THE EFFECTS OF SPATIAL AND TEMPORAL DISPERSION ON VIRTUAL TEAMS' PERFORMANCE

KRISTINA EGOROVA

(Specialist, ITMO University)

SUPERVISOR: A/P JUNGPIL HAHN

A THESIS SUBMITTED

FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF INFORMATION SYSTEMS

SCHOOL OF COMPUTING

NATIONAL UNIVERSITY OF SINGAPORE

2015

Declaration

I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

Kristina Egorova (A0106245N) ____________________

Acknowledgements

I would like to express my greatest appreciation to my supervisor, Associate Professor Jungpil Hahn, for his full support, invaluable guidance and advice throughout the course of this thesis and my stay in Singapore.

I would like to say “Thank you” to Jiao Anqing, who made this project possible with his hard work and dedication.

I am also deeply grateful for all the understanding and support from my family and friends.

Table of Contents

SUMMARY

It has been over than 20 years since organizations started relying on virtual teams, which are groups of geographically separated workers collaborating through IT-enabled communication channels. Virtual teams differ from co-located teams in the way they communicate, and this difference is one of the main reasons why virtual teams still experience the negative effects of geographical separation. Prior research has outlined several dimensions of the separation, i.e., spatial and temporal separation; however the consequences of different dimensions of separation and their impact is still unclear due to the challenges of conducting empirical research. In this thesis, we employ a simulation-based approach to systematically study the performance implications of a population of virtual information system development (ISD) teams under different spatial and temporal settings. The simulation framework provides us with a means to analyse the impact of spatial and temporal dispersion and their components. Our analyses suggest that spatial dispersion has a stronger negative effect compared to temporal dispersion, and that the overall effect of spatial dispersion can be attributed more to information distortion, rather than to information loss. In addition, our results suggest that goal alignment (an indirect effect of temporal dispersion) has a stronger impact on teams' performance, as compared to collaboration delay (a direct effect of temporal dispersion). Our results offer the theoretical and practical insights into the management of virtual ISD teams.

Classification: D.2.9 Management; G.1 Numerical Analysis; G.3 Probability and Statistics; H.1 Models and Principles; I.6 Simulation and Modelling; I.6.5: Model Development

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: Introduction

Virtual teams are defined as groups of workers, who are geographically, organizationally and / or time dispersed, but are brought together by information technology to accomplish organizational tasks (Lipnack 1997, Powel et al. 2004). Since the mid-1990s, virtual teams have been used in a variety of areas, such as new product development, new product manufacturing, customer service and information system development (Bergiel et al. 2008, McDonough et al. 2001, Townsend et al. 1998, Wakefield et al. 2008).

The use of virtual teams is a natural consequence of an overall globalization tendency, a shortage of qualified professionals in a given location, and the availability of high quality talents at low cost in different parts of the globe. These circumstances were coupled with advancements in information technology and a hyper-competitive environment where businesses were forced to look for more cost-effective approaches (Gajendran and Joshi 2012, Kankanhalli et al. 2006, Sarker and Sahay 2003). Thus, ***virtual teams*** have become one of a salient business practice (Maznevski and Chudoba 2000), and consequently an important topic for academic inquiry (Powel et al. 2004).

Despite the advantages they bring, virtual teams are associated with unique managerial challenges, such as temporal delays in getting and sending feedback, frequent misinterpretation of messages, and need for assurance of participation of remote team members, which are a natural consequence of the ***virtuality*** of teams (Powel et al. 2004). The virtuality of a team stems from two factors: *geographical separation* of the team members and heavy *use of* *information technology* in order to overcome the separation. Prior research on virtuality focused mostly on geographical separation and its (negative) consequences, while the use of IT was assumed to have mostly positive consequences, such as enabling the virtual teams to work and overcome the dispersion and related communication constraints (Powel et al. 2004).

However, despite several decades of organizational use of virtual teams, it is still not clear how exactly the use of virtual teams (adversely) affects team performance and what can be done to mitigate such challenges. Our understanding of virtuality is incomplete not only due to limitations of previously employed research methods (i.e., difficulties in findings a compatible measure for teams' performance), but also due to absence of studies at the population level: namely, it remains unclear, how well teams of different configurations (i.e., virtual vs. co-located) perform under different circumstances over time. We argue that this knowledge is important for long-term perspective of firms' survival, as it has been shown that organizational forms influence firms' performance and likelihood of economic survival (Levinthal 1997).

Thus, in this thesis, we aim to extend our understanding of virtuality and explore how virtuality (adversely) influences virtual teams' performance. Specifically, we focus on Information System Development (ISD) teams and look at two aspects of virtuality – geographical separation and use of IT-mediated communication, as these are the characteristics making virtual teams different from co-located ones. In our conceptual development, we treat geographical dispersion as a multidimensional construct, following O'Leary and Cummings (2007), and examine spatial and temporal dimensions of the geographical dispersion. Further, we examine the consequences of use of IT-mediated communication, such as loss and distortion of information. In this work, we explore the following research questions: *What are the effects of spatial and temporal dispersion on virtual team performance? Moreover, what is driving the effects of spatial and temporal dispersion?*

In order to answer the research questions, we employ a computational modelling approach using simulation by extending the *NK* fitness landscape model (Kauffman 1993) to model the different dimensions of virtuality. Our setting allows us to manipulate the key factors, which affect virtual teams' performance and observe the changes in agents' behaviours and performance at the population level. Overall, we find that spatial dispersion has a stronger impact than temporal dispersion, and that the overall effect is mostly driven by distortion of information, rather by loss of information. The negative impact of temporal dispersion is driven by indirect, rather than by direct, effect, and these effects can be mitigated by increasing the possibilities of interactions and by assuring that team members are pursuing a common goal, rather than working on multiple goals.

This thesis has both important theoretical and practical implications. From a theoretical perspective, we are able to systematically model and study the overall effects of spatial and temporal dispersion on virtual team performance. We also deepen this understanding by teasing out the effects of the components of dispersion: distortion vs. loss of information as components of spatial dispersion and overlapping interactions and goal (mis)alignment as components of temporal dispersion. From a practical perspective, we generate insights into management of the virtual teams, and provide guidance on where to place the distributed teams, how to coordinate communications and where to focus the efforts for different levels of project complexity.

The organization of the thesis is as follows. First, a review of the literature on management of virtual teams is presented in Chapter 2. Next, the motivation and choice of methodology are presented in Chapter 3, and the details of research methodology are provided in Chapter 4. The details of our experiments are presented in Chapter 5. The experiment results and their empirical validation are presented in Chapter 6. Finally, the theoretical and practical contributions of the thesis, followed by the limitations and the suggestions for future research are presented in Chapter 7.

CHAPTER 2: Literature Review

As we aim to understand the impacts of virtuality on teams' performance, we organize the literature review as follows. First, we review previous research on the first component of virtuality, which is geographical dispersion. Second, we review the literature on the second component of virtuality, which is use of IT-mediated communication. Third, we review the literature on the control variable – project complexity.

2.1 Geographical Dispersion

In the virtual team context, geographical separation is a multidimensional construct comprising of spatial, temporal and configurational dimensions. The spatial dimension corresponds to average distance among team members, temporal dispersion corresponds to number of overlapping work hours, and configurational dispersion corresponds to number of locations, at which team members are located (O'Leary and Cummings 2007).

As each of dimensions can be manipulated at any level of granularity, which would overly complicate the computational model and theory development, a choice has to be made in order to adequately scope this thesis. Here, we focus on the temporal and spatial dimensions, while leaving the configurational dimension for future research.[1]

Temporal Dispersion

Temporal dispersion is a dimension of geographical dispersion, which occurs when teams work in the different time zones. Temporal dispersion can be seen

---

[1] A discussion of how the computational model can be extended to incorporate the configurational dimension of dispersion is presented in Chapter 7.

as the extent to which team members' normal work hours overlap, as overlapping working hours allow team members to communicate in real time and concurrently solve problems collectively. Temporal dispersion is amplified with geographical distance, and it perplexes synchronous interactions thus making coordination of teamwork very challenging (O'Leary and Cummings 2007).

Prior research shows that the major ***direct consequence*** of temporal dispersion is collaboration delay, and this happens when virtual teams working in different times must collaborate asynchronously. It should be noted that collaboration delay can happen in a traditional, co-located settings due to various circumstances, such as absence of a colleague due to business trip, vacation leave, etc. However, in the virtual team setting the likelihood of facing collaboration delay is substantially higher, as there is a temporal separation among team members, among all other possible reasons.

As dispersed team members can make use of IT, one may expect that IT can help reduce collaboration delay, as team members can access information systems at any time, and extract the necessary data. Contrary to this expectation, as it was shown by Cummings and colleagues (2009), the use of synchronous and asynchronous information technologies does not significantly reduce collaboration delay, especially in the absence of overlapping work hours.

Thus, based on these arguments and findings of Cummings et al. (2009), we make two assumptions: [1] probability of collaboration delay is substantially higher for the case of virtual teams; and [2] collaboration delay is a consequence of temporal dispersion.

Further, we argue that collaboration delay, being a consequence of temporal dispersion, influences virtual teams' performance. The large proportion of prior studies has found a negative effect of collaboration delay (i.e., Espinosa et al. 2007b, Kankanhalli et al. 2006); while Warkentin and Beranek (1999) reported that collaboration delay can lead to both negative and positive consequences. The survey respondents indicated that delays and lags limited their communications, made them inefficient, and impeded the formation of consensus, while at the same time, the survey respondents also mentioned that such a setting allowed them to have more time to think through the issues and reply more carefully (Warkentin and Beranek 1999).

Thus, we can observe that from the subjective perspective of team members the collaboration delay can be even beneficial, and at the same time, when objective measures are employed, collaboration delay was shown to decrease the performance. In this thesis, we use objective measures of performance, and favouring approach of Espinosa et al. (2007a), we consider a gradation of time zone separation. We model three scenarios of temporal dispersion, namely: no overlapping working hours, partially overlapping working hours and fully overlapping working hours.

This gradation allows us to compare three stylized cases; however, it should be noted that these cases can be observed in real world. For example, if one site is located in East Asia and the other site is located in the east coast of US, there is a 12-hour difference between sites and thus there is no overlapping working hours. Two sites located in the east and west coasts of the US would represent the case of partial overall in working hours, and finally, one site in Singapore and the other in Beijing which share the same time zone, would be an example of fully overlapping working hours. It should be noted that here we assume that employees, working in the different temporal zones, are not likely to adjust their schedule to have more opportunities for real-time synchronous collaboration, and thus the probability of collaboration delay increases with time difference.

In addition to collaboration delay, which is a direct effect of temporal dispersion, we consider ***the indirect effect*** of collaboration delay. Using the result of Kankanhalli et al. (2006), we argue that task conflict is likely to occur due to a lack of immediacy of feedback. Task conflict implies that team members have different points of view regarding the team tasks. Thus, team members engage in independent work, and pursue their own goals, without taking into consideration the implications of their decisions for the other team members or for the whole project. Task conflict, or pursuing multiple goals (as compared to pursuing one common goal), was shown to hurt the performance, and make project management very challenging (Ethiraj and Levinthal 2009, Kankanhalli et al. 2006).

Overall, we expect the direct effect of temporal dispersion to decrease the performance of virtual teams, which is in line with previous findings (Espinosa et al. 2007b, Kankanhalli et al. 2006). Further, we argue that temporal separation has additional indirect effects, which is goal (mis)alignment. We expect goal (mis)alignment to hinder team performance, and we aim to assess and compare the magnitude of direct and indirect effects on virtual team performance.

Spatial Dispersion

Spatial dispersion is another dimension of geographical dispersion, and it emerges when virtual team members are *geographically* separated (i.e., team members work in different offices, cities or countries). Geographical distance is a measure of spatial dispersion, and the likelihood of spontaneous face-to-face communications drops rapidly as the distance between working sites increases (Allen 1977). Team members resort to relying on information and telecommunication technologies for collaboration (O'Leary and Cummings 2007).

