the number of links that a person has with other members of the group" (Mayo et al. 2003). This individual level information about an actor is of particular importance because "central positions are often associated with power and influence" (Brass and Burkhardt 1992). Betweenness was introduced by Freeman 1979 and "refers to the extent to which a point falls between pairs of other points on the shortest path connecting them" (Brass 1984). The betweenness of a point measures the extent to which an actor (broker) has potential control over others (Burt 1992). The third measure closeness, "is generally calculated by summing the length of the shortest paths from one point to all other points" (Brass 1984). This degree of proximity can be conceptualized as the extent to which an actor can avoid control by others (independence) or the extent to which an actor can reach all other actors in the shortest number of steps (efficiency) (Freeman 1979).

The leadership concept that was studied second most is that of *shared leadership*. Introduced by Pearce and Conger 2003b it argues that "leadership is an activity that can be shared or distributed among members of a group or organization" (Pearce and Conger 2003b). In their network-based approach, Mayo et al. 2003 recommend combining the two network indices *centralization* and *density*. This combination in which "dense networks imply greater numbers of interactions among members of the network [and] centralization refers to the degree to which all members of the network are unequally central in the network" (Mayo et al. 2003) allows a classification into four different levels of shared and vertical leadership (see Fig. 3.4).

Quadrant I is characterized by low density and high decentralization (low centralization). The resulting *low shared leadership* is characterized by an egalitarian exercise of influence at a low level.

Quadrant II represents the highest level of shared leadership. Here, both a high density and a high degree of decentralization can be observed. Mayo et al. 2003 note that in this case "team members attribute high influence to one another in an egalitarian way and perceive high degrees of power and influence in the team".

Quadrant III represents low levels of density and decentralization. This reflects the interesting case where no leadership is exercised at all within a team and members work independently without coordination.

Quadrant IV with high density and low degree of decentralization (high centralization) represents strong leadership in a very hierarchical way.

The model of distributed leadership presented here has been further developed in several areas. Contractor et al. 2012, for example, extended this model by offering a topology for the pattern or form of distributed leadership. Furthermore, some recent

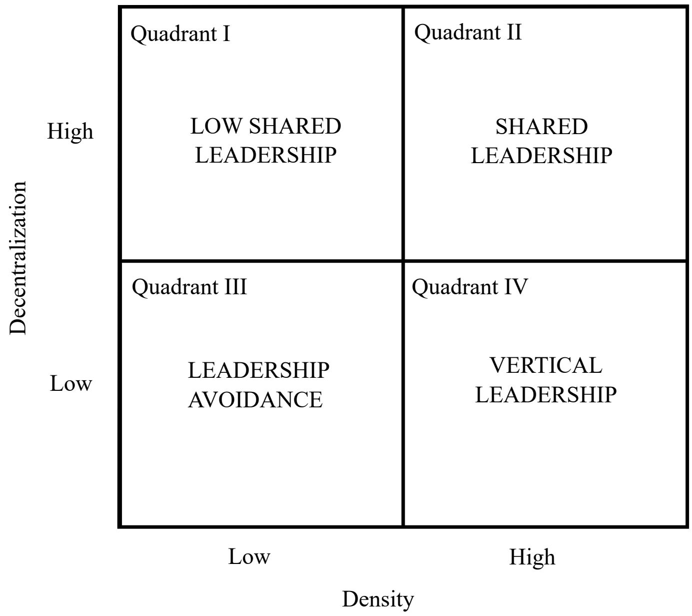

Figure 3.4: **Classification by Mayo et al. 2003**: Degrees of shared and vertical leadership

meta-studies have recommended the use of the underlying methodology (Nicolaides et al. 2014; Wang et al. 2014; D'Innocenzo et al. 2016). In particular, some were able to show that "both network density and (de)centralization approaches to the study of shared leadership–performance relations exhibited significant and higher effect sizes than did the aggregation-based studies" (D'Innocenzo et al. 2016).

Beyond that there are also important criticisms of the concept. Some scholars, for example, have warned to ignore formal leaders in studies of shared leadership (Pearce et al. 2008; Hernandez et al. 2011). Others point out that in the case of low network centralization scores, the results could refer to two competing situations (J. Zhu et al. 2018). This contradiction arises from the fact that while a decentralized network may not have a unique leader, this does not automatically mean that leadership is shared across the team (D'Innocenzo et al. 2016).

A relatively new approach is the study leadership in core-periphery organizations (Hoppe and Reinelt 2010; Brass 2011; Carter et al. 2015). This concept is based on the intuitive notion that groups consist of a dense, connected *core* and a sparse, disconnected *periphery* (Borgatti and Everett 1999). In combination with the idea that "leadership broadly distributed among a set of individuals instead of centralized in hands of a single individual who acts in the role of a superior" (Pearce and Conger 2003b), the study of this densely connected core offers various new opportunities for the exploration of leadership dynamics. To formalize this intuitive concept, Borgatti and Everett 1999 developed a set of algorithms that are able to identify the underlying *core/periphery* structures. Another concept that allows to divide a group into a cohesive core and the periphery is that of the k-core. This concept was introduced by Seidman 1983 and bases to the idea that “a k-core is a subgraph in which every actor has degree k or more with the other actors within the subgraph” (Borgatti et al. 2018). Based on these formalizations, groups can now be divided into “a group of people in positions of influence within an organization” (Collier 2012) (elite subgroup) and the periphery of less influential but possibly skilled actors (e.g., potential specialists). In this regard, Cross et al. 2002 see it as the job of leaders to integrate underutilized experts who are on the periphery of the network by helping them make the connections they need to be effective. “In reality, both clique and core-periphery structures exist, and in combination, they look a lot like organizational charts with an elite, central core of high-level managers and the peripheral actors grouped together in functional, clique-like departments with few connections across departments” (Brass 2018). The possibility of mapping reality, through core-periphery structures, therefore offers an opportunity to better understand and utilize collective leadership.

3.3 Interaction networks: Informal connections and what they are able to unveil

When it comes to understand what is really going on in organizations or teams, the potentials of informal interaction networks come into play. In their book, Cross and Parker 2004 present “the hidden power of social networks” and discuss how they can be applied to make invisible work visible. Further, the describe the principles by which these interaction networks influence teams’ performance. In particular, they highlight the benefits that organizational leaders can derive from using Social Network Analysis. In this regard, they note: “Getting an accurate view of a network helps with managerial decision making and informs targeted efforts to promote effective collaboration. Rather than leave the inner workings of a network to chance, executives can leverage the insights of a social network analysis to address critical disconnects or rigidities in networks and create a sense-and-respond capability deep within the organisation” (Cross and Parker 2004).

