B.Comp. Dissertation

Role of Spatial, Temporal Dispersions in Global Virtual Teams: A Simulation Approach

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Abstract

In the context of information systems development (ISD), organizations are increasingly relying on virtual teams which operate in different locations and different time zones. Scholars are more interested in the performance of virtual teams and how they are affected by spatial and temporal dispersions of virtual teams. However, how spatial and temporal dispersions affect the performance of virtual teams on modern organizations remains to be unclear and research has generally not established a systematic method to measure such impact. This research essay expands upon previous studies of virtual teams by presenting a simulation approach to study the impact of temporal and spatial dispersions of virtual teams under different project complexities. In this study, NK landscape model is used to simulate the ISD process. Based on the analysis on simulation results, the study shows the impact of temporal and spatial dispersion and how such impacts changes under different project complexities. This study also explored the impact of trust level among virtual team members. With the findings from simulations, this study offers practical recommendations for organizations who need to adopt distributed virtual teams for collaborative tasks. We hope that the study will open up a new direction to study virtual teams using NK simulation approach.

Subject Descriptors:

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Keywords: Information System Development (ISD), NK model, Computer Simulation, Virtual Team, Temporal Dispersion, Spatial Dispersion, Trust Level

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1. Introduction

In the context of information systems development (ISD), recent trends such as globalization, shortage of qualified ISD professionals at different locations in which major companies operate, the availability of high quality ISD talent at low costs in different parts of the globe, the hyper-competitive environment wherein businesses are under increasing pressure to develop more cost-effective strategies for software development, and advances in telecommunications have increasingly led to the creation and utilization of virtual teams (Sarker & Sahay, 2003). Virtual teams are used in more than half of companies with more than 5000 employees according to the Wall Street Journal (de Lisser, 1999). More than 60% of professional employees work in virtual teams according to a survey conducted by the Gartner group. (Kanawattanachai & Yoo, 2002). With advances in information technologies, virtual teams have become more popular nowadays.

A virtual team is defined as a group of geographically, organizationally and/or time dispersed workers brought together by information and telecommunication technologies to accomplish one or more organizational tasks (Lipnack, 1997). Compared to traditional teams, costs can be lowered since virtual workers may not need office space, organizational responsiveness and competitiveness may increase because the workers can work 24/7, and greater expertise and flexibility can be achieved by bring together professional talents from across the globe. However, the disadvantages of virtual teams lie in the fact that team members are isolated, dependence on technology to accomplish work increases, the ability for team members to network is reduced and the potential for miscommunication may also increase. However, the overall impact of virtual teams on modern organizations remains to be unclear and we realize that there is a need to find a systematic approach to measure such impact. In order to better understand how the use of virtual team can increase organization’s performance, this study aims to uncover the performance implications of virtual teams by scrutinizing the impacts of the two key aspects of virtual teams, namely temporal and spatial dispersion.

In this study, we mainly focus on virtual teams in the context of information systems development (ISD). Typical virtual teams, include everything from laboratory groups separated by temporary partitions to a team spread around the globe (Maznevski & Chudoba, 2000). When viewed from the perspective of ISD, the impact of such geographically dispersed teams can be divided into 3 categories: (1) spatial, (2) temporal, and (3) configurational. They capture (1) the average spatial distance among team members; (2) the extent to which team members have overlapping work hours; and (3) the number of sites at which members are located, their isolation from other members, and the balance between subgroups of members across sites (O'Leary & Cummings, 2007). We primarily focus on the spatial and temporal dimensions of virtual teams in this study.

This study aims to quantify the impact of virtual teams on the overall performance of collaborative work such as ISD. We hope to know how much of the impact comes from the spatial dispersion and how much of the impact comes from temporal dispersion. For ISD projects under different complexities, how does the impact from temporal dispersion and spatial dispersion change? With the findings, organizations can know how to adjust their management strategies on virtual team. For example, should organizations provide opportunities for virtual teams to work concurrently so that they can communicate on their work or make virtual teams work asynchronously so that they can have a better focus on their work? For multinational corporations with many ISD projects which range from very simple projects to complex projects, how can they allocate the projects to different kinds of virtual teams (e.g. virtual teams with no overlapping working hours and virtual team with overlapping working hours) so that they can achieve efficiency and effectiveness for ISD projects? And for organizations heavily relying on virtual teams, how can they improve their current strategies of people management to improve the performance of existing virtual teams?

In this study, computational modeling using simulations is used to theoretically explore the role of spatial, and temporal dispersion, which may serve as the basis for future empirical research. The reason simulation approach is used in the study is that it enables us to incorporate a greater number of interdependent elements in a model than is possible with analytical studies and field studies. In addition, the simulation methodology allows us to rigorously manipulate and combine the theoretical elements to achieve quantitative and in-depth insights. Furthermore, simulation is also an effective tool for developing theory from simple assumptions (Axelrod, 2003).

2. Literature Review & Theoretical Background

2.1. Spatial Dispersion in Virtual Teams

Spatial difference, which captures the spatial distance among members, naturally emerges when teams are geographically separated. Prior research shows that the probability of spontaneous face-to-face communication drops rapidly as the degree of spatial dispersion increases (Allen, 1977). With spatial difference, team members are not able to have face-to-face communication and they mainly rely on information and telecommunication technologies for information sharing.

According to prior research, technology-mediated communication has limits and is not able to transfer the same rich social, emotional, and non-verbal information present in traditional face-to-face settings (Walther & Burgoon, 1992). For example, Kayworth and Leidner (2002) argue that information in traditional settings, may be lost or distorted through computer-mediated communication. For instance, it is difficult to share complex knowledge with computer-mediated communication as the amount of information transferred in the computer-mediated communication channel is limited and it is also hard to provide the context with computer-mediated communication. Therefore, the major impact of spatial dispersion is that the accuracy of information sharing among different teams get reduced, which leads to information loss or distortion. Another challenge may lie in the fact that team members come from different linguistic and cultural backgrounds, which might result in misunderstandings in communications, which also essentially result in information distortion in communications.

Spatial dispersion can be captured with two scenarios. For teams without spatial difference, namely the sites stay in the same location (Scenario 1), they are able to use both face-to-face communication and technology as means of communication. For teams with spatial difference (Scenario 2), the spatial dispersion makes it much harder for different teams to communicate as they must rely on limited methods.

2.2. Temporal Dispersion in Virtual Teams

Nowadays, it is common for modern organizations to operate globally and have workers in different time zones. O'Leary and Cummings (2007) point out that temporal dispersion captures the extent to which team members' normal work hours overlap. Such dispersion amplifies with spatial separations, makes synchronous interaction less common and more difficult, and generally exacerbates the challenges of coordination (O'Leary & Cummings, 2007).