Currently, our theoretical understanding of the effects of *spatial dispersion* remains limited. This may be in part due to a rather simplistic view of spatial dispersion in prior research. Although the effects of dispersion are expected to vary by *degree of dispersion* (O'Leary and Cummings 2007), prior research employed simple and direct measures of spatial dispersion. For instance, spatial dispersion was coded as a binary variable (geographically dispersed vs. collocated teams, as in Espinosa et al. 2007b), as a categorical variable (7-point Likert scale, ranging from collocated teams to teams working in different countries, as in Espinosa et al. 2012), or as physical geographical distance (Gajendran et al. 2012, Joshi et al. 2009). Despite a simplified view of spatial dispersion, researchers have established that spatial dispersion leads to decreased performance of virtual teams (Espinosa et al. 2007b). However, due to oversimplification it is not clear what exactly – i.e., which process at individual or group level – leads to decreased performance.

Interestingly, when approaching spatial dispersion, it was either compared to temporal dispersion, or not separated from temporal dispersion.

Specifically, researchers reported a larger effect of temporal dispersion as compared to spatial dispersion (Espinosa et al. 2012), or attributed the dispersion effects to both temporal and geographical dimensions without separating them (e.g., Gajendran and Joshi 2012, Joshi et al. 2009). Thus, there are two perspectives on the effects of spatial and temporal dispersion in virtual teams literature, namely: [1] a perspective, which assumes that temporal and geographical dimensions of dispersion are correlated, and thus need not be disentangled; or [2] a perspective, which assumes that temporal and spatial dispersion should be separated and assessed separately, as they lead to different coordination challenges (Espinosa et al. 2012).

In this study, we follow the second perspective and argue that spatial and temporal dispersions need to be assessed separately. Based on the findings from previous research on virtual teams (e.g., Espinosa et al. 2012), we expect that spatial dispersion will lead to decreased performance of the virtual team. However, instead of conceptualizing spatial dispersion as geographical distance, we focus on the consequences of spatial dispersion and assess the potential implications of IT-mediated communications. We do so, as we rely on the following logic: spatial separation in terms of distance does not affect the way virtual team members use IT. It is rather obvious that use of synchronous (e.g., Skype) or asynchronous (e.g., email) technologies does not change with varying distance – i.e., the means of communication will work the same whether the recipients are 20 or 200 km apart from each other. Thus, it is not necessary to capture the exact geographical distance between virtual team members, as it will not show the effect of separation. Rather, we shift our focus to the consequences of use of IT-mediated communication.

2.2 Consequences of use of IT-mediated communication

The second aspect of virtuality is reliance on IT-mediated communication, which enables communication among virtual team members. However, despite its enabling role, IT-mediated communication has some limitations, which can adversely impact the performance of virtual teams.

One of the major limitations of IT-mediated communication is that ***information*** maybe ***lost*** or ***distorted*** during the transfer through IT-mediated channels (Kayworth and Leidner 2002). Loss or distortion happens due to technology's inability to convey social presence; specifically, technology cannot transfer nonverbal and paraverbal cues (Kayworth and Leidner 2002, Walther and Burgoon 1992). Nonverbal (e.g., eye movements, facial expressions, gestures, and body language) and paraverbal (e.g., tone of voice, inflections and voice volume) cues are important parts of the communication process, as they help to convey subtle meanings, facilitate turn taking during communication, and regulate the conversation flow (Shim et al. 2002). The absence of such nonverbal and paraverbal cues in synchronous text-based computer-mediated communication has been shown to have a significant negative effect on team effectiveness (Baltes et al. 2002).

The severity of such loss depends on the richness of technology being used: the richer the technology, the more it can convey (Kayworth and Leidner 2002). Thus, leaner technology, such as email, leads to more severe loss or distortion, as compared to richer technology, such as audio- and video-conference calls. For example, Byron and Baldrige (2005) showed that in email exchange the same email text was interpreted differently by different readers: a long email suggested negative emotion beyond the message to part of the group, while another part of the group interpreted the long email as carrying a positive emotion.

Further, Byron (2008) argued that such emotional inaccuracy could lead to two effects, namely neutrality and negativity. Both of the effects reflect the tendency of recipients to misinterpret the message: neutrality effect means that recipients will convey positive emotions are more neutral than intended by the sender, while negativity effect means that recipients will convey the neutral message as more negative as intended by the sender. Thus, we can see the examples of how use of an information technology can lead to information distortion and loss (Table 1).

Table 1. Examples of Information Distortion and Loss

The effect	**Description of the effect**	**Interpretation**
Neutrality effect	Positive message is interpreted as neutral – the information about positive emotion is lost.	**Information loss**: “When subordinates inaccurately perceive emails intended to convey positive emotion as more neutral, they receive **inaccurate information** about what behaviors elicit positive emotion from their superiors…” (Byron 2008, p. 321)
Negativity effect	Neutral message is interpreted as negative – the information about neutrality is distorted.	**Information distortion**: “When email receivers perceive an email sender as more angry than intended, they may receive **distorted information** about their past performance and desired future performance…” (Byron 2008, p. 322).

Further, information can be lost or distorted in the process of IT-mediated communication not only due to misinterpretation of the message, but also due to the misunderstanding of the personality of a message sender. This misunderstanding can happen due to the process of *dehumanization*, which is the ignorance of some human qualities of others, like emotions or feelings (Alnuaimi et al. 2010). As message recipients are likely to rely on knowledge about sender when interpreting the message emotional context (Byron 2008), dehumanization can strengthen the neutrality or negativity effects, and thus lead to bigger information loss and distortion.

Thus, group members using IT-mediated communication can experience loss or distortion of information, which happens due to inability of IT-mediated channels to completely convey social presence. This limitation of technology can be exaggerated in case of virtual teams, because virtual team members tend to come from different cultures. As cultural differences lead to language barriers, different attitudes, expectations and behaviours (Levina and Vaast 2008), virtual team members interpret the messages through their culture biases (Kayworth and Leidner 2002), and some information can be lost or distorted.

Overall, we argue that due to the limitations of IT-mediated communication, namely inability to convey social presence and dehumanization, some information can be lost and distorted. This loss or distortion can be exacerbated in virtual team setting due to different cultural background of team members. We expect that both loss and distortion will hinder the performance of virtual teams. As there were no prior systematic research on loss and distortion in virtual teams’ setting, we aim to compare the impacts of loss and distortion in order to understand, whether it is better to rely on partial or incorrect information.

2.3 Coordination Complexity

In addition to virtuality of the team, we also consider the complexity of group work tasks (i.e., project complexity), which is an important characteristic of ISD projects. Generally, complexity arises when there are a large number of elements, which interact with each other in non-trivial ways. Firstly, it is difficult for a person to comprehend the entire structure that binds the elements; second, in case a person can understand the structure, it is difficult for her to predict the effects of interactions among the system elements (Ethiraj and Levinthal 2004). Complexity increases as number of elements increases and the entire system gets larger, as there are more possibilities for interaction among the elements.

In the context of information system development, such understanding of complexity implies that a team member, working on a particular module of a system should carefully consider how the changes in a focal module would affect other related modules (i.e., see *structural complexity* in work of Espinosa et al. 2007b). For example, if a frontend developer implements user interface changes, which transform the input field to dropdown list, she should consider the respective changes in the backend database.

Previous research established that structural complexity plays a significant role in virtual team performance: as complexity increases, teams tend to perform worse, even if the team members are familiar with tasks and team members (Espinosa et al. 2007b). However, there is still a lack of systematic research on project complexity, since it is difficult to directly observe or manipulate this construct.

Our research approach allows us to manipulate project complexity directly, and observe the performance implications of virtual teams under different levels of project complexity. In line with prior research results, we expect virtual teams’ overall performance to decrease as project complexity increases. We aim to observe how different configurations of virtual teams perform under different levels of complexity.

This page is intentionally left blank.

CHAPTER 3: Research Approach

3.1 Motivation beyond the Research Approach

This thesis adopts the computational modelling and simulation approach to conduct a computational analysis of the implications of virtuality in ISD teams. Computational modelling and simulation approach is a method, which employs computer software to model various events, processes or systems (Davis et al. 2007). To utilize this method, a researcher has to create a "computational representation of the underlying theoretical logic that links constructs together" (Davis et al. 2007, p. 481). After creation of such representation, the researcher can run the software under different experimental conditions, so she can get results and analyse them to draw conclusions. Thus, a simulation approach can be seen as a virtual experiment, where computer software is used to vary the theoretical constructs of interest.

Davis and colleagues (2007) argue that simulation can be used not only for description, exploration, but also for theory building. Use of simulation for theory building is suitable for cases, when a *simple* theory exists but the phenomenon of interest is more nuanced than what the simple theory can fully explain. A *simple* theory implies that there are few constructs, which are linked by propositions, but the theory is limited by a rough theoretical logic, only few propositions or weak conceptualizations of constructs. In addition, simulation is useful for cases, when phenomenon of interest involves nonlinear effects, time delays, or complex interactions, and simulation approach can uncover nonintuitive insights through theoretical elaboration. In these cases, the simple theory can be expanded, because simulation enforces theoretical precision and enables the researcher to conduct systematically a variety of controlled experiments, ranging from incremental ones (where just one or two constructs are added) to elaborate ones (where alternative logic can be tested).

In the management literature, the simulation method has been successfully applied to address a variety of organizational policy questions, such as dealing with multiple goals (Ethiraj and Levinthal 2009), management of innovations (Almirall and Casadesus-Masanell 2010, Ethiraj and Levinthal 2004), choices of appropriate organizational form (Siggelkow and Rivkin 2005), and choices of managerial structure (Rivkin and Siggelkow 2003), among others (See Davis et al. 2007 for overview). As for the information systems literature, simulation-based studies are still nascent, but have been applied to study information systems development (Hahn and Lee 2011, Yeo and Hahn 2014) and online communities (Oh et al. forthcoming).

As with every other research method, simulation approach has its strengths and weaknesses. The strengths of simulation approach are high construct validity, as the approach requires accurate specification and measurement of theoretical constructs; high convergent and discriminant validities, as simulation studies avoid measurement errors, and high internal validity (Davis et al. 2007). As for the weaknesses, the external validity of simulation studies is often questioned.

Alternatively, we had a choice between conducting a field study and solving the formal mathematical model, as simulation is a “sweet spot” between formal modelling, multiple case studies and theory-testing studies, such as surveys or experiments (Davis et al. 2007). Field studies such as surveys and case studies provide the realism and rich data, but may be limited in the several ways. First, it is time and resource consuming to conduct surveys or interviews with a large sample of companies and employees, and the study findings will be of a limited generalizability. Second, performance of the virtual teams is a sensitive topic and thus the interviewees or survey respondents may not report on the difficulties and the real reasons of the project failures, despite the anonymity of the setting. Finally, it is **impossible to manipulate the dimensions of dispersion and project complexity in a field setting**, thus the results of surveys or field studies can be limited in their internal validity. Another alternative, which is mathematical/analytical models, allows one to conduct rigorous formal analysis. However, a problem solver must rely on and justify simplifying assumptions for analytical tractability. As a result, such a model cannot fully represent the richness of actual organizations. Thus, we employ the computational modelling methodology, which **frees the manipulation of the theoretical constructs of interest**. Our modelling allows us to incorporate a greater number of interdependent elements than in a closed-form analytical approach, and thus we can acquire theoretical insights through variations of combinations of experimental conditions and achieve generalizability (Amaral and Uzzi 2007, Davis et al. 2007).

Specifically to our research topic, choice of the computational modelling and simulation gives us **two important benefits**. First, the model allows us to **clearly differentiate** the effects of spatial and temporal dispersion, while controlling for project complexity. This differentiation is important as the effects of spatial and temporal dispersion tend to be correlated in real world, but each type of dispersion leads to different coordination challenges (Espinosa 2012). Thus, it is important to understand the separate effect of each type of dispersion. Second, the model provides us a setting where we can **observe and record the performance of virtual teams**. As simulation model is free from measurement errors (Davis 2007), and allows us to obtain an objective measure of performance, it is especially beneficial in context of ISD teams, since a measurement of teams' performance is a complex task (Maynard et al. 2012).

3.2 Choice of Simulation Approach

In accordance to Davis et al. (2007), existing simulation approaches differ in their underlying theoretical logic, research focus, key assumptions and types of research questions, that can be explored with a given simulation approach. From the point of theoretical logic, we can choose between models, which are based on descriptive logic (*system dynamics* and *cellular automata*), models, which are based on optimization problems (*genetic algorithms* and *NK fitness landscape* models), or *stochastic process* model.

The *system dynamics* approach focuses on understanding of how causal relationships among constructs influence the behaviour of a system, and can be used to understand the initial system states, which lead to abrupt, nonlinear changes, such as catastrophes, tipping points, etc.