When it comes to how organizations can benefit from this potential, they can draw on the findings of many years of research. A number of research streams dealing with different types of networks have emerged over the past decades. Actors within these networks may be connected in various ways, such as through communication, giving or receiving advice, or through the flow of resources such as information or money (Borgatti et al. 2009; Brass 2018). From the popularity point of view, the most studied tie contents in organizational research are: *communication* (16.5%), *advice* (15.8%), *workflow* (13.3%), and *friendship* (9.0%) (Grosser et al. 2019)[1]. Leadership relationships

1. Based on a sample of 492 journal articles from network-based team research over the past 25 years

are also a frequently studied tie content (Sparrowe 2014). This type of tie is primarily intended to map influence relationships between social actors, as these are "at the core of the leadership process" (Mayo et al. 2003). Some scholars go so far as to say that already the network of relationships itself can be regarded as a form of leadership (Carter and Dechurch 2012; Contractor et al. 2012; Friedrich et al. 2016).

When it comes to the impact of the network relationships, the type of the connection plays a decisive role. Both *positive networks* (e.g., friendship or advice networks) and *negative networks* (e.g., avoidance or hindrance networks) have an influence here. Chiu et al. 2017 found out that "managers who are central in the advice network are socially powerful and are seen as leaders by individual followers. In contrast, managers who are avoided by followers lack informal social power are not seen as leaders." White et al. 2016 therefore note that informal networks "can serve to support an organization and provide additional backstage support to formal leadership relations; however, they can also undermine the authority of formal leaders if the two are disconnected". Thus, Jokisaari 2016 concludes that from the social network perspective "leaders' ability to acquire resources depends on not only their formal position but also their informal relations within and outside the organization".

Another important tie content is communication. "Communication networks serve as an effective model of teams exchanging information over telecommunication systems, of computer-mediated communication systems, and of hierarchically structured organizations" (Mullen et al. 1991). This is of particular importance because various *relational theories* have described the leadership relationships as socially constructed through the exchange of communication (Hosking 1988; Dachler and Hosking 1995; Uhl-Bien 2006; Drath et al. 2008; DeRue and Ashford 2010; Cullen-Lester et al. 2017). Especially for illustrating shared leadership, communication is of great importance. Friedrich et al. 2016, for example, "describe [communication] as a "prerequisite" for understanding the problem that the team is facing, defining shared goals, understanding where the relevant expertise lies in the network, and sharing the leadership role."

Whereas communication networks are primarily concerned with transferring information, support networks involve exchanging resources. This exchange of resources can take the form of the transfer of tangible goods (e.g. raw materials or money) as well as intangible goods (e.g. advice or friendship). However, the primary focus of support networks is the interpersonal relationships developed through the exchange of resources. In a recent review of the *networking literature*, this exchange was identified as a key mechanism by which networking behaviors enable individuals to achieve effective outcomes (Porter and Woo 2015; Cullen-Lester et al. 2017).

The bottom line is that you can only understand what's happening in teams by looking at how the individual members interact with one another. The social network perspective enables these insights and therefore makes it possible to better understand teams and how they work together.

Chapter 4

Research in the Travian universe: history, game description and data collection

4.1 The history of MMOGs as research environments

The first papers exploiting the potential of MMOGs as research environments were published in the early 2000s. In these early years, especially researchers from the disciplines of computer science, engineering, mathematics, and social sciences were engaged in the exploration of these newly emerging virtual worlds. Most of this work was presented at computer science conferences (e.g., ACM International Conference, Conference on Human Factors in Computing Systems, IEEE Global Telecommunications Conference)[1]. But also some influential textbooks were published at this time. In 2005, Castronova published his landmark book, which primarily describes his own research experiences from *EverQuest* (Castronova 2005). Moreover, he describes in depth the nature of these virtual worlds and the players who populate them. Other researchers, in turn, focused their work on what constitutes a gamer and how they differ from non-gamers (Beck and Wade 2004). The virtual worlds that researchers mostly studied in the early era were *Ultima Online, Everquest, Lineage, Second Life, Dark Age of Camelot*, and *Star Wars Galaxies* (Castronova 2005). Later research focused on games like *World of Warcraft, Everquest II, Eve Online, Travian*, or *Pardus* (Yee 2006; Assmann et al. 2010b; Ducheneaut 2010; Wigand 2018).

As we can see in Figure 4.1, after the turn of the millennium, research in the MMOG field quickly gained in popularity. Leading scholars predicted a bright future for the research. For example, Bainbridge wrote in a Science article that "for at least a decade, experimentalists in the social and economic sciences have looked to the Internet as a mean of expanding the scope of their research, and virtual worlds may finally turn hopes into opportunities" (Bainbridge 2007). However, it quickly became apparent that the high expectations the research community had for the new research environment were not being fulfilled as expected. Following the high point of the research in 2012, interest increasingly waned.

The reason for this was that during this initial euphoria, it became clear that these

1. Information based on a Scopus search using the keyword "MMOG"

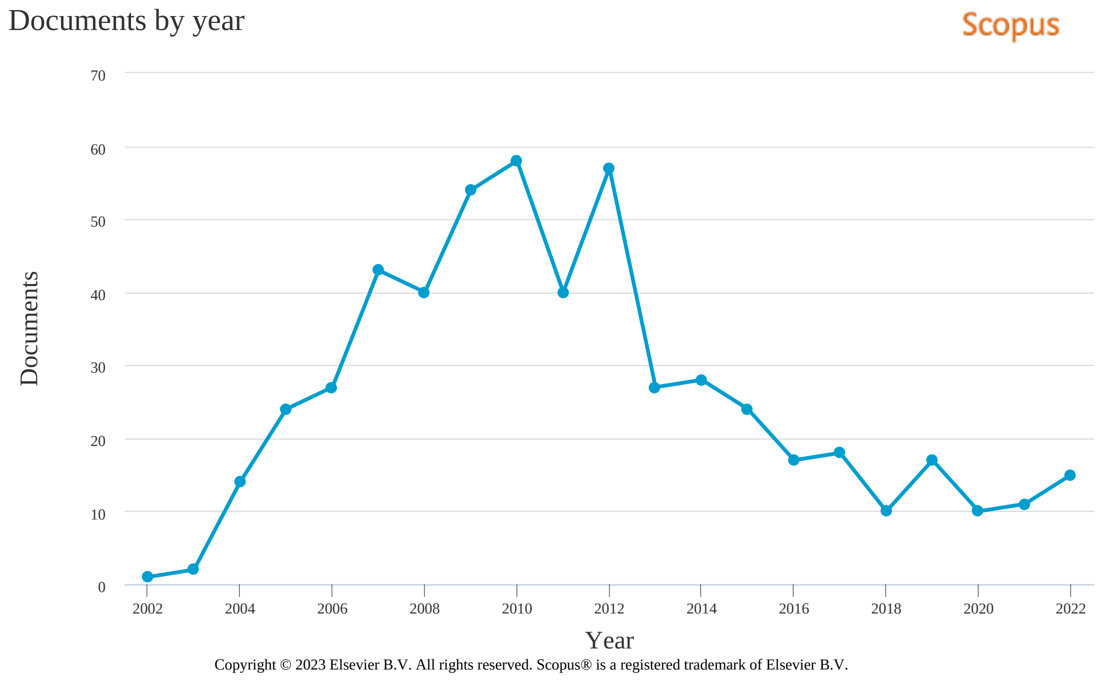

Figure 4.1: **Publications in MMOGs**: Keyword search in Scopus covering the period from 2002 to 2022, using the keyword: MMOG from the domains computer science, engineering, social science, mathematics, arts and humanities, psychology, business, decision sciences, and economics.

new research environments also brought with them a number of challenges. Of particular note here is the handling of large amounts of data, but also the diversity of the individual virtual universes. In addition to the very limited accessibility and availability of the game data, these aspects prevented the major breakthrough. However, a look at the data on the number of newly published studies also shows that, despite everything, MMOGs have established themselves as research environments. While they have not been a revolution in research, they have certainly been an opening of new avenues for researchers.