Temporal dispersion creates two effects on virtual teams. Firstly, virtual teams with temporal differences need to reply on asynchronous interaction to share information and therefore there will be delay in information sharing, which is the direct impact of temporal dispersion. However, the impact of asynchronous communications remains to be controversial in modern organizations. Two researchers conduct a survey in 1999 (Warkentin & Beranek, 1999) to ask people their experience on virtual teams. Regarding the effect of asynchronous communications, respondents actually had different opinions. Many people indicated that such delays and lags created asynchronous interactions limited their communications, making the communications inefficient and impeding the formation of consensus and conclusions. Yet quite a number of respondents also indicated that such asynchronous environment allowed them to have time to think through answers. With this study, we will explicitly explore the impact of asynchronous communications.

Secondly, with the temporal dispersion between different sites, people do not see what other people are doing, and they do not get responses immediately. It is more difficult for people to build social capital in such virtual setting. Social capital is defined by Putnam (1995) in his popular paper "Bowling Alone (...)" as "features of social organization such as networks, norms and social trust that facilitate coordination and cooperation for mutual benefit." (Putnam, 1995) Several other factors, such as shared experiences, repeated interactions and anticipation of future association have also been suggested to facilitate the development of trust (Lewis & Weigert, 1985) (Mayer, Davis, & Schoorman, 1995)

(Powell, 1990). However, shared experiences, repeated interactions and anticipation of future association are hard to achieve in virtual teams with temporal dispersions, which makes trust development rather hard in such virtual team. There is also a study to prove our inference. This study shows that such temporal dispersion breeds distrust so that people are not aware of the contributions and importance of other people's work (Coutu, 1998). Therefore, we may conclude that the lack of trust caused by temporal dispersion will result in ineffective communications between different sites which makes people feel that other site's work does not make enough contributions to the success of projects and other site' work is not as important as their own work.

However, with the existing studies on temporal dispersion of virtual teams, it is still hard to define whether temporal dispersion will lead to effective communications. Therefore, we find it very necessary to create a model to explicitly explore the effect of temporal dispersion.

We define three scenarios for the temporal dimension of virtual teams. In scenarios where the different sites of a team have no work hours of overlap (Scenario 1), members from different sites have to communicate with each other asynchronously. They rely on means such as emails to communicate instead of instant messages or virtual meetings. An example of this scenario could be two sites with 12 hours of time difference. In scenarios where sites have some work hours overlap (Scenario 2), they will communicate synchronously (e.g. use virtual meetings or instant messages) during the overlapping work hours. However, during the remaining (non-overlapping) working hours, the teams still communicate asynchronously such as sending emails. An example of this scenario would be two sites located in east and west coast of the USA. Lastly, there are scenarios where the sites have no temporal dispersion (Scenario 3), which means they can communicate synchronously. An example of this scenario could be one site of the team located in Singapore and the other site located in Beijing since they are on the same time-zone.

Moreover, in our settings, when two sites communicate with each other. They have a higher trust level when they are both working, which means they will acknowledge and value other site's contribution. However, if one site is working while the other site is not, the members of that site will not put significantly more attention to their own work and ignore the contribution from the other site to certain degree.

3. Hypotheses

As previously discussed, both spatial and temporal dispersion of virtual teams make communications or information sharing among members more difficult. However, the information sharing among team members are highly related to members' understanding of the overall project and the performance of ISD project greatly depends on members' understanding of the overall project. Thus it is expected that both spatial and temporal dispersions of virtual teams will have a negative impact on the performance of ISD projects.

Hypothesis 1: Both spatial and temporal dispersions of virtual teams will have a negative impact on the performance of ISD projects

Furthermore, when the ISD project become more complex, team members will rely more on other people in order to understand the overall project. And members' interaction will become more crucial for the success of projects. Thus, we hypothesize that:

Hypothesis 2: With increasing project complexity, spatial and temporal dispersions of virtual teams will have more negative impact on the performance of projects.

As we discussed before, virtual team results in the distrust between different sites and such distrust leads to a lack of awareness of other people's contribution and importance of work. However, if organizations take actions to build trust among members of virtual team, make them believe that they are all very important to the success of ISD projects and make members be aware of the contributions made by other people, the performance of virtual team will get increased. Therefore, we hypothesize that:

Hypothesis 3: With increasing the trust level, the performance of virtual teams in the context of ISD projects increases.

4. A Model of ISD with Global Virtual Teams

Prior research has conceptualized the Information Systems Development (ISD) as a problem solving process in which an information systems design is developed by ISD and creates value to the organization (Hahn & Lee, 2011). For example, Newell and Simon (1972) consider ISD as an information collection, processing and feedback process. ISD project is conceptualized as search within a configuration space, which is a problem solving process where the team searches for a system configuration to deliver the most value to the organization.

Simon (1947) defined problem solving as an iterative process of three phases - an intelligence phase wherein the organization identify the gap between existing and desired state, a design phase in which decision makers evaluate possible approaches and their expected outcomes, and a choice phase in which decision makers select and implement the chosen action to reduce the gap between existing and desired state. Since the action may not fully solve the problem, the process is typically iterative and incremental (Simon, 1947).

In the context of ISD, a problem, which is viewed as a gap between existing and desired states, is first identified by the project team (intelligence). Ideas are then generated and evaluated to bridge the difference between existing and desired state (design). In the end, the team chooses the best approach for the problem (choice). The process is generally iterative and the system may be modified several times before its formal launch. Therefore, ISD can be conceptualized as an iterative problem solving process.

Having established that the ISD process can be conceptualized as an iterative design problem solving where the team searches for a system configuration to deliver the most value to organization, the next step is to chooses a simulation approach and develop a computational representation of the key factors.

Among the various simulation approaches (e.g., systems dynamics, genetic algorithms, cellular automata, etc.), The *NK* fitness landscapes model (Kauffman, 1993) is most appropriate when organizational adaptation can be conceptualized as design problem solving (Davis, Bringham, & Eisenhardt, 2007). Since ISD can be conceptualized as a problem solving process, we select the *NK* fitness landscapes model for this study.

4.1. The *NK* Fitness Landscapes Model

The *NK* fitness landscape model, as a commonly used simulation approach for studying the speed and effectiveness of adaptation to an optimum within a modular system (Davis, Bringham, & Eisenhardt, 2007), is employed to study the influence of virtual teams. In the *NK* fitness landscape model, adaptation is performed on a "rugged" landscape, which represents the performance of all the combinations of factors. In this case, the factors refer to the decisions that the teams have to make. A variable N is defined in the model to represent the total number of factors in the overall decision space. The model also involves K interdependencies among the N decision factors. K also maps to the overall ruggedness of the landscape, which refers to the overall complexity of the decision problem. The *NK* model is used to describe the way an agent may move within a landscape by manipulating various characteristics of itself, just as an organization tries different configurations and adjusts decisions accordingly to attain the satisfactory results during a project.

We further extend the model to fit into the context of virtual teams. In this study, the N decision factors are equally divided into two parts, which represent a geographically dispersed virtual team with two sites. Each site will configure their factors and make their own decisions to optimize the virtual team's performance based on the factors assigned to the team. However, each site will take the other site's current decision into consideration when they make decisions, which represent the information sharing among virtual teams. When a team evaluates an action (an alternative configuration), it combines the configuration of its possible action with the latest configuration the site know about the other site. The two sites will have interactions with each other to share their latest decisions.