The *cellular automata* approach focuses on the emergence of macro level patterns from micro level interactions among semi-intelligent agents. The agents are assumed to influence each other, but their influence diminishes with distance between them. Thus, cellular automata are useful for examining dynamics of such processes as propagation, diffusion, segregation and competition.

The *genetic algorithms* approach focuses on adaptive learning of a heterogeneous agents composed of genes, and adaptation occurs through a process of evolution, which favours the gradual improvement. These algorithms are applied to understand whether a dominant form of agents emerges, or to reveal what affects the rate of learning, change or adaptation.

The *stochastic* process approach is a flexible approach that does not make any specific assumptions about the theoretical logic, research question or system. Thus, they are usually applied when research question and theory does not fit to any of the structured approaches, or the modifications of the structured are so extensive, that they can result in poor computational representation.

NK fitness landscapes model is an analytical framework for studying adaptive behaviours of goal-oriented agents (Kauffman 1993). A problem environment is characterized with set of *N* elements, and *K* interactions among the elements, and the agents are assumed to adapt to problem environment in search of an optimal point. The *NK fitness landscape* approach is applicable to explore the time necessary to reach the optimal point, effectiveness at the optimal point, and how system characteristics (e.g., number of nodes and interaction among them), types of adaption, or environment influence the performance at optimal point, and time to reach it.

Among the various simulation approaches, we employ the *NK* fitness landscapes model (Kauffman 1993, Levinthal 1997), as we are interested in performance of virtual teams, and specifically, we aim to understand how such characteristics of the team, as geographical dispersion, influence team performance in the face of different problem environments characterized by project complexity.

3.3 Application of NK fitness landscapes model to ISD

The *NK* fitness landscapes approach was extended to model adaptive agents' goal-oriented problem-solving process in modular systems, and to statistically find the speed and effectiveness of adaptation to an optimal performance (Davis et al. 2007). Thus, to apply *NK* fitness landscape model to information system development in virtual teams, we must show that ISD process can be conceptualized as result-oriented problem-solving process.

At the conceptual level, organizational problem solving generally can be characterized as an iterative process consisting of three phases (Simon 1947). During the first phase the organization identifies the gap between existing and desired states, and this phase is followed by evaluation of possible actions. During the final stage decision makers implement the chosen action to reduce the gap between existing and desired states. The process is iterative and incremental because the implemented action may not fully solve the problem. We argue that ISD projects progress in a similar way: ISD project consists of information collection, processing and feedback (Newell and Simon 1972). First, during information collection, a problem is identified by the project team; second, during the processing phase the implementation ideas are generated and evaluated by team members; finally, the team chooses the best approach and implements it. As implementation team gets feedback, the ISD process is generally iterative and the information systems may be modified several times before its formal launch. Thus, information system development can essentially be seen as search within a configuration space, where the project team searches for the best system configuration to deliver the biggest value to the organization.

Thus, we have shown that ISD can be seen as organizational problem solving process in which implemented information system creates value for an organization (Hahn and Lee 2011, Yeo and Hahn 2014). Consequently, we can apply *NK* fitness landscape approach to model ISD in virtual teams.

This page is intentionally left blank.

CHAPTER 4: A Model of Information System Development as Design Problem Solving by Virtual Teams

4.1 The *NK* Fitness Landscape Model

In the *NK* fitness landscapes setting, two primary modelling constructs must be specified – 1) the decision space (i.e., a fitness landscape), and 2) the agent's behavioural rules for goal-oriented adaptation (Hahn and Lee 2012). The decision space represents the variety of choices an agent can select from while performing the adaptation. Agent's behavioural rules determine *how* the agent is choosing from available options in the process of adaptation.

In the *NK* fitness landscapes setting, a decision space is specified as a fitness landscape. Essentially, fitness landscape maps all system configurations (i.e., organizational form) to different fitness values. The fitness landscape is initialized by specifying the fitness value of each of the 2^N possible system configurations, where N is the number of attributes of a system. For example, if a system consists of three elements, there are eight possible system configurations. For each possible system configuration, each element in the N-length string may take on 2^{K+1} values depending on the value of the K other elements with which it interacts. For example, if $K=2$, each of eight configurations can have $2^{2+1} = 8$ combinations, and each combination has its value. To get the value for each of these combinations, a random number is assigned, where the random number is drawn from a uniform distribution ranging from zero to one (Levinthal 1997).

The shape of the fitness landscape depends on the interaction among the elements: for very low K with little interaction, the corresponding landscape is smooth and there is one optimal point, and as *K* increases, landscape becomes more rugged with several local optima, and thus adaptation becomes harder as agents may stick to local points and never reach the globally optimal point (Levinthal 1997).

As for behavioural rules, agents are assumed to engage in hill-climbing to navigate around the neighbourhood within the landscape in search for the higher fitness values by adjusting their design choices (Davis et al. 2007). Such search process is called *local search*, and it is assumed that agents are able to identify the forms in their immediate neighbourhood whose fitness value is superior to their current level of fitness, and able to modify the single attribute that differs between two forms so as to achieve this higher level of fitness (Levinthal 1997).

Thus, basic *NK* model allows us to create a population of variety of agents, which are characterized with *N* nodes, and *K* interactions among nodes ($N = K$-1). Using *N* and *K*, we can generate the decision space for agents, namely we can create the fitness landscape. After the landscape is created, we can seed the agents on it and observe how they climb on the hills searching for the best point. Agents move each period, and we can observe their performance at the end of simulation process: essentially, the fitness value of the point the agent has reached represents the performance of the agent.

4.2 Application of Basic *NK* Model to ISD Project Teams

We apply basic *NK* model as following: we assume that each ISD team is working on one project, and thus project performance equals ISD team performance, or in other words, we assess ISD team performance by the performance of the project. *N* represents all the decisions that need to be made in the ISD process (i.e., design choices) while K indicates the ISD project coordination complexity, which is determined by the degree of interactions among ISD decisions.

Representing the ISD Project and its Performance

An ISD project P, is conceptualized as a set of configurations (i.e., configurations for business process requirements and technical systems specifications, etc.) and can be parsimoniously represented by a set of N decision variables, $P = \{d_1, d_2, \dots, d_N\}$, where each decision d_i can take on either one of the two possible values (0, 1). For example, decision d_1 can represent a design choice of whether a system should have Web interface (0 – no, 1 – yes), d_2 – a business process requirement choice of whether a system should have a mobile app, d_3 – a technical choice regarding architecture, etc.

Each decision contributes to overall project performance, and at the same time, the value of this contribution of each decision depends not only on the choice made concerning that decision (i.e., d_i=0 or 1) but also on choices regarding K other decisions – i.e., $c_i = c_i(d_i|K \text{ other } d_j\text{'s})$, where c_i is a contribution of an each decision choice. In other words, each configuration decision may be tightly linked to other ones, if $K > 0$.

Thus, the performance of the project, $F(P)$, depends on the performance contributions of all decisions based on the interdependencies among them and can be measured as the average of the *fitness* contributions of all decisions:

$F(P) = \sum c_i/N$, where

- $F(P)$ – fitness value of the project
- P – ISD project, consisting of the N design choices $d_1, d_2, \dots, d_N$

- $c_i = c_i(d_i|K \text{ other } d_j\text{'s})$ contribution of each design choice, and
- K – number of interdependencies among elements.

For example, if we have a project with $N = 3$ design choices and $K = 2$ (each element depends on another), to get the fitness value of the project, we must do the following calculations. First, we must calculate the contribution of each design choice: $c_1 = c_1(d_1|d_2, d_3)$, $c_2 = c_2(d_2|d_1, d_3)$ and $c_3 = c_3(d_3|d_1, d_2)$, meaning that we account not only for contribution of the design choice, but also for interaction among the elements. Second, we must get the average of the contributions of each design choice: Fitness value $(d_1, d_2, d_3) = (c_1 + c_2 + c_3) / 3$.

Representing ISD Teams and Their Behaviour

The virtual team is composed of M sub-teams that may be spatially and/or temporally dispersed. Each sub-team is responsible for N/M decisions. For simplicity, we focus on the simplest case where there are two sub-teams (i.e., $M = 2$), thus we have an ISD project split between two sub-teams, and each sub-team is responsible for their own half of the decisions. However, the choices of one sub-team can affect the performance of the entire team, as sub-teams search for the better configuration together, and move in the decision space as one entity. This corresponds to real life situation, when a technical choice (i.e., choice of the development environment) affects a quality assurance team, as they have to follow the developers team's choices.

The agents' (ISD sub-teams') adaptive behaviours are modelled as incremental experiential search. The agents perform local search for the configuration decisions they are responsible for, attempting to enhance the performance. In each simulated period, the agents select a neighbouring decision configuration at random (out of the decision variables that are within their scope), and evaluate the performance implications of the new configuration. A neighbouring configuration is one that differs from the current configuration with respect to one configuration decision. If the new configuration results in a performance increase, the configuration is adopted and implemented; else, it will be discarded.

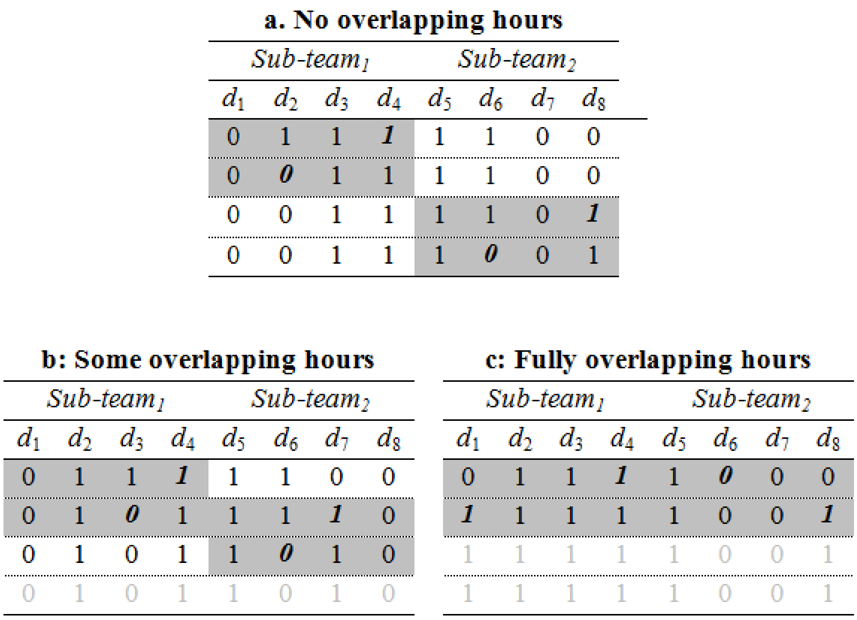
Note that we assume bounded rationality of the agents. In our context, this means that agents sample the available alternatives, evaluate them based on perceived fitness value, and make decisions without understanding the structure of interdependencies. Further, we assume that agents do not consider distant configurations (i.e., long jumps).

4.3 Extensions of Basic *NK* Model

Modelling Temporal Dispersion

The order in which the sub-teams make configuration decisions depends on the structure of temporal dispersion. As discussed above, there are three scenarios: no overlap of working hours (Scenario 1), some overlap in working hours (Scenario 2), and complete overlap of working hours (Scenario 3).

For exposition, take P = <0,0,1,0,1,1,0,0> as the current configuration for an ISD project (i.e., N=8). Sub-team 1 is responsible for configurations d_1~d_4 whereas sub-team 2 is responsible for configurations d_5~d_8 (i.e., P = <P_1, P_2>, where P_1 = <0,0,1,0> and P_2 = <1,1,0,0>). Further, we assume that each site can make two decisions per day. For example, in Figure 1a we illustrate the case without overlapping working hours (Scenario 1), and each row shows one decision of the team. Site 1 has to decide for d_1~d_4 across two time periods; then site 2, which starts working on the following day, makes decisions for configurations d_5~d_8 with has information about Site 1's updated configuration decisions for two time periods.



a. No overlapping hours

Sub-team₁				*Sub-team₂*			
d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8
0	1	1	***1***	1	1	0	0
0	***0***	1	1	1	1	0	0
0	0	1	1	1	1	0	***1***
0	0	1	1	1	***0***	0	1

b: Some overlapping hours

Sub-team₁				*Sub-team₂*			
d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8
0	1	1	***1***	1	1	0	0
0	1	***0***	1	1	1	***1***	0
0	1	0	1	1	***0***	1	0
0	1	0	1	1	0	1	0

c: Fully overlapping hours

Sub-team₁				*Sub-team₂*			
d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8
0	1	1	***1***	1	***0***	0	0
1	1	1	1	1	0	0	***1***
1	1	1	1	1	0	0	1
1	1	1	1	1	0	0	1

Notes: The grey rows represent when decisions are being made. The decisions are highlighted by the bold/italics typesetting. The values in grey represent idle periods where neither site is making a decision (i.e., off-hours).