4.2 Research in the Travian universe

While games such as World of Warcraft, Eve Online or Everquest II were used in the first phase of MMOG-based research, Travian gained increasing popularity from 2008 onwards. Based on data sets officially provided by the operator Travian Games, a total of about 25 studies have been published to date. The work was carried out as part of a series of research projects by various groups of researchers. The first works, from 2008 to 2012, deal primarily with the culture, conflicts, and general dynamics of online communities (Assmann et al. 2009; Gallenkamp et al. 2011; Riedl et al. 2012). A central role was also played by the possibilities of MMOGs as novel research environments (Assmann et al. 2010a). The research on trust and its influence on team success in Travian's virtual teams has established itself as the research focus with probably the most significant results. A whole series of publications were published on this topic between 2009 and 2014 (Picot et al. 2009; Korsgaard et al. 2010; Drescher 2014). Building on this, another group of researchers began to explore the potential of player interactions in more detail (Wigand et al. 2012). This brought the possibilities of social network analysis into focus for the first time. The communication between the players became an important issue (Hajibagheri et al. 2015). With the help of these interaction patterns in the communication networks, it was possible to show how community structures develop and what role they play in conflicts (Alvari et al. 2016; Hajibagheri et al. 2018). They also examine how these patterns affect team performance (Wigand 2018). The publications in this dissertation build on this previous research and include support networks in addition to communication networks. These studies examine the extent to which the patterns from the networks can be used to make predictions about team success (Müller et al. 2020) and leadership structures (Müller et al. 2022). The use of machine learning plays a central role here. The second central question of this thesis deals with the question of whether the behavioral patterns observed in MMOG environments also reflect the behavior of actors in the real world (Müller et al. 2023). A detailed overview of the background and context of the game environment of Travian is provided in the next section.

4.3 Introduction to the world of Travian

Originally released in 2004, *Travian* is a commercial browser-based MMOG. In 2009/10 - the period of the main data collection - Travian was one of the very few games that could be played worldwide (52 countries) on dedicated national servers[2]. These were operated in the respective national language. To date, more than 150 million players have registered and participated in one or more rounds (Müller et al. 2023). This setting provides a diverse user base, making it attractive for a variety of research applications, including cross-cultural research (Assmann et al. 2010a).

The game is a real-time strategy game (RTS), in which the players' mission is to build an empire. Players begin as chieftains of their own villages. They must gather natural resources, build armies, and grow their empire (Korsgaard et al. 2010). A major driving force is expansion, which is achieved by conflicting and cooperating. Players achieve this by improving their production capacities as well as building military units. Further, troops can also be used to raid resources from other players (instead of producing). Conflicts in Travian can thus be divided into two categories: *attacks* and *raids* (Hajibagheri

2. https://www.travian.com/international

et al. 2018). Each game cycle lasts about a year, during which players compete to be the first alliance to build one of the wonders of the world.

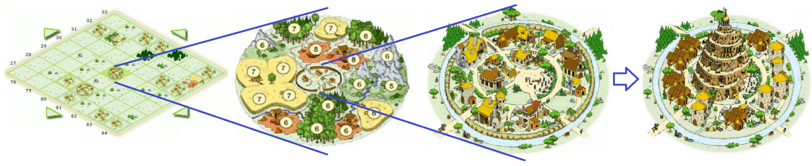

Figure 4.2: Travian - game screenshots show different zoom levels (map, fields and village) and final monument

In addition to upgrading one's infrastructure, the most important aspect of the game is being part of an alliance (Müller et al. 2020). Alliances have their own forum, chat room, and in-game messaging system. "As in the real world, teamwork and negotiation skills play a crucial role in game success" (Hajibagheri et al. 2018). The game environment is highly competitive. Only a high level of cooperation will allow an alliance to survive and achieve its goals. Alliance leaders are very much dependent on the contribution of each member. As a result, there is a great deal of social pressure to take things seriously and to invest a great deal of time (Müller et al. 2020). Players who do not show a certain level of commitment and/or performance (e.g., growth rate) will not be invited to join alliances or may even be dismissed. Because of this high social pressure, few external incentives are required to have motivated participants for research with the players (Assmann et al. 2010b). Thus, Wigand et al. conclude that "given these characteristics of Travian, the virtual teams in Travian afford an excellent opportunity to study various facets of virtual organizations" (Wigand et al. 2012).

The above-mentioned teams are the predominant way to get organized in Travian. These teams, known in-game as alliances, can range from 2 to 60 players. Their existence begins with the founder of the alliance, who invites the future members, grants them privileges, and assigns them tasks. This formation process is shown schematically in the figure 4.3.

Once an alliance has been established, it is subject to continuous change. The founder of an alliance, acting alone or in conjunction with a leadership team, may invite additional members to join or dismiss them at any time. This means that over the course of a game round (approximately 12 months), both the group size and the composition of a team can change continuously. Groups in the game Travian should therefore always be considered as a snapshot.

There are three main types of interaction between team members within alliances. The most important form of interaction here is communication. This is a key part of the game design and is central to the coordination and leadership of the group. In particular, coordinated actions emerge from communicating with each other. A downstream form of interaction can be seen as mutual support between team members. For this purpose, resources are exchanged and mutual military support is provided.

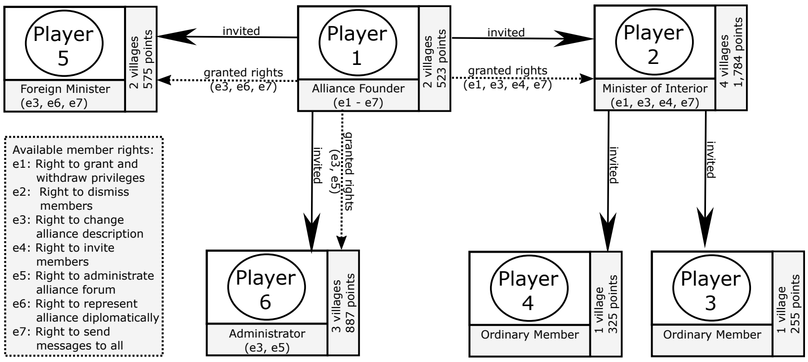

Figure 4.3: Alliances in Travian - schematic representation of the process of a foundation taken from Müller et al. 2023

The interactions between the players described here can be aggregated in interaction networks. The communication networks and support networks obtained in this way subsequently formed the data basis for the questions investigated in this thesis. The history of previous research and data collection is discussed in the next section.