4.2. Modelling the Fitness Landscape

We model a project as a configuration of N decisions, which is represented by an N-element vector $d = \langle d_1, \ldots, d_N \rangle$ where each d_i can take the value of 0 or 1 representing two different choices. Therefore the overall IS configuration can be modelled as a vector with N elements or design decisions $d = <d_{1}, \ldots, d_{N}>$, and therefore in total, there are 2^N possible configurations. A fitness value is assigned to each IS configuration, which can be interpreted as project performance if that particular configuration is adopted. The various systems design elements may interact in the sense that the value contribution of one decision may depend on K other design choices. Such interdependencies can exist within the decision elements assigned to a particular site or across decision elements assigned to different sites of the virtual team. The objective of virtual ISD team is to find an IS design with greatest performance, which is represented by the overall fitness value.

4.3. Modeling the Agents' Adaptation

Each agent represents an independent ISD project searching for the configuration that can produce the best performance. Their search strategy (i.e., the ISD approach of iterative and incremental design) is essentially local hill-climbing to navigate around the neighborhood within the landscape in search for the higher fitness values by adjusting their design choices. Here, we assume that agents are boundedly rational: meaning that agents are unable to discover the underlying structure of the interdependencies, rather, they sample the currently available alternatives and evaluate their feasibility based on associated fitness values. More specifically, they can only evaluate the nearby one-off alternatives that are in the immediate neighbourhood around the current configuration, rather than considering distant configuration which differ from the current configuration in more than one decision factor (Hahn & Lee, 2011).

For example, in a landscape with N= 4, if an agent starts with an random configuration of $<0,1,1,0>$, then the agent will consider four alternatives which are in the immediate neighborhood around the current position, namely $<\underline{1},1,1,0>$, $<0,\underline{0},1,0>$,$<0,1,\underline{0},0>$,and $<0,1,1,\underline{1}>$. The agent will evaluate the fitness value of the four alternatives and compare these with the fitness value associated with current position (i.e., $<0,1,1,0>$), and he will adopt the one with highest fitness value. In this example, suppose the agent selects $<0,0,1,0>$ which has the highest fitness value, then subsequently he will evaluate among $<\underline{1},0,1,0>$, $<0,0,\underline{0},0>$, and $<0,0,1,\underline{1}>$ ($<0,\underline{1},1,0>$ will not be considered as it has been evaluated to be inferior in the previous round). The agent will continue searching in this way until he reaches a configuration where all alternatives in the immediate vicinity are inferior. Such point may not be the highest peak, but rather a local peak which limits the agent's search and thus leads the agent to a competency traps. In this case the local peak will be regarded the best solution even though a global search might suggest a more superior solution (Gavetti & Levinthal, 2000).

4.4. Modeling Spatial Dispersion

As discussed before, spatial dispersion has two main impacts on virtual teams – information loss and information distortion, which should be reflected in our model. They both emerges when two sites of a team share their information. Information loss appears when a site does not capture part of the other site's information.

In our model, we have a setting that one site may lose part of the information when the other site share its decision, which is a representation of *information loss*. For example, suppose we have two virtual sites with a total of 8 factors ($d_1 \sim d_8$), where site 1 will be responsible for the decision factors $d_1 \sim d_4$ and site 2 will be responsible for $d_5 \sim d_8$. An example of this will be an ISD project team with one site focusing on back-end database and the other site focusing on front-end UI design. The back-end database consists of the decision factors $d_1 \sim d_4$ and the front end UI design consists of the decision factors $d_5 \sim d_8$. When site 2 shares its decision ($d_5 \sim d_8$) with site 1, site 1 may only receive $d_5 \sim d_7$ and lose the information on d_8. In this case, site 1 may need to make decisions without knowing the actual value of d_8.

Information distortion can be represented by misunderstanding of information. For example, in the above illustration, site 2 makes decisions for $d_5 \sim d_8$ and share the information with site 1. Suppose the value carried by d_8 is actually *1*. But because of information distortion, site 1 receives a value of *0* for d_8 and site 1 will make decisions based on an incorrect understanding of d_8.

In Figure 1, we provide an example for information los and distortion. In the case of information loss, the information sent from site 1 to site 2 is (*0, 1, 1, 0*). However, when site 2 receive the information, the last bit of information is lost, which makes the message become (*0, 1, 1, ?*). Site 2 will not know whether the last bit is actually 0 or 1. In the case of information distortion, when site 2 receive the information from site 2, the last bit of the message is distorted from *0* to *1*.

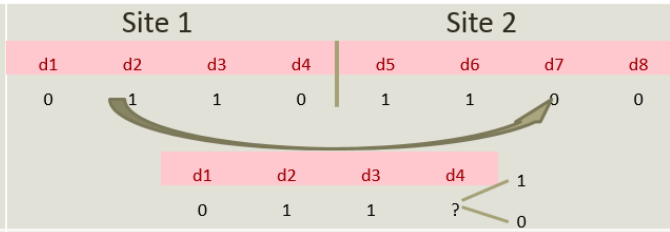
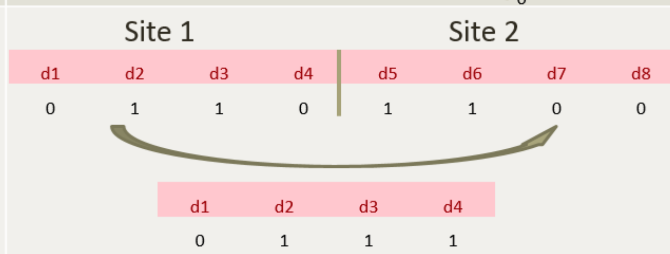
	Explanation	Example
Information Loss	One site may lose part of the information when the other site share its decisions	
Information Distortion	Misunderstanding of information during sharing decisions	

Figure 1

When the two sites have no spatial dispersion, they are able to have face-to-face communications, which is considered accurate and effective. In this scenario, there will be no information loss and distortion. Whenever site 2 receives information from site 1, the information will be the same as the information sent by site 1. And site 2 will get the complete information without the possibility of losing any part of it. For example, the information sent from site 1 to site 2 is (*0, 1, 1, 0*). After receiving the information, site 2 will get the same information, which is (*0, 1, 1, 0*).