Figure 1 Temporal Dispersion

When there are some overlapping working hours (Scenario 2), then the sites collaborate both synchronously (during overlapping work hours) and asynchronously (during non-overlapping work hours). For simplicity we assume that the sites have half of their working hours overlapping (see Figure 1b). Therefore, during the first half of site 1's working hours, site 1 makes decisions about configurations d_1~d_4 while taking information about site 2's decisions (d_5~d_8) from the previous day. During the second period when both sites share working hours, the two sites concurrently make decisions for their respective configurations. During the third period, site 1 goes off work and site 2 keeps on working for the rest of its workday. Finally, when working hours are completely overlapping (Scenario 3), then the two sites make decisions concurrently. In this case two sites make decisions together based on all eight decision factors (but search locally within each site's decision scopes).

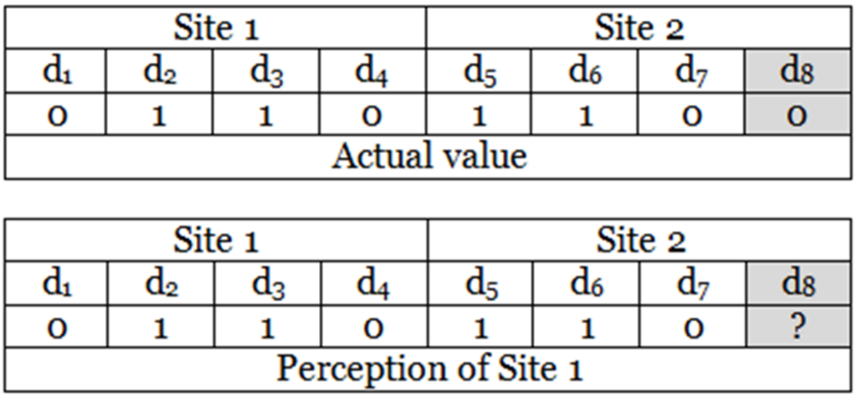
As discussed earlier, a consequence of overlapping work hours is that the work activities of the other site become more salient. In other words, when not working concurrently, each site is less likely to observe the other site working, so it will be less unaware of the contributions and importance of the other site's work. To incorporate such goal mis-alignment, we define a goal alignment parameter $v \in [0,1]$ which represents the extent to which each site considers the configuration choices of the other sites into its own decision making. Thus, each site, when making a decision will consider the performance implications of the project configuration where the fitness contributions of the other site's decisions are discounted by the alignment parameter:

$$F(P_1) = \frac{\sum_{i=1}^{N/2} c_i + v\left(\sum_{i=N/2+1}^{N} c_i\right)}{N} \quad \text{and} \quad F(P_2) = \frac{v\left(\sum_{i=1}^{N/2} c_i\right) + \sum_{i=N/2+1}^{N} c_i}{N}$$

such that when $v = 1$, then there is full alignment and the fitness contributions of the other site's decisions are not discounted. However, then $0 \leq v < 1$, then there will be discounting due to goal mis-alignment. For the three temporal dispersion scenarios, we set $0 \leq v < 1$ when the two sites are working asynchronously (i.e., always for Scenario 1 and during non-overlapping work hours for Scenario 2) and set $v = 1$ whenever the two sites are making decisions concurrently (i.e., during the overlapping hours for Scenarios 2 and always for Scenario 3). We vary the extent of goal mis-alignment by setting the v parameter to low vs. high values (e.g., $v = 0.2$ for severe goal mis-alignment vs. $v = 0.8$ for slight goal mis-alignment).

Modelling Spatial Dispersion: Consequences of IT-mediated Communication

As we discussed before, IT-mediated collaboration may result in two possible consequences – 1) information loss and 2) information distortion. Information loss appears when a site does not capture part of the other site's configuration decisions (Figure 2). When a site is making a decision, there is some non-trivial probability p_L that some of the information about the other site's configuration is not effectively transmitted. For example, if the current project configuration is $P = <0,0,1,0,1,1,0,0>$, and site 1 is considering $P_1 = <0,0,1,1>$ given $P_2 = <1,1,0,0>$, it may be possible (with probability p_L) that one of the configuration settings within the purview of site 2 (e.g., d_6) is lost in transmission. As a result, site 1 would make its decision given $P_2 = <1,1,?,0>$.

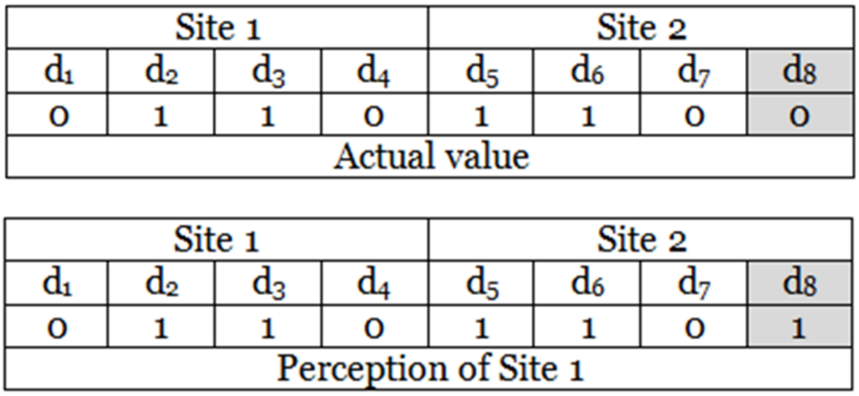


Site 1				Site 2			
d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8
0	1	1	0	1	1	0	0
Actual value							

Site 1				Site 2			
d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8
0	1	1	0	1	1	0	?
Perception of Site 1							

Figure 2. Information Loss

Information distortion occurs when a site incorrectly perceives part of the other site's configuration decisions. When a site is making a decision, there is some non-trivial probability p_D that some of the information about the other site's configuration is incorrectly transmitted (Figure 3). Using the same example above (i.e., with P = <0,0,1,0,1,1,0,0>, and site 1 is considering P_1 = <0,0,1,1> given P_2 = <1,1,0,0>), it may be possible that (with probability p_D) that one of the configuration settings within the purview of site 2 (e.g., d_7) is incorrectly understood. As a result, site 1 would make its decision given P_2 = <1,1,1,0> instead of <1,1,0,0> (i.e., $d_7 = 0$ switched to $d_7 = 1$).



Site 1				Site 2			
d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8
0	1	1	0	1	1	0	0
Actual value							

Site 1				Site 2			
d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8
0	1	1	0	1	1	0	1
Perception of Site 1							

Figure 3. Information Distortion

This page is intentionally left blank.

CHAPTER 5: Parameterization and Experiment Design

We adopt a full factorial design for the simulation experiments. At the aggregate level, there are two levels of spatial dispersion and three levels of temporal dispersion, resulting in six experimental groups (Table 2). In order to attribute the performance impacts to different consequences of spatial and temporal dispersion (i.e., information distortion vs. loss effects for spatial dispersion, and goal-alignment effects for temporal dispersion), we also manipulate these parameters.

For spatial dispersion, there are three lower-level settings when there is spatial dispersion – 1) spatial dispersion with information loss only, 2) spatial dispersion with information distortion only, and 3) spatial dispersion with both information loss and information distortion. For temporal dispersion, we manipulate goal alignment at two levels (i.e., high vs. low).

Table 2. Experimental Groups

	Spatial Dispersion	
Temporal Dispersion	**Co-located**	**Spatially dispersed**
Fully overlapping work hours	Group 1	Group 2
Partially overlapping work hours	Group 3[2]	Group 4
No overlapping work hours	Group 5	Group 6

Prior research using *NK* fitness landscapes model have used *N* ranging from 6 to 16 (e.g., Siggelkow and Rivkin 2005, Siggelkow and Rivkin 2006, Almirall and Casadesus-Masanell 2010). For $N = 16$, there are $2^{16} = 65{,}536$ possible configurations of the ISD project, and it is not practical to perform an

---

[2] Note that Groups 3 and 5 are not observed in ISD practice, but we use them as a baseline to estimate the effects

exhausting search through all of these configurations. Thus, to generate the fitness landscapes corresponding to ISD projects of sufficient size, N is set as 16 in this study. Moreover, the qualitative nature of the results of NK studies remains the same even with greater N (e.g., $N = 20$), but the requirements for computational resources increase exponentially (Hahn and Lee 2012).

For goal alignment and probabilities of information loss and distortion, we set the values such that the manipulations are non-trivial. Monte Carlo techniques are used to minimize any spurious effects due to initial settings. All results are based on 100 independently generated fitness landscapes for each level of complexity (K). The outcome of interest (i.e., dependent variable) is the performance of the virtual team, which is fitness value of the ultimate configuration the virtual team reaches as a conclusion to its search. The search is over, once the ISD project has reached a stable status, in other words, further performance improvements cannot be made. Table 3 summarizes the parameterization.

Table 3. Experimental Parameter Settings

Construct	**Parameter**	**Values**	**Notes**
Project size	N	16	Fixed
Project complexity	K	{0, 1, …, 15}	Variable
Goal alignment	v	{0.2, 0.8} for low vs. high	Variable
Information loss probability	p_L	0.25	Fixed
Information distortion probability	p_D	0.25	Fixed

CHAPTER 6: Results

6.1 Effects of Team Virtuality and Complexity

To assess the impact of virtuality and complexity, we have compared the ultimate performance[3] of four stylized types of ISD teams. These are co-located teams (*no spatial dispersion*) and three types of spatially distributed teams, including distributed synchronized teams (*fully overlapping work hours*), distributed phased teams (*partially overlapping work hours*) and distributed asynchronous teams (*no overlapping work hours*). Figure 4 shows the performance of all teams under the different levels of project complexity: low, moderate and high.

Immediately, we observe that co-located teams outperform distributed teams, and this result is consistent across all complexity levels. In accordance to Powel and colleagues (2004), prior research had reported mixed findings with respect to the differences in performance of co-located and virtual teams. Specifically, one part of prior studies showed that traditional teams outperformed their virtual counterparts, another part of prior studies reached the opposite conclusion, and the other part of prior studies had not found the differences in performance of traditional and virtual teams. At the same time, Powel et al. (2004) reported that the large proportion of prior studies found that co-located teams outperformed virtual teams with respect to the *effectiveness of information exchange*. Our result is consistent with the findings regarding information exchange, because we assume that virtual teams are different from co-located teams in the way they communicate (i.e.,

---

[3] Ultimate performance was the highest performance a team could reach at the end of simulation process

they use IT-mediated communication), and the communication means of virtual teams is inferior as compared to the communication means of traditional team (i.e., due to distortion or loss of information).

Next, we observe that ultimate performance decreases with increase of project complexity: the more complex the project is, the lower the performance levels the project teams can reach. This result is consistent with prior research, which has shown that project complexity may hinder teams' performance (i.e., Espinosa et al. 2007b, Espinosa et al. 2012).

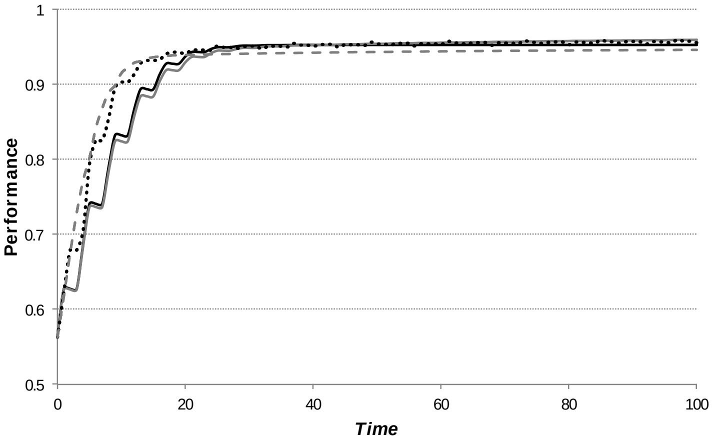
Next, we compare the effects of temporal and spatial dispersion in ISD teams. It should be noted that a distributed synchronized team is influenced by spatial dispersion (i.e., distortion and loss of information), while phased and asynchronous teams experience the effects of spatial and temporal dispersion simultaneously. As can be seen from Figure 4a, for the case low complexity (K = 1, Figure 4a), there is less need for coordination of the teams' efforts, and distributed teams may be more effective initially, and reach almost the same ultimate performance levels as the co-located teams do. Low complexity implies that there are not many dependencies among the decisions of distributed team members, and thus both co-located and virtual team members can effectively perform their search.