4.4 The history of the raw data collection for the Travian research project

The research cooperation between Travian Games GmbH and the two universities Ludwig-Maximilians-Universität (LMU) and Technische Universität München (TUM) started in 2007 and was initiated by Prof. Philipp Sandner (PhD student at that time). It was continued by Dr. Jakob Assmann and Prof. Markus Drescher (both PhD students at that time) in cooperation with Prof. Arnold Picot, Prof. Audrey Korsgaard, and Prof. Isabell Welpe.

During the first phase of the research cooperation, various surveys were conducted in the online game Travian. The researchers were also provided with initial logfile data from the game worlds. This first "proof-of-concept" phase served as a basis for the later more extensive data collection.

In 2008, the first formal cooperation was established. Travian Games provided the researchers with a dedicated game world for research purposes with a total of 20,000 inventory players. This game world (LMU Experimental Server) had no payment features and could be manipulated by the researchers in various ways.

As part of the data collection of the experimental server, LMU and TUM was granted access to 23 additional game worlds. This data collection period was one year. For this purpose, copies of the regularly created backups (usually a snapshot at 2 o'clock) were made available for download on a daily basis. Table 4.1 provides an overview of the different projects.

Table 4.1: A list of the data collections from the Travian research collaboration

Project	**Period**	**Size**	**Institution**
AOM – Proof of Concept (Assmann, Sandner)	2007	20 MB	LMU
LMU Experimental Server (Assmann, Drescher, Korsgaard)	2008/2009	80 GB	LMU
International Data Collection (Assmann, Drescher, Korsgaard)	2008/2009	900 GB	LMU/TUM
DFG Data Collection (Müller, Uhlemann)	2019	76 GB	TUM

The archive log file data consists of three different types of data that can be classified as follows: *static*, *status*, and *interaction* data. "Static data define constant parameters that influence the game dynamics such as production rates. Status data yield information on individuals or teams at a certain time such as the status of the infrastructure, team membership, or team size. Finally, interaction data provide information on relational actions between individuals or teams such as sending messages, resources, or troops" (Drescher 2014).

For privacy reasons, the operator removed all personal information and communication content before data transfer to the researchers. Furthermore, all players were informed by the game operator that they were (anonymously) part of a scientific research project, which they agreed to by acceptance of the general terms and conditions (Müller et al. 2020).

4.5 Processing of the raw data

One challenge was the processing of the raw data provided by Travian Games. In order to conduct scientific research and analysis on it, a number of processing steps were necessary. The basic idea in processing the raw data was that every game action causes at least one change in the data base (Drescher 2014).

In order to trace which transaction in the game results in which entry in the game database (MySQL), Travian Games provided a documentation. With the help of this documentation, it was possible to identify the columns and tables that are relevant to the research project.

It was also necessary to decide how to deal with data that was missing or that was corrupted. In addition, the researchers had to find solutions for handling of the sheer volume of raw data that was initially cached on tape storage and external hard drives. During the subsequent consolidation, a total of 7,271 backed up copies of the raw databases were merged into 23 target databases. The resulting databases (organized by national game world) contained all transaction data generated during the data collection period. Essentially the same principles were followed in processing data from the subsequent data collection in 2019.

The result of this data consolidation was a total of 35 databases. Each database contained extensive transaction data from the respective game worlds. The majority of the data collected originates from the period of 2009/10 (23 + 1 databases) (Drescher 2014). This data set was supplemented by a smaller follow-up collection in 2019 (10 databases), which was primarily used for a verification study (Uhlemann 2023).

4.6 Overview of available data

The data collected in this way contains a variety of different types of information. In line with Williams et al. 2011, the available log data can be divided into the following categories (Bendeich 2014)[3]:

Static framework conditions and statistics: The following listing describes the available database entries that contain framework conditions and statistics for the following features:

- *a_karte*, *a_land* & *a_truppen*: This includes information on the construction and upgrade costs of buildings, the location of villages, and the distribution of resource fields for a village; it also contains information on the effectiveness of each troop unit, its maintenance and training costs, and its training requirements
- *a_stats*: Includes aggregated statistics, such as daily registrations, collected daily during the course of the game
- *s2_stats24*: Contains daily aggregated performance data relating to the group strength, the inhabitants (represents the aggregated expansion level of all buildings in a village), the attacks and the attacks fended off by a player

Status data: The following listing describes the available database entries that contain the status data for the following features:

- *x_onlinezeit*: When and for how long a player was online
- *s_allianz*: Master information on alliances, in particular their date of foundation and their name
- *s_ally_member*: Information about the members of the alliance and their authorizations for the alliance

3. This overview describes the data preparation methods and is taken from an IDP report submitted in 2014

- *s_dorf* & *s_dorfliste*: Information about the current status of a village (the latter contains additional information after conquests and further village foundations from this village)
- *s_forschung1* & *s_forschung2*: Provide information about the expansion levels of the troops and thus their defense or attack capabilities of a village during a battle
- *s_gebaeude*: Provides information about which building is located on which building site and in what stage of expansion
- *s_truppen*: Changed troop stages as a result of combat actions (see note on reporting tables for interaction data), training and other troop movements
- *s_spieler*: Information on the player, in particular gender (if specified), can be found in the tables *s_player*, *s_details1*, *s_details2* and *s_gold*; it also shows the aggregated number of inhabitants across all of a player's villages
- *s_vertretung*: provides information about sitter entries over the course of the game

Interaction data: The following listing describes the available database entries that contain the interaction data for the following features:

- *s_ally_news* & *s_ally_diplo*: Intra-alliance changes (new members, exclusions, exclusions) and inter-alliance changes (conclusion of a non-aggression pact, declarations of war, alliances)
- *s_ally_offer*: Information on invitations to join alliances
- *s_marktplatz*: All trading offers for commodities
- *x_handel*: The actual exchange of goods
- *s_nachrichten1*: Information about who has sent a message to whom and when, and whether the recipient has read it
- *x_eroberungen*: Who conquered which enemy village when
- *x_raid*: Information on troop movements and associated attacks, raids, reconnaissance operations (in combination with the tables: *s_berichte_supportattacked*, *s_berichte_support*, *s_berichte_battle*, *s_berichte_greetings*, *s_berichte_spy*)

Chapter 5

Peer reviewed publications

Using Communication Networks to Predict Team Performance in Massively Multiplayer Online Games

Authors

Siegfried Müller, Raji Ghawi and Jürgen Pfeffer

In

IEEE/ACM International Conference on Advances in Social Network Analysis and Mining (ASONAM) 2020, pp. 353-360. DOI: https://doi.org/10.1109/ASONAM49781.2020.9381481

Abstract

Virtual teams are becoming increasingly important. Since they are digital in nature, their "trace data" enable a broad set of new research opportunities. Online Games are especially useful for studying social behavior patterns of collaborative teams. In our study we used longitudinal data from the Massively Multiplayer Online Game (MMOG) Travian collected over a 12-month period that included 4,753 teams with 18,056 individuals and their communication networks. For predicting team performance, we selected 13 SNA-based attributes frequently used in team and leadership research. Using machine learning algorithms, the added explanatory power derived from the patterns of the communication networks enabled us to achieve an adjusted R2 = 0.67 in the best fitting performance prediction model and a prediction accuracy of up to 95.3% in the classification of top performing teams.