4.5. Modeling Temporal Dispersion

To reflect this in our *NK* model, we have 3 different cases corresponding to the 3 scenarios discussed above. For scenario 1 where sites have no overlapping working hours, each site will not have synchronous communication. Therefore, the sites will not make decisions at the same time and the information they receive about the other site is from the previous working day of the other site. For example, suppose we have a virtual team with 2 sites with a total of *8* factors as before. On the very first day of an ISD project, site 1 will make decisions for the factors $d_1 \sim d_4$ without considering the latest result of $d_5 \sim d_8$ because site 2 has not started working on this project. Site 1 will use the initial configuration of site 2 since it is still same as the original setting of the ISD project. Before site 1 finishes its work, the members send the information about their work today to site 2 and leave the office. Later when site 2 starts to work, it will use the decisions made by site 1 and its knowledge on $d_5 \sim d_8$. Based on that result, site 2 makes decisions for $d_5 \sim d_8$ and it send the information about their work today to site 1 before they leaving. When site 2 start to work on the second day, it receives the information and it makes decisions based on the information received from site 2 and the knowledge within their own knowledge area. This process is repeated until the end of an ISD project.

For scenario 2, the team has some overlapping working hours and they communicate both synchronously and asynchronously. This scenario is more complex since the number of overlapping working hours may vary. To simply the scenario, we assume that the sites have half of their working hours overlapping. Therefore, during the first half of site 1's working hours, site 1 will make decisions for $d_1 \sim d_4$ based on the information of $d_5 \sim d_8$ received from site 2. During the second half of site 1's working hours, site 2 also starts to work and the two sites will communicate with each other synchronously. The two sites will make decisions based on all *8* decision factors from both their knowledge areas and all the *8* decision factors will be up-to-date. After the site 1 get off work, site 2 will continue. The site 2 members will also receive site 1's latest decisions and make decisions based on the information provide by site 1 and their own expertise.

For scenario 3 wherein the two sites have complete overlapping working hours, they will work synchronously via methods like instant messaging or virtual meeting. In this case, the two sites will make decisions together based on *8* up-to-date decision factors and they will behave like a unified team.

In order to control the variables of duration, we assume that each site can perform two decisions per day in our model. Here we provide figure 2 to illustrate our model. In the case where there is no overlapping working hours. Site 1 and 2 will work totally asynchronously and the information they received from the other site is from the previous working days. In the case of some overlapping working hours, site 1 and 2 will have half of their working hours overlapped and they can communicate synchronously at these working hours. As for the case of complete overlapping working hours, site 1 and 2 behaves like one team.

	Explanation	Example
No overlapping working hours	Asynchronous communication, information about the other site is from the previous working day of the other site	Site 1: 0 1 1 0 / 0 1 1 1 Site 2: 1 1 0 0 / 1 1 0 1
Some overlapping working hours	Communicate both synchronously and asynchronously	Site 1: 0 1 1 0 / 0 1 1 1 Site 2: 1 1 0 0 / 1 1 0 1
Complete overlapping working hours	Share up-to-date information	Site 1: 0 1 1 0 / 0 1 1 1 Site 2: 1 1 0 0 / 1 1 0 1

Figure 2

As we discussed before, such temporal difference also leads to lack of awareness on other site's contribution and importance, which should be reflected in our model. Therefore, if the two sites are not performing their work at the same time, they will not consider the other site's decisions factors as important as their own decisions factors. Therefore, when they measure the performance of project, there will be a *trust level* (<=1) assigned to the decision factors from other party which reflects that the decision factors of other site are as important as their own decision factors. For example, site 1 may not fully trust site 2 regarding the value of its work. When site 1 receives information from site 2, the actual value created by site 2 is v_1. However, since site 1 does not fully trust site 2, the value created by site 2 in site 1's mind will be deducted and not as high as it actually is *(trust level* * v_1).

5. Experiment Design

5.1. Experiment 1: Explore the Impact of Temporal and Spatial Dispersions in Moderately Complex ISD Projects

The first experiment compares the impact of virtual teams with different temporal and spatial settings in a moderately complex ISD project. It also serves as a base case for subsequent experiments with varying parameters (i.e. *N*, *K*, etc.) for comparison.

5.1.1. Experiment Design & Setting

The factors will be divided into 2 parts, which represents two sites in the virtual team. And we assume that a site can make two decisions every day. There are 4 types of agents to be modelled in this experiment (see Figure 2): each with different combination of settings within the model. The two categories of spatial settings are respectively “With spatial dispersion” and “Without spatial dispersion”, while the three temporal settings are “With temporal dispersion, no overlapping working hours”, “With temporal dispersion, some overlapping working hours.” and “Without temporal dispersion”. Very importantly, if two sites are temporally dispersed, they will appear at the same location at the same time. In that sense, they are still spatially dispersed. That is why when there is a temporal difference, the team will definitely have spatial dispersion. Therefore, there are two cases in the figure which are not applicable in real life. However, in order to separately explore the impact of temporal and spatial dispersions, we need to have some control experiments. And simulation allows us to provide environments which are impossible in real life. That is why we still include the two groups in our experiment.

In our experiment, the number of each type of agents is set to be 100, which is large enough for Monte Carlo method to rule out randomness and reduce the impact of outliers.

	With temporal difference, no overlapping working hours	**With temporal difference, some overlapping working hours**	**Without temporal difference**
With spatial difference	Group 4	Group 3	Group 2

Without spatial difference	Group 6 (Not applicable in real life)	Group 5 (Not applicable in real life)	Group 1

For a single round, the number of periods allocated to each type agent is 100, which is sufficiently large for agent to have enough time to search on the landscape and attain their own optimized performance; *N* is set relatively large (16) to let agents have enough space to search, and the landscape is set to be neutrally complex (*K*=8), which means the ISD project is moderately complex. A total number of 100 rounds will be conducted and the average performance of each type of agent will be used for final comparison.

5.1.2. Property Setting with Respect to Spatial Dispersion

For agents without spatial dispersion, the two sites (i.e., the two parts of the 16 factors) always know the current values and performance of each other. They can make movement based on the overall performance of all 16 factors.

For agents with spatial dispersion, the two sites have the probability of misinterpreting the information of other site. There will be a 25% probability of information loss, which means a random position of other site's decision will be unavailable with a 25% probability. There will also be a 25% probability that a random position of other site's decision will be flipped (from 1 to 0 or 0 to 1), which represent information distortion. When we add the two probabilities together we get a 50% of probability, which is large enough to see the impact of spatial difference.

5.1.3. Property Setting with Respect to Temporal Dispersion

For agents with no temporal dispersion, there will be no change in the model. The two parts of the 16 factors, represent the two sites. The two sites will make decisions concurrently for every period, which means there will be one update in the first 8 factors and one update in the last 8 factors every period. And every two rounds represent one day in real life. The two sites should share equal and perfect information with each other, which means they always know the performance and decisions of the other site. Therefore the two sites make configuration changes based on the overall performance of all 16 factors.

For agents with temporal dispersion and no overlapping working hours, the agent will make decisions on parts 1 (i.e., $d_1 \sim d_8$) and 2 (i.e., $d_9 \sim d_{16}$) of the 16 factors sequentially, which refers to the fact that the two sites are in different time zones. Therefore, for each day, site 1 (the first 8 factors) will make two movements. After that, site 2 (the last 8 factors) will make two movements. The two sites will not make movements concurrently.