However, as project complexity increases, we observe a stronger effect of virtuality. As can be seen from Figure 4b, for case of moderate complexity (K = 8) co-located teams outperform others, and they are followed by synchronized teams, and teams with temporal dispersion perform worse than the other teams. As the performance of teams with temporal dispersion is not much worse than performance of synchronized team, we conclude that spatial dispersion affects the performance more, as compared to temporal dispersion.

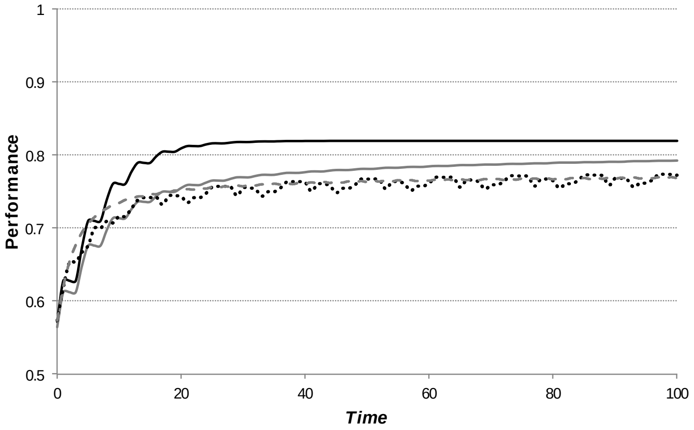
We observe almost the similar pattern for the case of high complexity (K = 15, Figure 4c): co-located teams reach the highest performance levels, while distributed teams perform much worse. Distributed synchronized team reaches stable performance, while the performance of temporarily dispersed teams fluctuates. These fluctuations indicate that teams are inefficient in their search, and can result in changing their fitness value to a lower one, when they have to make decision in situation of collaboration delay and/or goal misalignment.

Thus, we conclude that spatial dispersion has a stronger impact on ultimate performance of ISD teams, as compared to temporal dispersion. This result differs from prior findings of Espinosa et al. (2012), which has reported that time separation has a stronger negative effect on virtual team performance, as compared to spatial separation.

a. Low Complexity ($K = 1$)



b. Moderate Complexity ($K = 8$)



c. High Complexity ($K = 15$)

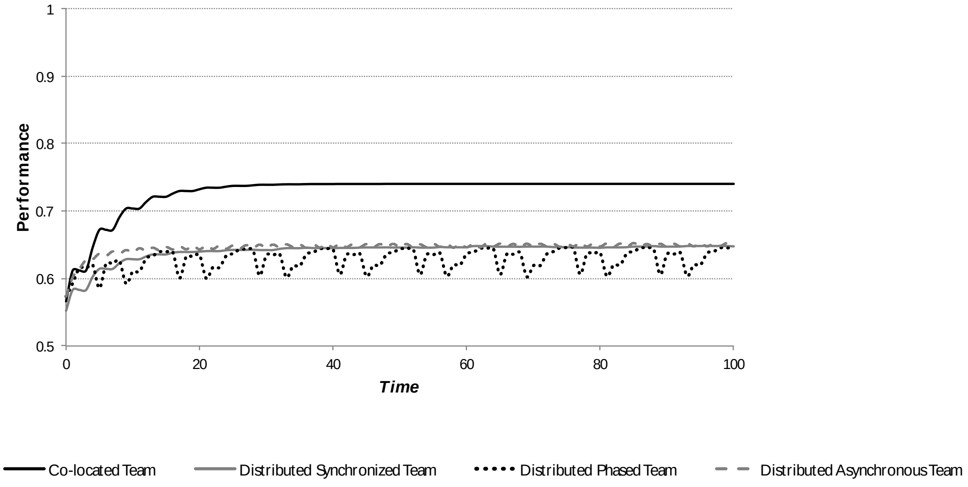


Figure 4. Overall of ISD Teams Performance over Time

However, there is a substantial difference between this work and work of Espinosa et al. (2012). Espinosa and colleagues (2012) used different research approach, and they employed different measures of spatial, temporal separation and team performance. For spatial separation, the authors used 7-pt categorical scale, including the following items: 1: same room, 2: same hallway, 3: same floor, 4: same building, 5: different building, 6: different city, 7: different country. For temporal separation, the authors considered the maximum time zone span between team members. The performance was measured using three factors: completion on time and within the budget and meeting of product requirements.

Our model relies on the assumption that technology use does not degrade in effectiveness with distance, thus we do not consider physical distance explicitly. Instead, we focus on consequences of use of IT-mediated communication, such as distortion and loss of information. For temporal dispersion, our model is similar, as we consider the possible cases, ranging from no synchronous work hours to fully overlapping work hours. Finally, our measure of ISD team performance is different: we measure the effectiveness of the team instead of using a combination of three factors.

In addition, we observe that as temporal dispersion increases, performance of the distributed ISD team tends to worsen. For instance, Figure 4b shows that for moderate levels of complexity, a synchronized distributed team outperforms two other distributed team types and demonstrates a slowly increasing performance trend. As complexity increases to a very high level (Figure 4c), the synchronized team keeps slowly increasing performance over time, whereas performance of two other distributing teams fluctuates. This implies that in case of spatial dispersion, it is important to minimize the temporal dispersion across the sites. Our findings are in line the results of a laboratory experiment on gradation of overlapping working hours (Espinosa et al. 2007a): the authors reported that performance (accuracy of results) declined as teams had less overlapping hours.

Proposition 1: Effects of spatial and temporal dispersion under different complexity levels

In virtual ISD teams, spatial dispersion among team members has a stronger impact, as compared to temporal dispersion, and this effect is observed for substantially complex projects, where the decisions of team members affect the work of the other team members.

6.2 Effects of Spatial Dispersion: Loss and Distortion

Further, to reveal what is driving the impact of spatial and temporal dispersion, we have estimated two regression models and obtained the effect sizes for components of spatial and temporal dispersion. Both models were estimated on aggregated data: for model [1], we aggregated the observations across different cases of information loss and distortion; for model [2], we aggregated the observations across different cases of temporal dispersion and goal alignment. Both models were estimated using the OLS estimator in the STATA statistical package.

To assess the effect of the information loss and distortion, we have estimated the following model:

$$Performance = InformationLoss + InformationDistortion + Both + ErrorTerm, \qquad [1],$$

Where

- *Performance* is a dependent variable, which represents the ultimate performance of the agent.
- *InformationLoss* is an independent variable, which is coded as the following: “1” – the probability of information loss is 0.25, “0” – otherwise.
- *InformationDistortion* is an independent variable, which is coded as the following: “1” – the probability of information distortion is 0.25, “0” – otherwise.
- *Both* is a control variable, which is coded as the following: “1” – the probability of information loss is 0.25 and the probability of information distortion is 0.25, “0” – otherwise.

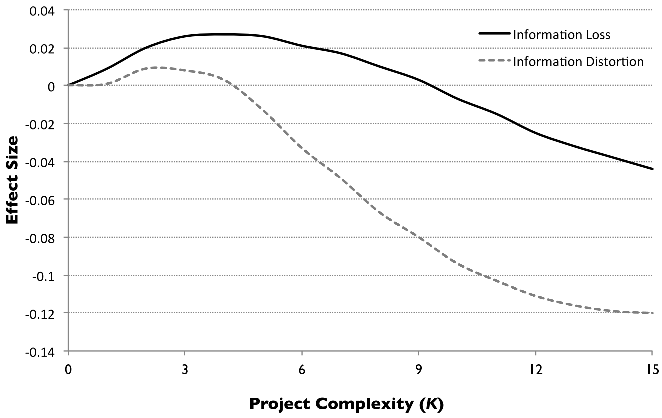
  Note: This is not a variable of our interest, we use it to control for the interaction of information loss and distortion (e.g., for cases, when information got lost and distorted).
- *Error* represents the omitted variables, which we have excluded from our estimation (e.g., the starting point of the agent, etc.).

We have run the separate regression estimations for different levels of complexity, and have obtained the standardized coefficients for each case. The estimation results are shown in Appendix A, and for illustration purposes we plot the effect sizes (beta-coefficients) over the different levels of complexity (Figure 5a).

Figure 5a shows how the negative impact of information loss and distortion changes with project complexity: the more complex projects suffer more from both information loss and distortion. We observe that information distortion has a stronger impact than information loss, and this implies that relying on partial information is better than relying on full, but incorrect information.

To verify the robustness of these results, we have tried estimation of the models on the data with different level of aggregation: we have split the data sample into three samples, which represent the different temporal settings, and we re-run the models for different levels of complexity. Our result is robust across the different temporal settings. The estimation results are reported in Appendix C.

a. Information Loss vs. Information Distortion



b. Direct vs. Indirect Effects of Temporal Dispersion

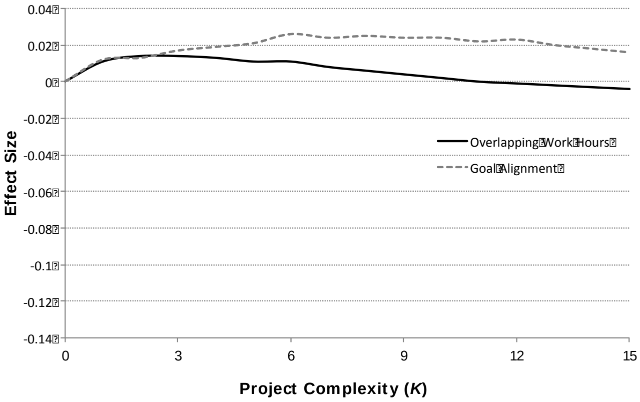


Figure 5. Effect Sizes of Spatial and Temporal Dispersion

Proposition 2: **Effects of information loss and distortion under different complexity levels**

In virtual ISD teams, distortion of information has a stronger impact than loss of information, and this effect is amplified with project complexity: the more complex projects are more susceptible to information distortion and loss, as compared to simpler projects.

6.3 Effects of Temporal Dispersion: Direct and Indirect

Next, to assess the effect of the direct and indirect components of temporal dispersion, we have estimated the following model:

$$Performance = OverlappingHours + Goal\ Alignment + ErrorTerm, \quad [2],$$

Where

- *Performance* is a dependent variable, which represents the ultimate performance of the agent.
- *Overlapping hours* is an independent variable, which is coded as the following: “-1” no overlapping working hours, “0” – some overlapping working hours; “1” full overlapping working hours.

  This variable captures the direct effect of temporal dispersion.
- *Goal alignment* is an independent variable, which is coded as the following: “1” means low goal alignment, “0” – otherwise.

  This variable captures the indirect effect of temporal dispersion.
- *Error* represents the omitted variables, which we have excluded from our estimation (e.g., the starting point of the agent, etc.).

We have run the separate regression estimations for different levels of complexity, and have obtained the standardized coefficients for each case. The estimation results are shown in Appendix B, and for illustration purposes we plot the effect sizes over the different levels of complexity (Figure 5b).

As can be seen from Figure 5b, the indirect effect is stronger than the direct one: increase in goal alignment improves performance to larger extent as compared to simple increase in overlapping working hours. This implies that a project manager should not only increase the possibilities of communication, but also inspire the interactions among the virtual team members, so the team members align their goals and consider the overall implications of their decisions.

To test the robustness, we have estimated the extended model, in which we have controlled for the spatial dispersion. The data sample was aggregated in a different way, as compared to original estimation, so we could get the effects of spatial dispersion. Our result is robust across the different spatial settings. The estimation results are reported in Appendix D.

Proposition 3: **Direct and indirect impact of temporal dispersion under different complexity levels**

In virtual ISD teams, improving goal alignment of a virtual team members helps to improve project performance more, as compared to simply providing virtual team members with more opportunities to collaboration simultaneously (i.e., by adjusting the working schedules of both sides), and this effect becomes stronger with increase of project complexity.

6.4 Summary of Results

The results of the study are summarized in Table 4.