Contribution of thesis author

Theoretical operationalization, iterative evaluation of computational implementation and analysis, qualitative evaluation and contextualization, as well as manuscript writing, revision, and editing.

Identifying Power Elites in Massively Multiplayer Online Games by Applying Machine Learning to Communication and Support Networks

Authors

Siegfried Müller, Raji Ghawi and Jürgen Pfeffer

In

IEEE/ACM International Conference on Advances in Social Network Analysis and Mining (ASONAM) 2022, pp. 277-284.
DOI: https://doi.org/10.1109/ASONAM55673.2022.10068676

Abstract

The aim of this paper is to show how machine learning can predict whether an individual is more powerful than others in the group. The crucial point here is to consider the structural position of the actors in the social networks in which they are embedded. The approach we have taken for constructing these intra-group networks is the aggregation of communication and support interactions. Our research is based on longitutional data from the Massively Multiplayer Online Game (MMOG) Travian that was collected over a 12-month period. The data includes 202,764 communication and 96,913 support interactions between players that we applied for the construction of interaction networks. We also had access to status information on a daily basis for 21,431 individual players who were members of 4,758 alliances. Methodically, we applied 10 established metrics from SNA-based team research in combination with the Random Forstest classification algorithm. Our results show that interaction networks are well suited to assign members into two groups of powerful (elite) and non-powerful (non-elite) players. It turned out that the identification of non-elite members was much easier to accomplish than that of elite members. Regarding the application of multiplex networks, we could not confirm a higher explanatory power by using combined networks. In summary, we can say that the network patterns of elite members are clearly different from those of non-elite members. In this way, we were able to predict affiliation to each category with an accuracy (F1) of 0.88 for communication networks and 0.83 for support networks.

Contribution of thesis author

Theoretical operationalization, iterative evaluation of computational implementation and analysis, qualitative evaluation and contextualization, as well as manuscript writing, revision, and editing.

Reviewing the potentials of MMOGs as research environments: A case study from the strategy game Travian

Authors

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In

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Abstract

Massively Multiplayer Online Games (MMOGs) provide many opportunities for scientists. Previous research ranges from personality trait prediction to alternative cancer treatments. However, there is an ongoing debate on whether these virtual worlds are able to represent real world scenarios. The mapping of online and offline findings is key to answering this question. Our work contributes to this discussion by providing an overview of the findings from network-based team and leadership research and by matching them with concrete results from our MMOG case study. One major finding is that team size matters. We show that high diversity in the type of teams is a major challenge, especially when combined with the immense amount of data in MMOGs. In our work, we discuss these issues and show that a well-grounded understanding of the data and the game environment makes it possible to overcome these limitations. Besides the team size, the aggregation periods play an important role. Regarding MMOGs as research environments, we show that it is important to pay close attention to the specific game-related contexts, the incentive structures, and the downside risks. Methodologically, we apply support and communication networks to show the influence of certain group-based measures (e.g., density, transitivity) as well as leadership-centered characteristics (e.g., k-core, group centrality, betweenness centralization) on team performance. Apart from our findings on centralization in communication networks, we are able to demonstrate that our results confirm the theoretical predictions which suggest that the behavioral patterns observed in MMOG teams are comparable to those observed in offline work teams.

Contribution of thesis author

Theoretical operationalization, iterative evaluation of computational implementation and analysis, qualitative evaluation and contextualization, as well as manuscript writing, revision, and editing.

Improving team performance prediction in MMOGs with temporal communication networks

Authors

Raji Ghawi, Siegfried Müller and Jürgen Pfeffer

In

Social Network Analysis and Mining 11.1 (2021): 65. https://doi.org/10.1007/s13278-021-00775-7

Abstract

Virtual teams are becoming increasingly important. Since they are digital in nature, their "trace data" enable a broad set of new research opportunities. Online Games are especially useful for studying social behavior patterns of collaborative teams. In our study we used longitudinal data from the Massively Multiplayer Online Game (MMOG) Travian collected over a 12-month period that included 4,753 teams with 18,056 individuals and their communication networks. For predicting team performance, we selected several Social Network Analysis-based attributes frequently used in team and leadership research. We find that using these features, the accuracy of predicting the team performance, in terms of R^2, is about 60%; whereas the accuracy of classifying the top performing teams exceeds 95%. Moreover, we examine the ability to predict the team performance based on historic data of the network features, i.e., before several weeks. We find that the best accuracy can be achieved using the features in the present and the past, as well as the past performance. For a delay of one week, the accuracy of this model is about R^2=97%.

Contribution of thesis author

Theoretical operationalization, iterative evaluation of computational implementation and analysis, qualitative evaluation and contextualization, as well as manuscript writing, revision, and editing.

Chapter 6

Discussion

6.1 Achievements and contributions

This final section of this thesis will show what has been achieved in the course of this research project and what contributions this dissertation has been able to make to the state of research. The central question for this work was to find out to what extent reliable predictions about team performance and team leadership can be made from the patterns that emerge from the interactions of the group members (*structural signatures*). Both social network analysis and machine learning algorithms have been key in this process. Simultaneously, the theoretical foundations of the behavioural patterns of individuals in groups and organizations formed an important basis for this (*organizational network analysis*). The second central question that arose in the context of this work was whether the data obtained from MMOGs can be used to answer general research questions about the behavior of individuals in the real world. The *mapping principle*, based on the work of Williams 2010, provided the theoretical basis for this. In the following section it will be shown to what extent this work has been able to answer these questions and to what extent new insights have been gained.

6.1.1 Successful predictions

One of the first challenges in the development of the research question was the identification of the target variables. Drawing on the *organizational behavior literature*, we were particularly interested in what factors of cooperation make groups successful and what specific traits (*structural patterns*) make a leader. One of the first steps was to filter out the data points that were suitable for mapping team performance and identifying power elites from the enormous amount of around 900 GB of raw data (Bendeich 2014). An existing team ranking within the game Travian that was calculated in real time was a particularly good fit for the first target variable. This team ranking is a central element of the game, as it reveals how successful alliances have been in comparison to the other alliances. It is important to note that the success of alliances in the game Travian depends essentially on the effectiveness and efficiency of cooperation within the team (Assmann et al. 2010a; Wigand et al. 2012; Müller et al. 2020). By identifying this ranking, we were able to define a target variable that we assumed would reflect the success of cooperation within the group particularly well. In order to identify criteria that could capture the most influential or powerful members within the group, it was necessary to take a closer look at the process of alliance formation. It turned out that the leaders of the alliances within Travian have certain privileges. These special rights, which distinguish a normal player from an influential player, are also included in the game data used on a daily basis (Müller et al. 2022). The aforementioned relationship between the existence of these privileges and membership in the leadership group within the team allowed us to establish the second central target variable (*elite membership*).