For agents with temporal dispersion and some overlapping working hours, the agent will make decisions on parts 1 (i.e., $d_1 \sim d_8$) and 2 (i.e., $d_9 \sim d_{16}$) of the 16 factors sequentially but there will be one round every day where the two parts can make moves concurrently. For each day, site 1 (the first 8 factors) will make its first move. Later in that day, sites 1 *and* 2 will make move at the same time. Lastly, site 2 will make a move while site 1 stays in its current position.

For each site, we also add a *trust level* to the decision factors of the other site. When the two sites of the agent are in the overlapping working hours, such *trust level* is set to 1, which represent the fact that they trust each other. This is because the two sites can communicate synchronously and they are aware of the importance and contribution of the other site. When only one site is working, it does not have any synchronous communication with the other site and the site does not have enough trust on the contribution and importance of the other site. Therefore the *trust level* is set to 0.2. Which is a significantly small number to see the impact of such distrust.

5.1.4. Performance Measurement

Subsequently after 100 rounds of experiments have been conducted, the average performance and the standard deviation over 100 rounds will be recorded. Every record of the experiment will have the following variables: the complexity of ISD project K (equal to 8 in this experiment), the *temporal dispersion* (0 means no temporal dispersion, 1 means with temporal dispersion), the *spatial dispersion* (0 means no spatial dispersion, 1 means with spatial dispersion), *overlap* (0 means the two teams have overlapping working hours, 1 means they do not have overlapping working hours), the performance of the virtual team (a normalized double which ranges from 0 to 1), and the time period (a integer which ranges from 0 to 100).

To verify the first hypothesis, we organize the records in Excel. In order to know the impact of spatial dispersion, we first divide the records into 3 categories (no temporal dispersion, with temporal dispersion no overlapping working hours and with temporal dispersion with overlapping working hours). For each category, we will plot line chart of performance with respect to time period. Then we will compare the performance from the line chart within each category. If the agent without spatial dispersion have better performance than the agent with spatial dispersion, the hypothesis on spatial dispersion can be verified. Besides, by comparing the performance among the 3 categories, we may have extra findings on temporal and spatial dispersion.

In order to know the impact of temporal dispersion, we divide the records in to 2 categories based on whether the virtual team has spatial dispersion. For each category, we will plot line chart of performance with respect to time period. Then we will compare the performance from the line chart within each category. If the agent without temporal dispersion have better performance than the agent with temporal dispersion, the hypothesis on temporal dispersion can be verified. Besides, by comparing the performance between the agent with overlapping working hours and the agent without overlapping working hours, we may have extra findings on the variable overlap.

5.2. Experiment 2: Explore the Impact of ISD Project Complexity

The objective of second experiment is to verify the robustness of (or examine the differences with) the above results given different level of ISD project complexity (i.e., by varying the parameter K). We design this experiment based on our findings on experiment 1. Our findings from experiment 1 allows us to know what the variables that have impact on virtual team's performance are.

5.2.1. Experiment Design & Setting

Essentially the setting is the same as in the first experiment, but this time will use Group 1 and 2 to explore the impact of spatial difference under different project complexity. We will also use Group 2 and 4 to explore the impact of temporal difference under different project complexity. In this experiment, we will vary the complexity K. In the first experiment the environment is set to be neutrally complex with K = 8, hence here K is set to be *0, 1, 2 ... 13, 14, 15* to reflect different levels of complexity and examine the performance of each group of agents in the environment with such complexity.

5.2.2. Performance Measurement

We will maintain the records of experiment 2 in Excel and the format of records (columns in Excel) will be same as the records in experiment 1. Then we divided the records according to *complexity* (from *0* to *15*) and store the records separately in 16 CSV files by different complexities. After that, we will use the R language to do statistical tests on the 16 files. By importing the 16 CSV files into R environment, we can run linear regression for each of them. For the linear regressions, the independent variable will be the *performance* and the dependent variable will be *temporal dispersion*, *spatial dispersion, overlap* and the *joint variable between temporal dispersion and spatial dispersion* (temporal dispersion x spatial dispersion). With the results we get from linear regressions, we can organize the coefficients of each variable, which represents the impact of each variable in Excel. The rows will reflect the impact from different dependent variables and the column will reflects the impact from different complexities. If a variable under certain complexity is not statistically significant (P value>0.05) we will consider the variable to have no impact on the performance for that complexity. By observing the Excel sheet generated by the analysis, we can get our findings on how different variables affect the virtual teams' performance under complexities of ISD projects. If for both the impacts of temporal dispersion and spatial dispersion remain to be negative and keep increasing as *K* changes from *0* to *15,* Hypothesis 2 can be verified.

5.3. Experiment 3: Explore the Impact of Trust Level

The objective of third experiment is to verify the trust level among virtual teams will have an impact on the performance of ISD projects. It is expected that the higher trust level the virtual team has, the better the virtual team will perform.

5.3.1. Experiment Design & Setting

Essentially the setting is the same as in the first experiment, but this time will vary the trust level in temporal dispersion. Previously, we adopt 0.2 for the trust level. This time we will vary the weight from 0.2 to 0.6 and 1 to see the impact of the trust level among virtual teams.

5.3.2. Performance Measurement

For this experiment, we will plot the performance of teams for each trust level on the same graph. Then we will compare the performance between different trust levels. For example, for the group (with temporal dispersion, no overlapping work hours), we will compare the values from all three trust levels and see whether there is a difference among them. We get our conclusions through the graph obtained from this experiment. If the virtual team with higher trust level outperforms the virtual team with lower trust level, our hypothesis 3 will be verified.

6. Results and Insights

Our simulation results generated interesting insights about the impact of temporal and spatial difference on the performance of organizations. First, the modeling results show that both spatial difference and temporal difference have a negative impact on the performance of organizations. More interestingly, the impact of both temporal and spatial difference on the level of the complexity (i.e., interdepence) of requirements environment. Now, let's view our findings for spatial and temporal differences **separately.**

6.1. The Impact of Temporal and Spatial Dispersions in Moderately Complex ISD Projects

6.1.1. The Impact of Spatial Dispersion:

Through the experiment, we get three different figures (*Figure 3 ~5*) on spatial dispersion under the three different cases of temporal dispersion. We can find that under all 3 cases, the spatial dispersions all have negative impacts on the performance of virtual team within the context of ISD projects.

In order to decide the impact of spatial dispersion, we need to reduce the impact from temporal dispersion in case the two elements have a joint impact on the virtual team's performance. Therefore, in order to decide the impact from spatial dispersion, we will observe the result from *Figure 3*. By observing the *Figure 3* for the impact of spatial difference, we can get the following finding: when the complexity of ISD project is 8, the spatial difference will have a negative impact on the performance of organizations. This finding is intuitive since the impact of spatial dispersion is negative according to people's common sense and the previous studies. However, we can use this as a method to verify the correctness of our model.

From the graph, we also find out that the agent without spatial dispersion spend less time than the agent with spatial dispersion to achieve the maximum performance. It shows that spatial dispersion also has a negative impact on the time spent to complete ISD project. It extend the duration for virtual teams to reach the maximum performance.