Table 4. Summary of Results

##	Result	Consistent with prior research
1	Co-located teams outperform virtual teams.	Yes (Powel et al. 2004)
2	Teams' performance decreases as project complexity increases.	Yes (Espinosa et al. 2007b, Espinosa et al. 2012)
3	**Proposition 1:** **Effects of spatial and temporal dispersion under the different complexity levels** In virtual ISD teams, spatial dispersion among team members has a stronger impact, as compared to temporal dispersion, and this effect is observed for substantially complex projects, where the decisions of team members affect the work of the other team members	No (Espinosa et al. 2012)
4	ISD performance decreases, as temporal separation increases	Yes (Espinosa et al. 2007a)
5	**Proposition 2**: **Effects of information loss and distortion under different complexity levels** In virtual ISD teams, distortion of information has a stronger impact than loss of information, and this effect is amplified with project complexity: the more complex projects are more susceptible to information distortion and loss, as compared to simpler projects.	No prior research on: [1] assessment of impacts of information distortion and loss [2] comparison of effects of information distortion and loss
6	**Proposition 3:** **Direct and indirect impact of temporal dispersion under different complexity levels** In virtual ISD teams, improving goal alignment of a virtual team members helps to improve project performance more, as compared to simply providing virtual team members with more opportunities to collaboration simultaneously (i.e., by adjusting the working schedules of both sides), and this effect becomes stronger with increase of project complexity.	No prior research on: [1] assessment of direct and indirect effects of temporal dispersion [2] comparison of effects of information distortion and loss

6.5 Empirical Validation of the Results

Validation of the computational model is an important step in the simulation-based theory development process (Davis et al. 2007). As computational models have a high level of abstraction, the validity of computational models is assessed with a different set of criteria, as compared to empirical models (Burton and Obel 1995). Specifically, to assess the validity, a researcher must assess ***content*** and ***construct validity***. For the ***content validity***, researcher must ensure that the model is built in a way it yields outcomes corresponding to the real world. To ensure that our model produces outcomes, corresponding to the real world, we verified that our basic results are in line with prior research. Specifically, we have showed that (1) teams' performance decreases with project complexity and (2) co-located team outperforms virtual teams. These findings are consistent with prior research (Espinosa et al. 2007b, Espinosa et al. 2012, Powel et al. 2004) and thus our model exhibits content validity.

Further, to assess the ***construct validity***, a researcher has to answer the question of whether the computational representation makes sense to a group of experts. In other words, group of colleagues or industry experts should judge whether model captures the important aspects of phenomenon, and if the findings can be interpreted with respect to their experience. From theoretical perspective, the assumptions of *NK* fitness landscape model are consistent with information system development process, which was documented in the literature (Hahn and Lee 2011, Yeo and Hahn 2014). To ensure that the model assumptions reflect current software development practices, we conducted face-to-face interviews with industry experts. We interviewed the employees of large international company operating in *travel technology*. The company owns more than 100 branded points of sale in more than 60 countries, and has approximately 14,000 employees working in more than 30 countries. A select group of employees worked on different aspects of software development, including UI design and backend development. All of the interviewed employees collaborate with colleagues located in different geographical locations on daily basis, and thus they were a pool of experts familiar with aspects of virtual collaboration, as well as with information systems development. During the interviews, we presented the experts our research questions, model and results. The experts agreed with our stylized computational representation of virtual teams in terms of configuration (split of the project into parts between parts of virtual teams), the way we presented development process (as the search for the best solution), the way we presented project complexity (as the number of dependencies among the decisions) and effects of temporal and spatial dispersion (increased possibilities of collaboration delay, difficulties in communication, and possible information delay or loss). The experts admitted that they could relate the findings to their practical experience, and that research has important implications for their daily operations. Thus, we have ensured both content and construct validity, and validated our computational model and results.

This page is intentionally left blank.

CHAPTER 7: Conclusion

7.1 Discussion

In this thesis, we aim to fill the gap in understanding the impact of virtuality and complexity on ISD teams' performance. To do so we use a simulation approach, which allows us to develop a computational representation of the key theoretical factors and manipulate them in simulation experiments. We have extended *NK* fitness landscape model in order to model the components of virtuality.

We have considered two components of virtuality, which are geographical separation and use of IT-mediated communications. We have conceptualized geographical separation as temporal and spatial dispersion, and have argued that each of these dimensions of geographical separation leads to unique managerial challenges. Geographical separation increases the opportunities for collaboration delay among team members (direct effect), which in turn leads to goal (mis)alignment (indirect effect). Spatial dispersion increases the reliance on IT-mediated communication, which in turns leads to distortion and loss of information due to inability of technology to fully convey social presence.

We have extended *NK* model to represent six stylized types of ISD teams: co-located and virtual teams with different cases of temporal dispersion. As co-located teams without overlapping working hours or with partially overlapping working hours are rarely observed in information system development practice (except for the cases of technical support), we compared the performance of four types of teams (co-located team and three virtual teams with different temporal dispersion).

We have found that spatial dispersion has a stronger impact than temporal dispersion under moderate to high complexity, and that this impact is amplified with project complexity. Our finding was different from prior research on virtual teams, and we have attributed this difference to the fact that prior research employed direct measures of spatial dispersion, rather than considering the consequences of IT-mediated communication, such loss and distortion of information.

We have found that impact of spatial dispersion is mostly driven more by distortion of information, than by information loss, and this implies that it is better to rely on partial knowledge than on incorrect information. Finally, we have found that goal alignment (an indirect effect of temporal dispersion) has a stronger impact on temporally distributed teams' performance, as compared to collaboration delay (a direct effect of temporal dispersion). Thus, simply reducing the temporal dispersion (i.e., increasing the number of overlapping working hours) would not help to improve project performance, because team members need to align their decisions to work on achieving a common goal.

7.2 Theoretical and Practical Implications

Our work has important theoretical and managerial implications. From a theoretical perspective, we have *systematically* analysed the impacts of two major factors of virtuality (geographical separation and reliance on IT-mediated communication channels) under different levels of complexity. This systematic approach is important, as the previous body of theoretical knowledge is limited to several cases, whereas simulations allowed us to study the continuum, including extreme points (e.g., from collocated teams working on a very easy project to completely separated teams working on a very complex project).

Moreover, the use of *NK* fitness model allowed us to create a computational representation of the existing theory, and conduct experiments to tackle the challenges, which could not be approached from a perspective of a field researcher. For instance, if one is employing a survey, it is rather difficult to distinguish between spatial and temporal dispersion effects, as there may be measurement error (i.e., employers are not sure whether the effect is due to spatial or temporal dispersion or something else). Next, it is rather hard to find a suitable measure of a project (team) performance, which would be *comparable,* such that teams can be compared faithfully.

Next, our study explained the drivers beyond the temporal and spatial dispersion. Instead of imposing the temporal and spatial dispersion (i.e., creating time difference and varying the distance) and observing the performance implications, we considered the theoretical implications of temporal and spatial dispersion. For temporal dispersion, we accounted not only for a direct effect, which is collaboration delay, but also for goal (mis)alignment, which is a consequence of collaboration delay. For spatial dispersion, we argued that virtual team members experience loss and distortion of information, and that loss or distortion do not depend on geographical distance between team members. Instead, we showed that loss and distortion are the consequences of the use of information technology and its characteristics.

Current management methodologies, such as PRINCE / PMBOK, contain guidelines about ensuring goal alignment and putting efforts to overcome national or organizational cultural barriers. However, it is still unclear how exactly different levels of goal alignment (e.g., high vs. low) or distortion and loss of information during IT-mediated communication affect the performance, and how this effect is different under the different temporal and spatial settings. The existing literature has not addressed such questions as whether high level of goal alignment can overcome low / high information distortion and loss, or whether high level of goal alignment is helpful when a team works on a highly complex project. We have brought up these questions, and believe that future research can further extend the theory, using our work as a foundation.

Finally, the taken approach is a study at the population level, as we model different types of rational agents, seed them on the different landscapes and observe the population level results. Prior research has been conducted at the individual, dyadic or group levels, whereas the studies on population outcomes are mostly absent in virtual / outsourcing literature. Thus, our study has systematized and extended the prior literature and laid the foundation for further investigation.

From a practical perspective, we hope that our findings will help managers to make informed decisions during the preparation and management stages of virtual teams' management (Hertel et al. 2005). During preparation stage, the main tasks are ***determination of team virtuality*** and ***personnel selection*** (Hertel et al. 2005). The first task during the preparation stage is to determine the degree of virtuality of the team. The degree of virtuality of a team comprises team distribution, work-place mobility and variety of work practices (Chudoba et al. 2005), or in other words, the degree of virtuality refers to ISD team configuration over space, time and sites. Thus, we hope that manager can consider the complexity of a project (simple, moderate and complex) and decide ***whether a project should be implemented in a virtual setting***, i.e., if the project is low-to-moderately complex, virtuality of a team would not impact the ultimate project performance, thus a project can be implemented in virtual setting, and if the project is moderately-to-highly complex, the virtuality of the team may severely hurt project performance, and more coordination efforts will be necessary to successfully execute a project in a virtual setting.

If a project must be implemented in a virtual setting despite its high level of complexity, we believe that a manager can ***adjust the level of virtuality*** in order to mitigate the effects of spatial and temporal dispersion for moderately and highly complex projects. Spatial dispersion implies that team members rely on IT-mediated communications and may suffer from information distortion or loss. Thus, at the preparation stage a manager can allocate functions in a way such that extensive collaboration among units is reduced, thus ongoing collaboration becomes less intense (Carmel and Agarwal 2001) and thus there would be less severe repercussions of information distortion and loss as there would be fewer opportunities coordinated interaction. Temporal dispersion results in collaboration delay and goal misalignment, thus a manager should maintain at least some overlapping work hours between sites if there is a possibility to do so.

The second task during project preparation stage is personnel selection (Hertel et al. 2005), and given the project virtuality and complexity, there may be a need for hiring personnel who meets the specific requirements. For example, if company chooses to follow “75/25 rule of thumb”, when 75% of employees are allocated offshore and 25% are onshore, 25% of the employees would serve as a bridge between clients and 75% of the team (Carmel and Agarwal 2001). Thus, if project is substantially complex, the bridging employees must be experienced and culturally assimilated in order to help alleviating the effects of spatial and temporal dispersion. Another example is when a company choose to have a cultural liaison, who is a project manager or executive who travels between the sites. Similarly, a cultural liaison must be experienced and culturally assimilated (Carmel and Agarwal 2001). Thus, a manager can consider the complexity of project, foresee the potential distortion and loss of information, and hire a culturally assimilated person, which would help mitigating the negative consequences of IT-mediated communication.

Next, during management stage, the manager is required to manage different aspects of virtual teams, such as performance, communications, knowledge and motivation (Hertel et al. 2005). Thus, we hope that given our findings, a project manager can better manage the communications within the team members and put additional effort to mitigate the potential information distortion and loss, and to ensure the necessary level of goal alignment. For instance, consider a project manager working on a complex project; the team can use asynchronous collaboration tools (e.g., emails, software requirements and task management systems) and synchronous tools (e.g., instant messaging, audio or video calls). A project manager can establish regular audio and video conference calls to ensure the goal alignment of a team, reduce collaboration delay (i.e., solve the immediate questions) and reduce the distortion and loss of information, as audio and video calls are richer technologies, as compared to emails and task management systems.

7.3 Limitations and Future Research Directions

Despite the advantages of our analytical setting, our study has several limitations. First, we focus only on the effects on spatial and temporal dispersion in case of a virtual ISD team with two geographically dispersed sites. Real ISD projects are usually more complex than their simulated versions because they may have more design decision factors ($N > 16$). Further, there are several important factors such as different management styles, team composition, development methodology (e.g., Agile vs. Waterfall), and all of them may have impact on the ISD performance. Second, we do not include the impact of configurational dimension (number of sites) of virtual teams, which is also an important factor. In order to assess the impact of configurational dimension, our model can aptly be extended further. For example, to model different management styles, we can add a manager, who is leading her sub-team and is responsible for decisions within the team. In order to represent the different management style, two parameters may be needed: leadership competency and technical competency. Leadership competency will capture the ability of a manager to facilitate knowledge and information sharing. Leadership will be represented as the degree to which the manager cares the ramifications of her actions on other sub-teams, and thus will capture how well the manager understands not only her scope of responsibility, but also the scope of the entire project. Technical competency will capture the ability of a manager to understand the solutions, which are suggested by the team. Technical competency can be varied from extreme points, such as a rubberstamping manager, who is only checking the delivery time / budget, to an active manager, who is an experienced technologist herself. Next, to model the various team compositions, we can vary the distribution of decisions among sub-teams (i.e., equal distribution, as it is implemented in current thesis; “rule of thumb” distribution with 25/75, “extreme” distribution 5/95 to represent the case where manager is separated from the rest of the team). Alternatively, we can add a parameter for changing the probability of information loss and distortion, as more variability in team composition is associated with increased probability of misunderstanding due to cultural biases (Kayworth and Leidner 2002).