With the help of our machine learning work (especially the *random forest algorithm*), we were able to show that insights from the theoretical literature can be successfully applied to prediction tasks. In order to do this, we first conducted a comprehensive analysis of the literature on network-based team and leadership research. Our third and final paper provides an overview of this research task in a theoretical summary (Müller et al. 2023). The focus was on the identification of those network patterns that are known to have a positive or negative impact on the success of the groups. In addition, we were interested in finding out which network patterns are able to make statements about the leadership structure within a team. The second step was to ask how the now-identified leadership patterns affect team success. A number of meta-studies have shown that especially density, centrality and centralization play an important role in this context (Evans and Dion 1991; Balkundi and Harrison 2006; Wang et al. 2014; Nicolaides et al. 2014; D'Innocenzo et al. 2016). In addition, we were able to identify that core-periphery structures are also well suited to reflecting leadership structures (especially about membership in the core leadership group) (Borgatti and Everett 1999; Everett and Borgatti 2005) and making statements about team success (Collier 2012; Brass 2018). However, so far only fundamental work exists in this field and established knowledge in the form of meta-studies is often still lacking (Borgatti and Everett 1999; Cummings and Cross 2003; Contractor et al. 2012). Our task, then, was to show whether these theoretical principles could be used to make accurate predictions about team success or leadership group membership. In summary, we can state here that on the basis of these theoretical foundations, we were able to demonstrate with our first two machine learning-based studies that it is possible to predict team success (prediction accuracy up to 95.3 %) and membership of an elite group (accuracy F1: 0.88 %) with a very high degree of precision (Müller et al. 2020, 2022).

6.1.2 Virtual worlds map real world

A central and as yet unanswered question that repeatedly arises in the context of MMOG-based research is whether virtual worlds are at all suitable for making statements about the real world (Ducheneaut 2010). This is the question that the third paper of this dissertation is devoted to. The idea is to use the available data set from the game Travian to investigate whether well-established dependencies observed in real-world teams can also be found in the game world. As a first step, we have compiled an overview of the scientific work done in the field of MMOGs. We realized that the games differ greatly as research environments and it is therefore necessary to have a scientific basis to make them comparable. The theoretical model developed by Williams 2010 (*mapping principle*) played an important role in answering the question of whether MMOG environments are capable of reflecting real-world contexts. Next, we used this theoretical foundation to integrate findings from our first two studies. Our approach was to check whether the correlations we observed in our MMOG environment of the game Travian correspond to those that meta-studies could prove in the offline world. The model for this was a similar idea by Castronova et al. which used MMOG data to test the validity of economic laws (Castronova et al. 2009). Using an analogous approach, we were able to test nine hypotheses and found that the expected correlations in the Travian game environment were (in almost all cases) consistent with the theoretical predictions (Müller et al. 2023). Thus, our findings provide further evidence that people's behavioral patterns in traditional offline settings (e.g., work environments) and more recent online settings (e.g., online games) may be the same. Our results therefore suggest that it may ultimately not be so important to distinguish between the online and offline worlds. Rather, it should also be important to keep a close eye on the wider context in which a team works together. Especially given that the lines between offline and online are becoming increasingly blurred in today's working environment.

As the central contribution of our scientific work, it can therefore be summarized that we could not find any evidence in our work that the behavior of players in virtual environments differs significantly from human behavior in similar situations in the offline world. To put this in a broader context, the following section provides a general overview of MMOGs as a research environment.

6.2 General considerations of MMOGs as research environments

At the dawn of research in MMOG there was great enthusiasm. The aspect that most intrigued researchers about the new possibilities of virtual game worlds was the seemingly infinite amount of data. For instance, Ross et al. wrote that those virtual worlds "free the researcher from the burden of data collection and take advantage of large-scale databases and the computational power of virtual worlds to provide huge datasets that can be generalized to the real world" (Ross et al. 2012). Originally, it was assumed that the dynamics in these virtual environments would largely coincide with those in the offline world. In light of this potential, Castronova and Falk 2009 wrote that virtual worlds may be the modern equivalent of supercolliders for social scientists, and should therefore be the next area to receive significant attention. This assumption has been increasingly challenged as research in this area progressed. Therefore, Williams developed a mapping-framework that allows researchers to systematically investigate the question of whether the dynamics in MMOGs correspond to those in the real world (Williams 2010). Various studies subsequently dealt with the answer to this question (Castronova et al. 2009; Ducheneaut 2010; Ross et al. 2012; Ahmad et al. 2014; Müller et al. 2023). The general conclusion of this work was that these virtual game worlds are very special and it is especially important to keep in mind the context and game design of the games. Further, the "evidence [from past research in MMOGs] suggests that virtual worlds lie somewhere in between" (Ross et al. 2012). To summarize, it can be said that MMOGs can be used to draw conclusions about the behavior of individuals and groups in the real world, but a number of aspects have to be taken into account (Müller et al. 2023). In particular, it is important to note that "a typical game is designed to attract players" (Ross et al. 2012) and researchers have to take the game data with all compromises as they arise from player interactions and technical processes within the game. The quality of the resulting data sets (secondary data) can therefore differ greatly from data collected on the basis of a well thought-out study design. At the same time, this type of data collection opens up entirely new ways of unobtrusively testing hypotheses and theories. In this context, Williams writes that MMOGs can enable communication scholars to unobtrusively test theories of group interaction, organizational theory, communication modalities, social capital, interpersonal behavior, networks, and countless others. He goes on to say that network measures are even more attractive when unobtrusive behavioral data is available. Networks can be built more easily from virtual world data than from real world data because they can be based on seamlessly recordable actions such as chatting or teaming (Williams 2010).

Therefore, we conclude with a statement from Ross et al. who claim that "virtual worlds are undoubtedly an interesting new tool, [but] it must be borne in mind that they are unique in many ways" (Ross et al. 2012).

6.3 Obstacles and limitations

In the course of this doctoral thesis, we regularly came up against the limits of feasibility when designing the studies, processing the data and selecting the statistical methods. Many of these feasibility limitations stemmed from the fact that we were working with a dataset based on secondary data that had been collected and processed several years earlier. Despite the many data points and players, we had to deal with the data as it was. In particular, we had to accept that it was simply impossible to collect missing data that was important to study. This played an important role, as it was not possible for us to validate scientific constructs via surveys. A lot of potential research questions that would have been of interest for this work therefore had to be sorted out. In addition to these limitations in the research design, we also had to deal with the aforementioned general (1) limitations of MMOG worlds as research environments, (2) applicability of the available secondary data, (3) problems of delimitation of group membership and temporal allocation, and (4) limitations of existing statistical methods. We take a closer look at these issues and challenges in the following sections.

6.3.1 Applicability of the available data

The first question that arose in the course of this work was whether the available secondary transaction data were at all suitable for answering the research questions we sought to answer. In particular, the fact that various types of data points were simply missing from the dataset was a major challenge. The most important missing data were: (1) data at individual level (*demographic data and psychological profiles*) (2) content of communications between the players (3) information on the distribution of functions and tasks within the groups (*formal organization chart*). This lack of important information had a number of consequences for the design of our research questions.