Finally, by comparing the performance difference (performance of the team without spatial dispersion – performance of the team with spatial dispersion) in *Figure 3* with the performance in *Figure 4* and *Figure 5*, we can find that the performance difference in Figure 3 is smaller than the performance difference in *Figure 4* and *Figure 5*. What set *Figure 3* different from *Figure 4* and *Figure 5* is the existence of temporal dispersion. And the way we calculate the performance difference for each figure (performance of the team without spatial dispersion – performance of the team with spatial dispersion) already rule out the standalone impact from temporal dispersion. Therefore, such variance reflects that the spatial dispersion and temporal dispersion also have a joint impact on the performance of virtual teams. And the joint impact is negative, which makes Figure 4 and Figure 5 have a larger difference than Figure 3. Based on this findings, we decide to add a joint variable for temporal dispersion and spatial dispersion in our statistical test of experiment 2. To summarize, we have the following finding based on the analysis above: The spatial dispersion and temporal dispersion have a joint negative impact on the performance of virtual teams.

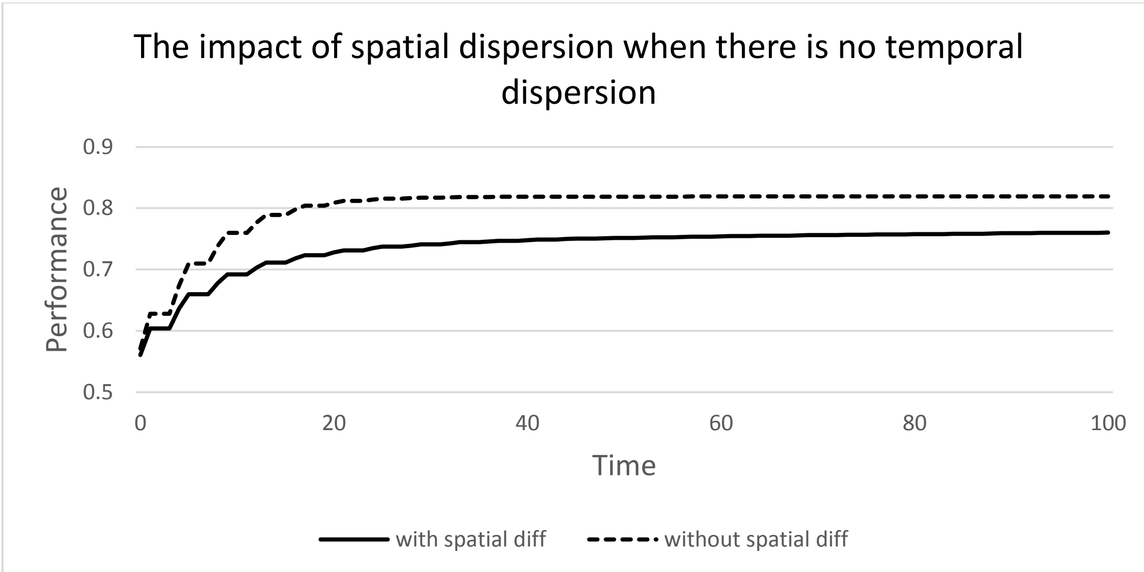


Figure 3

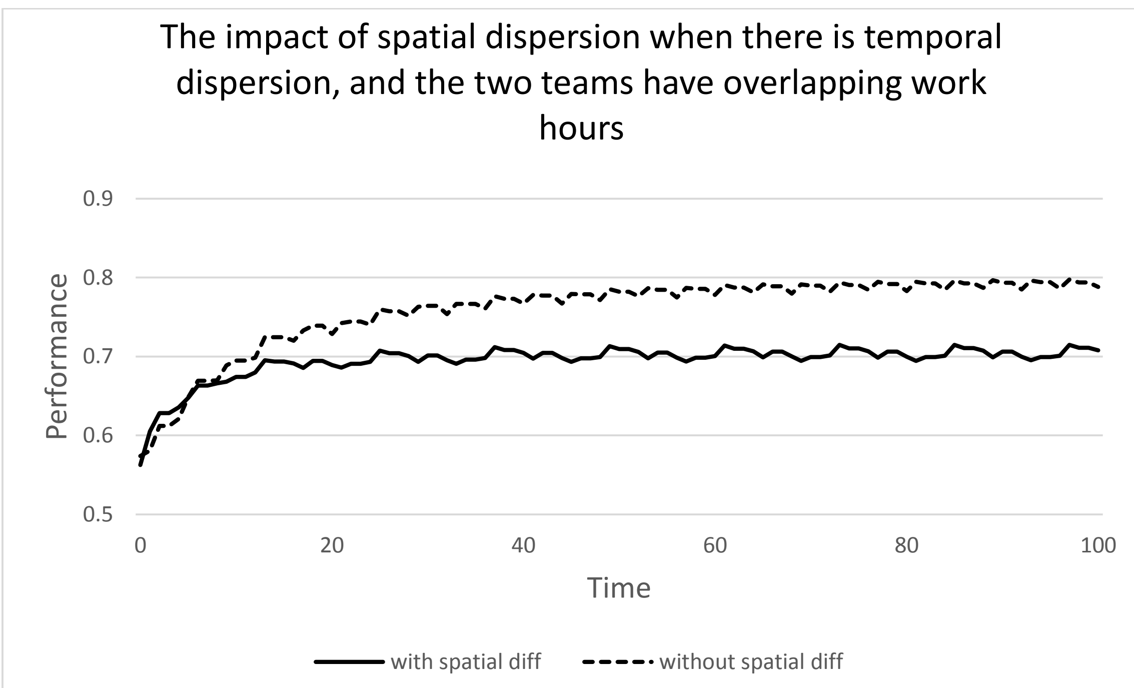


Figure 4

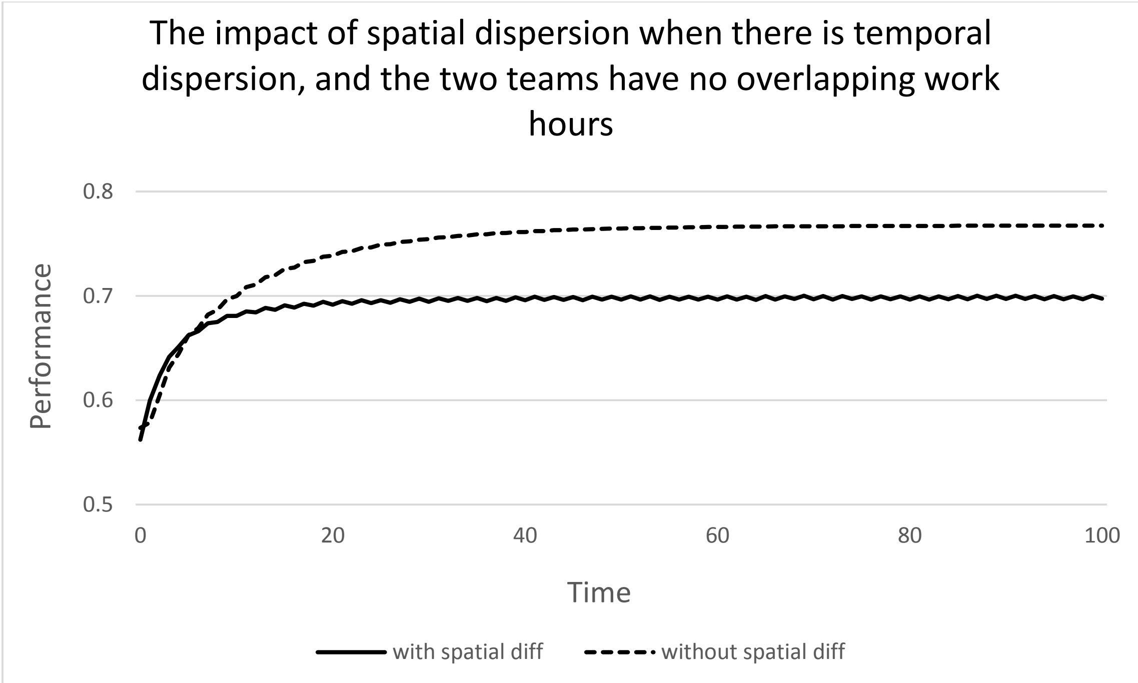


Figure 5

6.1.2. The Impact of Spatial Dispersion

Through the experiment, we get three two figures (*Figure 6 ~7*) on temporal dispersion under the two different cases of spatial dispersion.

In order to decide the impact of temporal dispersion, we need to reduce the impact from spatial dispersion since we already know the two elements have a joint impact on the virtual team's performance. Therefore, in order to decide the impact from spatial dispersion, we will observe the result from *Figure 6*. Moreover, the temporal dispersion also have two cases: overlapping working hours and no overlapping working hours. We can find that the two cases actually have different performance according to *Figure 6*. This shows that the variable – whether the teams have overlapping work hours also has an impact on the performance of virtual teams and the impact is positive when the complexity of ISD project is 8. Therefore, in our statistical test, we decided to reduce the categories of temporal dispersion from 3 cases (with temporal dispersion, with overlapping working hours & with temporal dispersion, without overlapping working hours & without temporal dispersion) to 2 cases (with temporal dispersion & without temporal dispersion). Also we will add an extra variable called overlap to indicate whether the two teams have overlapping work hours. Based on the analysis, we find that: for the ISD projects with complexity of 8, whether the two sites in a virtual team have overlapping working hours will have a positive impact on the performance of the virtual team.

In order to know the direct impact of temporal dispersion, we should only focus on the performance difference between the case without temporal dispersion and the case with temporal dispersion but without overlapping working hours in order to rule out the impact from overlap. From *Figure 6*, we realize that when there is temporal difference, the temporal difference will not have a significant impact on the performance of organizations. We can see that the agent without any temporal dispersion has similar performance as the agent with temporal dispersion but without overlapping working hours. Therefore, our finding on temporal dispersion is that: for the ISD projects with complexity of 8, the temporal dispersion does not have a significant impact on the performance of virtual teams.

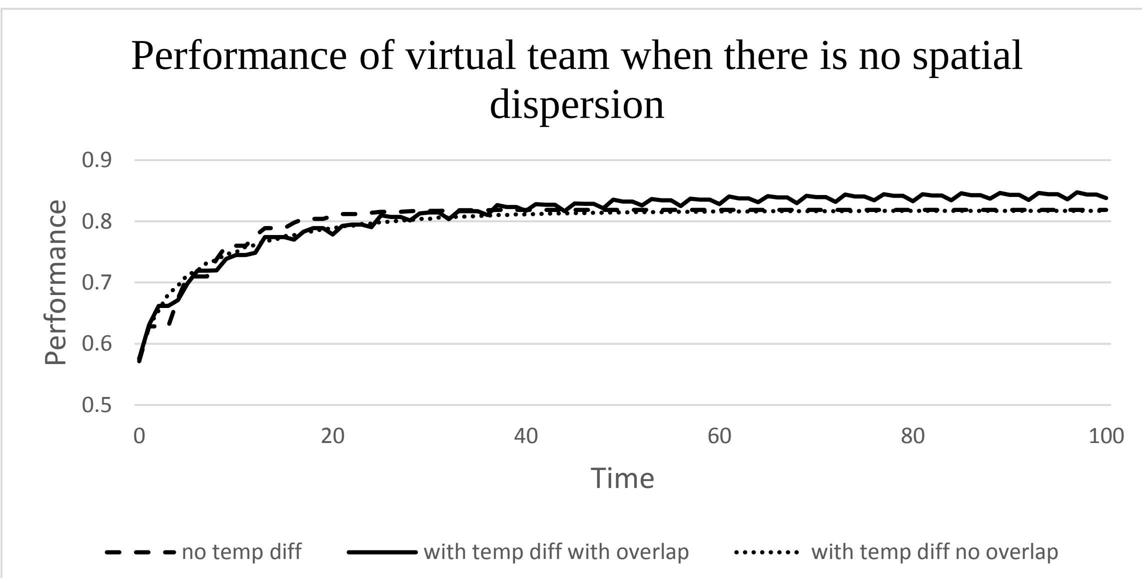


Figure 6

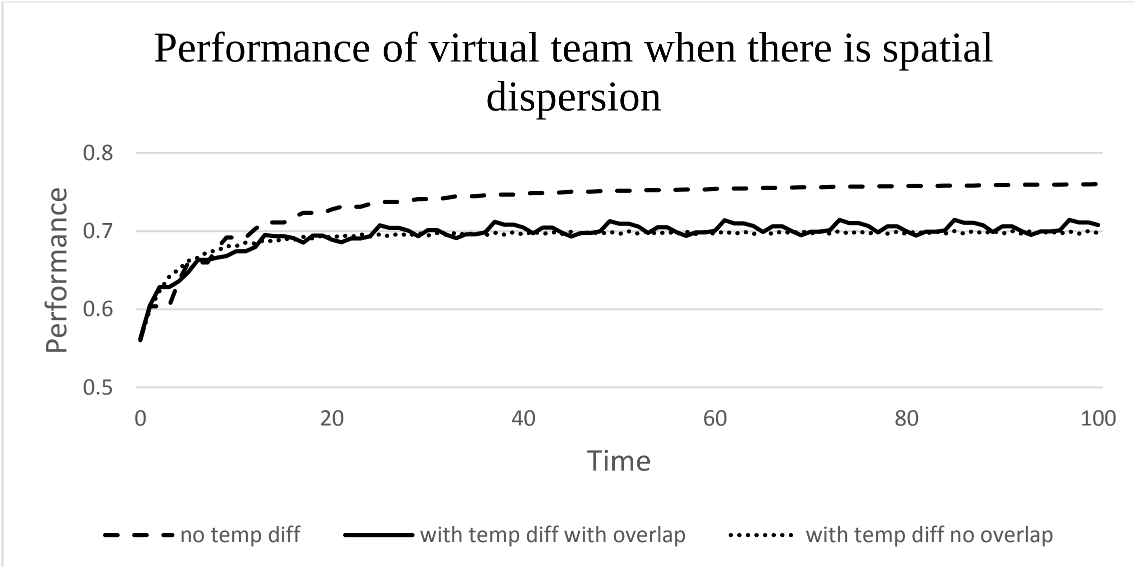


Figure 7

Based on our analysis from experiment 1, we find that under a moderate complexity, the spatial dispersion has a negative impact on virtual teams' performance, which is consistent with our hypothesis on spatial dispersion. However, under a moderate complexity, the spatial dispersion does not have a significant impact on virtual team's performance.