To model various development methodology, we can follow approach of Yeo and Hahn (2014). To represent different information system development methodologies, a research can consider two stylized types of met, which are Agile and Waterfall. These stylized types bring the main difference between Agile and Waterfall methodologies, namely: completing several small subprojects (Agile) vs. completing one big project (Waterfall). To model Agile projects, we can split the decisions within sub-teams into modules, model the iterations, and change the search process in such way that a sub-team will be searching for better fit only within part of the system (module). For instance, during first iteration only module 1 is improved, during second iteration module 1 and 2 are improved, and so on. Thus, an Agile team will incrementally implement the project. To model Waterfall projects, no changes need to be made – each period a sub-team can consider all decision variables and look for a better fit. Finally, to understand the impact of configurational dimension, we can increase the number of sub-teams from 2 to 3, 4, 5 and re-run the experiments using the various temporal and spatial configurations.

Third, our model did not incorporate the concept of team and/or task familiarity. Familiarity refers to knowledge of employees about the aspects of their work, and this knowledge accumulates as team members work together (Espinosa et al. 2007b). As task and team familiarity were shown to be important factors, which can help the distributed teams to perform better, it is necessary to understand if these factors can help distributed team members and their managers to overcome the effects of information loss, distortion and goal misalignment. In order to study the concept of familiarity, a different research approach should be used: for instance, one can design and execute a laboratory study using several teams of 3-4 members. To model spatial dispersion, team members can be asked to use only emails (lean technology and high probability of distortion and loss) or can be asked to use Skype (rich technology and low probability of distortion and loss). To model temporal dispersion, team members either can be placed in different time zones, or asked to “work” in a certain time span, i.e., member 1 is working 8-10 am; member 2 is working 9-11 am and so on.

Goal misalignment should be measured, rather than manipulated, and a researcher should develop the instrument. To model task familiarity, a researcher can either model the task and hire participants (un)familiar with types of tasks, or allow participants to have different time to familiarize with the tasks (i.e., have training tasks vs. not having training tasks during experiment). Finally, to model team familiarity a researcher can hire the participants who know each other (i.e., students from one study group) and the participants who do not know each other (i.e., students from different universities).

Thus, a researcher can run the following series of experiments: (1) moderate level of complexity, no temporal dispersion, 2x2 between subject experiment: high vs. low probability of distortion/loss, familiar vs. non-familiar task (team); (2) moderate level of complexity and temporal dispersion, 2x2 between subject experiment: high vs. low probability of distortion/loss, familiar vs. non-familiar task (team). Alternatively, one can conduct a survey or in-depth qualitative study in order to save resources, such as time and money.

Finally, we believe that future research can enrich the theory by considering the differences between temporary and ongoing distributed teams. Temporary and ongoing distributed teams are different in terms of their structure, collaboration processes and outcomes (Saunders and Ahuja 2006). Saunders and Ahuja (2006) argue that cause of the differences between temporary and ongoing distributed teams is life span of their tasks, and any team with a (perceived) finite time limit is considered temporary. The perception of life span leads to different psychological outcomes, for instance, the authors argue that periodic face-to-face meetings are more effective in case of ongoing teams, rather than in case of temporal teams. In order to investigate the direct and indirect effects of temporal and spatial dispersion in ongoing and temporal distributed teams, one can conduct a survey or qualitative study, as extension of *NK* fitness model is not possible in this case, and manipulation of the independent variable (ongoing vs. temporal) is not possible either.

BIBLIOGRAPHY

Amaral, L. A. N., & Uzzi, B. (2007). Complex systems-a new paradigm for the integrative study of management, physical, and technological systems. *Management Science*, 53(7), 1033-1035.

Allen, T. J. (1977). *Managing the flow of technology: Technology transfer and the dissemination of technological information within the R & D organization*. *MIT Press*.

Almirall, E., & Casadesus-Masanell, R. (2010). Open versus closed innovation: A model of discovery and divergence. *Academy of Management Review*, 35(1), 27-47.

Alnuaimi, O. A., Robert, L. P., & Maruping, L. M. (2010). Team size, dispersion, and social loafing in technology-supported teams: A perspective on the theory of moral disengagement. *Journal of Management Information Systems*, 27(1), 203-230.

Baltes, B. B., Dickson, M. W., Sherman, M. P., Bauer, C. C., & LaGanke, J. S. (2002). Computer-mediated communication and group decision making: A meta-analysis. *Organizational Behavior and Human Decision Processes*, 87(1), 156-179.

Bergiel, B. J., Bergiel, E. B., & Balsmeier, P. W. (2008). Nature of virtual teams: a summary of their advantages and disadvantages. *Management Research News, 31(2)*, 99-110.

Burton, R. M., & Obel, B. (1995). The validity of computational models in organizational science: From model realism to purpose of the model. *Computational and Mathematical Organizational Theory*, 1(1), 57-71.

Byron, K., & Baldridge, D. C. (2005, August). Toward a model of nonverbal cues and emotion in email. In *Academy of Management Proceedings*. Academy of Management.

Byron, K. (2008). Carrying too heavy a load? The communication and miscommunication of emotion by email. *Academy of Management Review*, 33(2), 309.

Carmel, E., & Agarwal, R. (2001). Tactical approaches for alleviating distance in global software development. *IEEE Software*, 18(2), 22-29.

Chudoba, K. M., Wynn, E., Lu, M., & Watson-Manheim, M. B. (2005). How virtual are we? Measuring virtuality and understanding its impact in a global organization. *Information Systems Journal*, 15(4), 279-306.

Cummings, J. N., Espinosa, J. A., & Pickering, C. K. (2009). Crossing spatial and temporal boundaries in globally distributed projects: A relational model of coordination delay. *Information Systems Research*, 20(3), 420-439.

Gajendran, R. S., & Joshi, A. (2012). Innovation in globally distributed teams: The role of LMX, communication frequency, and member influence on team decisions. *Journal of Applied Psychology*, 97(6), 1252.

Davis, J., Bringham, C., & Eisenhardt, K. (2007). Developing Theory through Simulation Methods. *Academy of Management Review*, 32(2), 480-499.

Espinosa, J. A., Nan, N., & Carmel, E. (2007). Do gradations of time zone separation make a difference in performance? A first laboratory study. In *Second IEEE International Conference on Global Software Engineering*, IEEE, 12-22.

Espinosa, J. A., Slaughter, S. A., Kraut, R. E., & Herbsleb, J. D. (2007). Familiarity, complexity, and team performance in geographically distributed software development. *Organization Science*, 18(4), 613-630.

Espinosa, A., Cummings, J. N., & Pickering, C. (2012). Time separation, coordination, and performance in technical teams. *IEEE Transactions on Engineering Management*, 59(1), 91-103.

Ethiraj, S. K., & Levinthal, D. (2004). Modularity and innovation in complex systems. *Management Science*, 50(2), 159-173.

Ethiraj, S. K., & Levinthal, D. (2009). Hoping for A to Z while rewarding only A: Complex organizations and multiple goals. *Organization Science*, 20(1), 4-21.

Hahn, J., & Lee, G. (2011). Knowledge overlap in information systems development: An *NK* fitness landscapes model. *International Conference on Information Systems*. Shanghai.

Hahn, J., & Lee, G. (2012). Toward a Theory of Shared Domain Knowledge in Information Systems Development: A Complex Adaptive Systems Perspective. *Working Paper*.

Hertel, G., Geister, S., & Konradt, U. (2005). Managing virtual teams: A review of current empirical research. *Human Resource Management Review*, 15(1), 69-95.

Joshi, A., Lazarova, M. B., & Liao, H. (2009). Getting everyone on board: The role of inspirational leadership in geographically dispersed teams. *Organization Science*, 20(1), 240-252.

Kankanhalli, A., Tan, B. C., & Wei, K. K. (2006). Conflict and performance in global virtual teams. *Journal of Management Information Systems*, 23(3), 237-274.

Kauffman, S. (1993). *The Origins of Order: Self-Organization and Selection in Evolution*. New York: Oxford University Press.

Kayworth, T. R., & Leidner, D. E. (2002). Leadership effectiveness in global virtual teams. *Journal of Management Information Systems*, 18(3), 7-40.

Levina, N., & Vaast, E. (2008). Innovating or doing as told? Status differences and overlapping boundaries in offshore collaboration. *MIS Quarterly*, 32(2), 307-332.

Levinthal, D. A. (1997). Adaptation on rugged landscapes. *Management Science*, 43(7), 934-950.

Lipnack, J., & Stamps, J. (1997). *Virtual teams: Reaching across space, time, and organizations with technology*. Jeffrey Stamps.

Maynard, M. T., Mathieu, J. E., Rapp, T. L., & Gilson, L. L. (2012). Something (s) old and something (s) new: Modeling drivers of global virtual team effectiveness. *Journal of Organizational Behavior*, 33(3), 342-365.

Maznevski, M. L., & Chudoba, K. M. (2000). Bridging space over time: Global virtual team dynamics and effectiveness. *Organization Science,* 11(5), 473-492.

McDonough, E. F., Kahnb, K. B., & Barczaka, G. (2001). An investigation of the use of global, virtual, and colocated new product development teams. *Journal of Product Innovation Management*, 18(2), 110-120.

Newell, A., & Simon, H. A. (1972). *Human problem solving* (Vol. 104, No. 9). Englewood Cliffs, NJ: Prentice-Hall.

Oh, W., Moon, J.-Y., Hahn, J., & Kim, T. (forthcoming). Leader influence on sustained participation in online collaborative work communities: A simulation-based approach. *Information Systems Research.*

O'Leary, M. B., & Cummings, J. N. (2007). The spatial, temporal, and configurational characteristics of geographic dispersion in teams. *MIS Quarterly*, 31(3), 433-452.

Powell, A., Piccoli, G., & Ives, B. (2004). Virtual teams: a review of current literature and directions for future research. *ACM SIGMIS Database*, 35(1), 6-36.

Rivkin, J. W., & Siggelkow, N. (2003). Balancing search and stability: Interdependencies among elements of organizational design. *Management Science*, 49(3), 290-311.

Sarker, S., & Sahay, S. (2003). Understanding virtual team development: An interpretive study. *Journal of the Association for Information Systems*, 4(1), 1-38.

Saunders, C. S., & Ahuja, M. K. (2006). Are all distributed teams the same? Differentiating between temporary and ongoing distributed teams. *Small Group Research*, 37(6), 662-700.

Siggelkow, N., & Rivkin, J. W. (2005). Speed and search: Designing organizations for turbulence and complexity. *Organization Science*, 16(2), 101-122.

Simon, H. A. (1947). Administrative behavior; A study of decision-making processes in administrative organization. New York: Macmillan.

Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R., & Carlsson, C. (2002). Past, present, and future of decision support technology. *Decision Support Systems*, 33(2), 111-126.

Townsend, A. M., DeMarie, S. M., & Hendrickson, A. R. (1998). Virtual teams: Technology and the workplace of the future. *The Academy of Management Executive*, 12(3), 17-29.

Walther, J. B., & Burgoon, J. K. (1992). Relational communication in computer-mediated interaction. *Human Communication Research*, 19(1), 52-92.

Wakefield, R. L., Leidner, D. E., & Garrison, G. (2008). Research note - a model of conflict, leadership, and performance in virtual teams. *Information Systems Research*, 19(4), 434-455.

Warkentin, M., & Beranek, P. M. (1999). Training to improve virtual team communication. *Information Systems Journal*, 9(4), 271-289.

Yeo, Y. N., & Hahn, J. (2014). The Role of Project Modularity in Information Systems Development. *International Conference on Information Systems*, Auckland.