The main limitation we faced throughout the study design process was that we had interaction data at the individual level, but no demographic or psychological profiles of individual players. Therefore, we were not able to investigate research questions at either the micro or meso level and had to make do with studying at the macro level. Many of the side effects that could have been captured by the use of control variables were not examined in this way. This was particularly unfortunate as a number of questions about group leadership are closely linked to the individual characteristics of the leaders and those who follow them (Hernandez et al. 2011; Crawford and Lepine 2013; Sparrowe 2014). Leadership theories such as leader-member exchange or servant leadership have been particularly difficult to integrate in this context (Dierendonck 2011; Eva et al. 2019). Another interesting set of questions that were excluded were those relating to the impact of group diversity on group success (Reagans et al. 2004).

In conclusion, we can say that despite all the problems mentioned, we were able to work around some limitations with the help of social network analysis tools and thus were able to work with incomplete data. However, this meant that we had to give up some of the theoretical underpinnings of group and leadership models much more than we had originally intended.

6.3.2 Delineation issues: the role of group size and temporal aspects

One of the biggest challenges when working with the pre-existing Travian dataset was the variety of team sizes, as well as the temporal aspects. The origins of the problems related to team size were twofold.

The first part of this issue had a theoretical background and thus also had a conceptual impact on the study design. The literature shows that it is important to treat groups of different sizes differently (Bettenhausen 1991; Kozlowski and Bell 2012; Lord et al. 2017). This is particularly relevant because they have significant differences in leadership structure, different approaches to problem solving, and different rates of participation in problem solving (Slater 1958; Sundstrom et al. 2000; Crawford and Lepine 2013). Similarly, large and small groups show differences in the stability of their composition and communicate differently (Wageman et al. 2012). Finally, larger groups can draw on a wider range of skills and resources (Caplow 1957; Campbell et al. 1993). At the same time, it has been proven that the larger a group becomes, the less effective it is in terms of cooperation and coordination (Gist et al. 1987; Stewart 2006; Korsgaard et al. 2010).

The second part resulted from the game design of Travian. This allows group sizes of between 2 and 60 members. Further, the game is designed in such a way that larger teams with more members automatically received an advantage in the team ranking. Both of these facts make it difficult to design a study in which team size as an additional influencing factor exerts as little influence as possible. In the end, we were only able to compensate for this confounding factor by only comparing teams of a similar size in our analyses. This approach allowed us to avoid the problems described above, but at the rather high price of a small sample size and limited statistical analysis.

Another part of the delimitation problem was that we had to summarize the daily data points into time periods. This further exacerbated the problem of the wide range of team sizes in our data. In concrete terms, this meant that the original range of 2-60 members increased to 2-143 members. Fortunately, this problem was also solved by strictly separating teams of different sizes (small teams, medium teams, large teams) in our analysis.

The need to aggregate the individual points in time into periods of 14-60 days had its origins in the process of creating transaction networks. Although the original Travian dataset contained all daily interactions between players, initial analyses showed that the interaction networks (communication and support networks) did not contain enough information density on a daily basis to perform the analyses. This meant that we could not use the daily network data provided by the game and had to resort to aggregating the data. Again, the reason for this had its origins in the design of the game: the team members of the Travian alliances simply do not interact with each other on a daily basis. As a result, there was a need to aggregate a number of days in order to be able to identify meaningful patterns within the transaction networks. Two competing effects had to be balanced.

On the one hand, there is evidence that longer time periods can have a greater number of interactions. This had a positive effect on the analyses to be carried out. It was found that the first meaningful analyses could be carried out from an aggregation period of 7 days. The effects observed also became more and more pronounced the longer the aggregation periods were chosen. The most statistically robust results were obtained with an aggregation period of 60-90 days.

On the other hand, there was the problematic aspect that the team composition in Travian can change constantly (fluctuation) and thus cause a number of disruptive effects. The reason for this is that the game design allows members to join and leave an alliance at any time. It should be noted, however, that it is not possible to have an accurate picture of the team dynamics that actually took place due to the turnover of team members. Rather, the observations from several days overlapped and thus only provided a rough picture of the interactions that took place in the alliance. In summary, we can say that in the end we were able to work with the fuzziness described here, but we would have preferred to work with a dataset in which membership remained stable over time.

Also from a theoretical perspective, turnover within teams has a significant impact on the observed patterns of interaction in the alliance. Based on Tuckman's original model of team development, the different phases of a team development process play a particularly important role over time. As part of the development of their collaboration in most models, groups go through four phases. These four stages are (1) *forming*, (2) *storming*, (3) *norming*, and (4) *performing* (Tuckman 1965). Similarly, in another example, in Hackman's model, the steps of managerial work in creating an effective group are (1) *prework*, (2) *creating conditions for performance*, (3) *forming and building the team*, and (4) *providing ongoing support* (Hackman 1987). Many similar models exist. The decisive factor is that the way in which team members interact with each other is different in each phase (Leenders et al. 2016). This can mean: The observed patterns (structural patterns) change from level to level. As far as the agglomeration period is concerned, this can have a number of different effects. If the aggregation periods are chosen to be too long, this can have the consequence that several stages of development of the team will be mapped within one aggregation period. However, if the selected time period is too short, it is possible that only part of the development period is represented, and the picture is incomplete. The effect of this is that the particular stage of development of the team can no longer be captured in the analysis, which leads to additional distortions. As an example of this, Balkundi et al. write that "either type of error might manifest in undetected network effects in short-range teams, composed of relative strangers, that would instead emerge in long-range teams, composed of members that know each other well" (Balkundi and Harrison 2006).

6.3.3 Statistical limitations

Right from the beginning, the statistical part of this thesis was characterized by a series of limitations. Three major obstacles played a central role in that: (1) the limitations resulting from the nature of the existing secondary data, (2) the availability of a limited number of techniques and methods for analyzing (dynamic) social networks, and (3) the high degree of interdependence between the independent network variables in our dataset.

The biggest obstacle we had to deal with when working with our existing data set was the fact that the composition of the groups was constantly changing. One of our early analyses showed that there were virtually no alliances in the entire data set where the composition of members remained unchanged over an observation period of 2-3 periods. This problem was exacerbated by the previously discussed need for aggregation of individual observation points (single days) into periods of 14-60 days. Against this background, the SIENA analysis method was ruled out. This was a regrettable outcome, as it would have been our preferred method for investigating the dynamic changes within the networks. Despite an extensive literature search, we were unable to identify any alternative established techniques suitable for analyzing dynamic social network data. This outcome was in line with the statement of researchers who wrote that "unfortunately, very few techniques exist for analyzing these data as continuous information" (Hennig et al. 2012). They see the reason for this in the fact that "analyzing the evolution of social structure and behavior simultaneously poses an enormous theoretical and empirical challenge and very few studies have succeeded in accomplishing this goal" (Hennig et al. 2012). As a result, we unfortunately had to abandon the analysis of dynamic network effects for this thesis.