APPENDICES

Appendix A. Information Loss vs. Information Distortion

Table A1. The estimation results of the effects information loss vs. information distortion

VARIABLES	k=0	k=1	k=2	k=3	k=4	k=5	k=6	k=7
loss	0.000	0.004	0.009	0.011	0.011	0.009	0.005	0.002
	(0.011)	(0.010)	(0.010)	(0.009)	(0.008)	(0.007)	(0.007)	(0.006)
distortion	-0.000	-0.003	-0.002	-0.006	-0.011	-0.025***	-0.040***	-0.053***
	(0.011)	(0.010)	(0.010)	(0.009)	(0.008)	(0.007)	(0.007)	(0.006)
both	0.000	-0.002	-0.000	-0.007	-0.014*	-0.031***	-0.049***	-0.064***
	(0.011)	(0.010)	(0.010)	(0.009)	(0.008)	(0.007)	(0.007)	(0.006)
Constant	0.973***	0.925***	0.895***	0.874***	0.857***	0.841***	0.828***	0.816***
	(0.008)	(0.007)	(0.007)	(0.006)	(0.006)	(0.005)	(0.005)	(0.004)
Observations	404	404	404	404	404	404	404	404
R-squared	0.000	0.001	0.004	0.013	0.029	0.092	0.205	0.335
Adj. R-squared	-0.007	-0.006	-0.003	0.005	0.021	0.085	0.199	0.330

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table A1. Continued

VARIABLES	k=8	k=9	k=10	k=11	k=12	k=13	k=14	k=15
loss	-0.004	-0.009**	-0.017***	-0.022***	-0.030***	-0.035***	-0.040***	-0.045***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
distortion	-0.067***	-0.077***	-0.089***	-0.097***	-0.104***	-0.108***	-0.111***	-0.113***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
both	-0.080***	-0.092***	-0.105***	-0.113***	-0.121***	-0.126***	-0.129***	-0.131***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Constant	0.806***	0.796***	0.784***	0.775***	0.763***	0.755***	0.745***	0.734***
	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Observations	404	404	404	404	404	404	404	404
R-squared	0.486	0.598	0.701	0.767	0.817	0.851	0.876	0.896
Adj. R-squared	0.482	0.595	0.699	0.765	0.815	0.850	0.875	0.895

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Appendix B. Indirect vs. Direct Effects of Temporal Dispersion

Table B1. Estimation results of the direct and indirect effects of temporal dispersion

VARIABLES	k=0	k=1	k=2	k=3	k=4	k=5	k=6	k=7
Overlap	0.008**	0.002	0.002	0.001	0.001	0.002	0.004*	0.003
	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
GoalAlignment	0.000	0.012**	0.013**	0.018***	0.020***	0.022***	0.027***	0.026***
	(0.007)	(0.006)	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)
Constant	0.973***	0.931***	0.904***	0.883***	0.863***	0.841***	0.820***	0.800***
	(0.005)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)
Observations	606	606	606	606	606	606	606	606
R-squared	0.007	0.007	0.010	0.019	0.028	0.041	0.074	0.084
Adj. R-squared	0.003	0.004	0.007	0.016	0.025	0.038	0.071	0.080

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Notes: [1] *K* represents the complexity levels; [2] Variable ***Overlap*** represents the cases of no, some and full overlapping working hours, [3]

Variable ***GoalAlignment*** represent cases of low and high goal alignment

Table B1 (continued)

VARIABLES	k=8	k=9	k=10	k=11	k=12	k=13	k=14	k=15
Overlap	0.003	0.003*	0.002	0.001	0.001	0.001	-0.002**	-0.003***
	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
GoalAlignment	0.026***	0.026***	0.025***	0.024***	0.024***	0.022***	0.020***	0.018***
	(0.004)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Constant	0.800***	0.764***	0.744***	0.728***	0.712***	0.699***	0.685***	0.671***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	606	606	606	606	606	606	606	606
R-squared	0.084	0.125	0.146	0.157	0.189	0.192	0.192	0.199
Adj. R-squared	0.080	0.122	0.143	0.154	0.186	0.189	0.190	0.196

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Notes: [1] *K* represents the complexity levels; [2] Variable ***Overlap*** represents the cases of no, some and full overlapping working hours,

[3] Variable ***GoalAlignment*** represent cases of low and high goal alignment

Appendix C. Robustness Check 1: Loss and Distortion Effects in different temporal settings

Table C1: Case: No overlap of working hours

VARIABLES	k=0	k=1	k=2	k=3	k=4	k=5	k=6	k=7
loss	0.000	0.004	0.010	0.014*	0.014*	0.011*	0.006	0.003
	(0.010)	(0.009)	(0.008)	(0.008)	(0.007)	(0.006)	(0.006)	(0.005)
distortion	-0.000	-0.002	0.002	-0.002	-0.008	-0.024***	-0.042***	-0.053***
	(0.010)	(0.009)	(0.008)	(0.008)	(0.007)	(0.006)	(0.006)	(0.005)
both	0.000	-0.001	0.002	-0.004	-0.011	-0.030***	-0.050***	-0.064***
	(0.010)	(0.009)	(0.008)	(0.008)	(0.007)	(0.006)	(0.006)	(0.005)
Constant	0.980***	0.924***	0.893***	0.871***	0.853***	0.838***	0.825***	0.814***
	(0.007)	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)
Observations	404	404	404	404	404	404	404	404
R-squared	0.000	0.001	0.004	0.015	0.035	0.121	0.275	0.418
Adj. R-squared	-0.007	-0.006	-0.003	0.007	0.028	0.115	0.269	0.413

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table C1 (Continued)

VARIABLES	k=8	k=9	k=10	k=11	k=12	k=13	k=14	k=15
loss	-0.003	-0.008*	-0.015***	-0.020***	-0.028***	-0.032***	-0.036***	-0.040***
	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
distortion	-0.068***	-0.077***	-0.088***	-0.095***	-0.103***	-0.106***	-0.109***	-0.111***
	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
both	-0.080***	-0.091***	-0.103***	-0.111***	-0.119***	-0.123***	-0.126***	-0.128***
	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
Constant	0.804***	0.795***	0.784***	0.776***	0.765***	0.758***	0.749***	0.739***
	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Observations	404	404	404	404	404	404	404	404
R-squared	0.573	0.672	0.761	0.816	0.858	0.885	0.905	0.921
Adj. R-squared	0.570	0.670	0.759	0.815	0.857	0.884	0.905	0.920

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table C2. Case: Some overlap of working hours

VARIABLES	k=0	k=1	k=2	k=3	k=4	k=5	k=6	k=7
loss	0.000	0.003	0.007	0.007	0.006	0.004	-0.001	-0.006
	(0.011)	(0.010)	(0.010)	(0.009)	(0.008)	(0.007)	(0.006)	(0.006)
distortion	-0.000	-0.004	-0.005	-0.012	-0.019**	-0.035***	-0.052***	-0.066***
	(0.011)	(0.010)	(0.010)	(0.009)	(0.008)	(0.007)	(0.006)	(0.006)
both	-0.000	-0.003	-0.005	-0.014	-0.023***	-0.042***	-0.062***	-0.078***
	(0.011)	(0.010)	(0.010)	(0.009)	(0.008)	(0.007)	(0.006)	(0.006)
Constant	0.977***	0.932***	0.904***	0.883***	0.865***	0.849***	0.834***	0.823***
	(0.008)	(0.007)	(0.007)	(0.006)	(0.006)	(0.005)	(0.005)	(0.004)
Observations	404	404	404	404	404	404	404	404
R-squared	0.000	0.002	0.005	0.019	0.044	0.133	0.277	0.424
Adj. R-squared	-0.007	-0.006	-0.002	0.011	0.037	0.126	0.272	0.420

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table C2 (Continued)

VARIABLES	k=8	k=9	k=10	k=11	k=12	k=13	k=14	k=15
loss	-0.012**	-0.018***	-0.027***	-0.033***	-0.040***	-0.047***	-0.052***	-0.055***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
distortion	-0.081***	-0.093***	-0.105***	-0.112***	-0.118***	-0.123***	-0.125***	-0.125***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
both	-0.095***	-0.107***	-0.120***	-0.128***	-0.134***	-0.138***	-0.140***	-0.140***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Constant	0.811***	0.801***	0.789***	0.778***	0.766***	0.757***	0.747***	0.735***
	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Observations	404	404	404	404	404	404	404	404
R-squared	0.572	0.671	0.755	0.804	0.839	0.860	0.873	0.880
Adj. R-squared	0.569	0.669	0.753	0.803	0.838	0.859	0.872	0.879

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table C3: Case: Full overlap of working hours

VARIABLES	k=0	k=1	k=2	k=3	k=4	k=5	k=6	k=7
loss	0.001	0.005	0.011	0.013	0.014	0.013	0.011	0.007
	(0.013)	(0.012)	(0.011)	(0.010)	(0.010)	(0.009)	(0.008)	(0.007)
distortion	-0.001	-0.003	-0.001	-0.003	-0.006	-0.017*	-0.027***	-0.038***
	(0.013)	(0.012)	(0.011)	(0.010)	(0.010)	(0.009)	(0.008)	(0.007)
both	0.000	-0.001	0.001	-0.002	-0.007	-0.021**	-0.034***	-0.049***
	(0.013)	(0.012)	(0.011)	(0.010)	(0.010)	(0.009)	(0.008)	(0.007)
Constant	0.963***	0.921***	0.889***	0.869***	0.853***	0.837***	0.824***	0.812***
	(0.009)	(0.008)	(0.008)	(0.007)	(0.007)	(0.006)	(0.006)	(0.005)
Observations	404	404	404	404	404	404	404	404
R-squared	0.000	0.001	0.004	0.008	0.015	0.045	0.101	0.186
Adj. R-squared	-0.007	-0.006	-0.004	0.001	0.008	0.037	0.094	0.180

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table C3 (Continued)

VARIABLES	k=8	k=9	k=10	k=11	k=12	k=13	k=14	k=15
loss	0.003	-0.002	-0.008	-0.014***	-0.021***	-0.027***	-0.033***	-0.038***
	(0.006)	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)
distortion	-0.051***	-0.062***	-0.075***	-0.083***	-0.090***	-0.096***	-0.101***	-0.103***
	(0.006)	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)
both	-0.065***	-0.078***	-0.091***	-0.101***	-0.109***	-0.116***	-0.119***	-0.123***
	(0.006)	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)
Constant	0.801***	0.792***	0.780***	0.770***	0.759***	0.750***	0.740***	0.728***
	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
Observations	404	404	404	404	404	404	404	404
R-squared	0.311	0.428	0.551	0.640	0.710	0.764	0.804	0.839
Adj. R-squared	0.305	0.423	0.548	0.637	0.708	0.762	0.803	0.838

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Appendix D. Robustness Check 2: Indirect vs. Direct Effects in Different Spatial Settings

Table D1. Robustness check for the indirect and direct effects of temporal dispersion

VARIABLES	k=0	k=1	k=2	k=3	k=4	k=5	k=6	k=7
overlap	-0.008***	-0.002	-0.002	-0.001	0.000	0.001	0.003	0.002
	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
low	0.000	-0.011***	-0.011***	-0.015***	-0.016***	-0.017***	-0.020***	-0.019***
	(0.005)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
spatialdisp	0.000	-0.000	0.002	-0.000	-0.005	-0.016***	-0.028***	-0.038***
	(0.005)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Constant	0.973***	0.931***	0.901***	0.881***	0.865***	0.850***	0.838***	0.826***
	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
Observations	1,212	1,212	1,212	1,212	1,212	1,212	1,212	1,212
R-squared	0.007	0.006	0.008	0.013	0.020	0.043	0.109	0.183
Adj. R-squared	0.004	0.003	0.005	0.011	0.018	0.041	0.107	0.181

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table D1 (Continued)

VARIABLES	k=8	k=9	k=10	k=11	k=12	k=13	k=14	k=15
overlap	0.002	0.002	0.001	-0.000	-0.001	-0.002*	-0.003***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
low	-0.019***	-0.019***	-0.018***	-0.017***	-0.018***	-0.016***	-0.014***	-0.012***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
spatialdisp	-0.050***	-0.060***	-0.070***	-0.077***	-0.085***	-0.090***	-0.093***	-0.096***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
Constant	0.815***	0.805***	0.793***	0.783***	0.772***	0.763***	0.752***	0.740***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Observations	1,212	1,212	1,212	1,212	1,212	1,212	1,212	1,212
R-squared	0.298	0.404	0.518	0.600	0.667	0.717	0.756	0.788
Adj. R-squared	0.296	0.402	0.516	0.599	0.666	0.717	0.756	0.788

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1