The application of machine learning methods opened up an interesting alternative. Our initial concept studies have shown that they are very well suited to making accurate predictions on the basis of the structural patterns that emerge from the network analyses. In our first paper, we applied four different methods (k-Nearest Neighbors, Random Forest Classifier, Logistic Regression, Support Vector Machine) for comparison purposes. All four methods performed relatively equally when the results were compared. However, the Random Forest algorithm proved to be the most flexible for the application (Müller et al. 2020).

The use of other established statistical methods proved to be more difficult for us. In particular, the use of multiple linear regression confronted us with unexpected limitations which was in line with the statement that "unfortunately, most of the techniques used to compute inferential statistics in non-network analysis cannot be applied to network analysis. This is because a large proportion of inferential statistics used in non-network analysis make the assumption that the data are independently and identically distributed. [...] Thus, many of the standard statistical techniques used to analyze attribute social scientific data are not appropriate for analyzing network data" (Contractor and Chunke 2011).

The background was that for our third paper we wanted to use a traditional OLS regression to show how the influence of different network variables (such as density, centrality, or transitivity) affects team success. In addition to other problems, which we were able to solve, we found that ultimately a very high colinearity between the (total of 9) independent variables made it impossible to apply this technique (Müller et al. 2023). This, in turn, is consistent with Carter et al. 2015 who noted that the relational observations that make up network data are, by definition, not independent and therefore not well suited to traditional analysis. In the end, this led us to restrict ourselves to using the Pearson coefficient, which also coped with the non-normality of our data.

Other possible statistical methods only became apparent to us during the review process. We will return to this in the next section.

6.4 Future Work

As part of this doctoral thesis, we have looked at a whole range of topics related to research in MMOGs, networks, and teams. As we imagined and analyzed, we often reached the limits of feasibility. Some of these topics were simply not feasible with the given data or framework conditions. For other topics, the scope of this dissertation was simply not large enough. The following is therefore a brief overview of the topics that are of particular interest in continuation of the topics presented here.

Probably the most important single point for the continuation of further scientific studies in the context of the Travian universe is the recommendation to carry out the study design before collecting the data. Although this requires an enormous effort to collect data, it greatly reduces the limitations described. In particular, such a future approach would make it possible to investigate a very exciting question. This question is about finding out the chronological order: *do successful teams exhibit certain structural patterns, or do certain structural patterns lead to a team being particularly successful?* Such an study could build on the conceptual framework of Quintane et al. 2013 which allows us to understand how past interactions influence the emergence of future interactions without assuming that these are entirely determined by them.

Furthermore, with the new data collection there would be the possibility of the collection of player data on an individual level. In addition to recording psychological and demographic profiles, various constructs can also be validated in this way, particularly through surveys. Such data and validated constructs (e.g. on (distributed) leadership, team trust or helping behavior) could, for example, form a basis to "establish a computational social science of leadership" (Carter et al. 2015). This is a crucial point as the "access to digital trace data has the potential to transform leadership studies from being based on cumbersome self-report data to highly scalable high-resolution digital data" (Carter et al. 2015). Such an approach could therefore help to learn more about how (1) individuals can use their networks more effectively, (2) how formal leaders can better understand and utilize the existing networks in their groups, and (3) how collectives can develop greater leadership capacity by building networks among their members (Cullen-Lester and Yammarino 2016).

There are other exciting possibilities for future work when the capabilities of custom data collection are combined with the newer statistical methods. Carter et al. 2015 note in this context: "These new methods detect the prevalence of distinct structural signatures that are uniquely associated with certain theoretical mechanisms of leadership emergence and enable simultaneous tests of multiple relational theories, including theories that involve longitudinal and multilevel dynamics". The following methods are of particular importance in this regard: (1) Exponential Random Graph Models (Wasserman and Pattison 1996; Robins et al. 2007; Chrobot-Mason et al. 2016; Contractor and Chunke 2011), (2) SOAMs (Snijders 2001, 2002), and (3) Structural Equation Models (Thakkar 2020). After this outlook with regard to the future fields of work, a conclusion on the results of this work is drawn in the following section.

6.5 Conclusion

In retrospect, the starting point for this work was a data set that was collected 10 years earlier as part of an interdisciplinary research project. This data set from the MMOG Travian attracted a great deal of attention from the outset and initial discussions with other researchers revealed a great deal of interest in working with the available data. For them, the main attractions were the size (900 GB of raw data, 23 different countries, approximately 3 million unique players) and the long time periods (12 months) documented. A special interest was shown in the area of trust research and the analysis of organizational networks. In both cases, the focus was on teamwork and leadership.

In the subsequent search for possible *research questions*, however, a disillusionment with regard to the possibilities that could be realized quickly became apparent. There were two main reasons for this: (1) The lack of ability to retroactively collect and complete missing data, and (2) the fact that the initial storage of the data was for the purpose of efficient live operation, and that there was no consideration of the data's usefulness in scientific studies. In particular, the conversion of the daily snapshots of the SQL databases into interaction networks for social network analysis was severely affected by these limitations.

As a result, these hurdles severely limited the possible questions to be investigated in the field of research into the organizational behaviour of teams and their leadership. For many very interesting research questions, it would have been absolutely necessary to use questionnaires in addition to the available transaction data. These surveys would have allowed various scientific constructs to be validated and used as explanatory variables.

Much more encouraging were other aspects of the MMOG data. For example, the interaction data showed that the majority of game participants were highly engaged and showed great continuity in their participation. As the game sets clear objectives and makes the achievement of objectives transparent on an ongoing basis, individual and team performance was an ideal dependent variable for potential research questions. This starting point made it possible to take a closer look at a whole range of questions from the field of team and leadership research. In particular, the question of how certain types of distributed leadership affect group success could be placed at the center of this work. A very exciting side effect was the question of which network patterns could best be used to map the degree and structure of distributed leadership.

Two further questions, which have not yet been conclusively answered in the literature, arose during the course of this work. (1) From a methodical point of view, this is the question of the statistical procedures to be applied. (2) On the contextual side, there is the generally difficult question of whether the insights about the dynamics observed in MMOGs can be transferred to the context of the real world. In the course of our work, we were constantly confronted with the limits of individual methods in the application of statistical options. Unfortunately, with the data as it was available, we were only able to apply a very small proportion of the techniques at all. In contrast, the applicability of machine learning methods proved to be a stroke of luck. The main results of the papers in this thesis are therefore based on this relatively new method of data analysis.

Apart from the topics described above, the question of whether the findings from the MMOG data are at all transferable to the real world arose repeatedly during the course of this dissertation. Although we were also unable to answer this question conclusively, our case studies provided further evidence for the thesis that the social laws observed in the real world also apply in a virtual context. The same seems to apply in reverse.

In conclusion, by working with the existing dataset, we have been able to highlight the limitations, but also the potential of MMOGs as a research environment. In addition, we were able to contribute to the discussion on whether MMOGs can be a reflection of reality with the help of another case study. Last but not least, we have also succeeded in demonstrating the potential of machine learning analyses. This applies in particular to understanding leadership and predicting how groups perform. Further research can build on this and ensure that MMOGs can continue to make their contribution as alternative and innovative research environments in the future.

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