Moreover, based on our analysis, we find it necessary to have further studies on the impact of sptial and temporal dispersion, the joint impact of spatial and temporal dispersion and the impact from the variable overlap on different complexities of ISD projects. Therefore, we redefined our settings and approaches for experiment 2 in order to implement these studies.

6.2. The Impact of ISD Project Complexity

From experiment 2, we get an Excel sheet with 16 complexities (*K* ranges from 0 to 15). It refers to the results of linear regression for different variables and under different project complexities. However, because of the constraint of A4 paper, we cannot display the whole table here. Therefore, we select the complexities (*2, 4, 6, 8, 10, 12, 14*) and display them in this section to show our results. If you want to see the full version of the table, you may refer to the Appendix. The value in the cell refers to the estimate of each variable's impact. In the table, if the value of certain cell is underlined, it means that variable it related to does not have a statistically significant impact (P value >0.05) on virtual team's performance under the complexity level that cell reflects. The values which are not underlined means they are statistically significant. From the table, we can have many interesting findings on virtual teams.

Result of Linear Regression for Experiment 2

Complexities	K=2	K=4	K=6	K=8	K=10	K=12	K=14
(Intercept)	0.918388	0.87737	0.84519	0.81896	0.7959	0.77364	0.75243
Temporal	-0.020246	-0.0167	-0.0074	-0.0017	0.00342	0.00864	0.01362
Spatial	0.017092	0.01138	-0.0202	-0.0593	-0.094	-0.1162	-0.1276
Overlap	0.032388	0.03502	0.02998	0.02515	0.0199	0.01467	0.01021
Temporal x Spatial	-0.017889	-0.0358	-0.0595	-0.0596	-0.048	-0.0389	-0.0324
Adjusted R-squared	0.584	0.8757	0.98	0.9909	0.995	0.9948	0.9958
F-statistic (on 5 and 594 DF)	169.2	845.1	5857	13060	23730	23080	28430

Figure 8

6.2.1. The Impact of Spatial Difference against Different Project Complexities

With the full table, we generate a line chart of the impact of spatial dispersion against different levels of complexity (*K*). According to the full table, when k is 0, none of the dependent variables are statistically significant. Therefore, when k is 0, the spatial dispersion does not have impact on the performance of virtual teams. So we do not include the k=0 case in our line chart. When k changes from 1 to 4, the impact of spatial dispersion are positive and the impact is quite minute. Such positive impact increases from k1 to k3 and decrease from k3 to k4. When k is 5, the impact becomes 0, which means the spatial dispersion does not have impact on virtual teams' performance. If we continuously increase k from 5 to 15, spatial dispersions tend to have more and more negative impact on virtual team's performance.

One explanation for this trend is that when ISD projects are simple, the elements in the projects are less related and people in one site does not really need the help of other site in order to perform their tasks. Therefore, the spatial dispersion does not have a negative impact on team's performance. When projects become more complex, people start to reply on other site's knowledge to perform their work. However, with spatial dispersion, the communication between different sites become hard and results in information loss and distortion. Thus, the impact of spatial dispersion starts to become more and more negative.

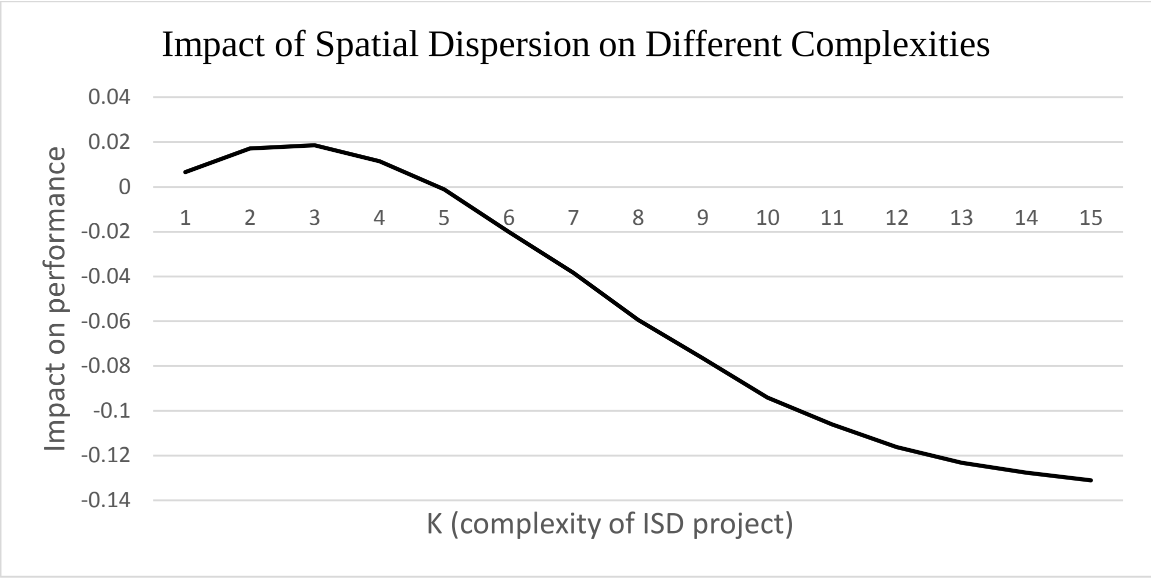


Figure 9

6.2.2. The Impact of Temporal Difference against Different Project Complexities

With the full table, we generate a line chart of the impact of temporal dispersion against different levels of complexity (*K*). According to the full table, when k is 0, none of the dependent variables are statistically significant. Therefore, when k is 0, the temporal dispersion does not have impact on the performance of virtual teams.

For the rest, we can find that the impact of spatial dispersion starts from negative and gradually become positive when k increases from 1 to 15. One possible explanation for this trend is that when projects are simple, people are able to provide meaning information to other sites immediately. Therefore, if they are working without temporal dispersion, they can provide instant help to people in other sites. If temporal dispersion exists, such instant help will be affected and the performance will be reduced. However, when project become complex, people need some time to approach and analyze problems before they can generate meaningful information to help other sites. Therefore, the temporal dispersion gives them some buffer time to approach problems and generate meaningful information, which creates a positive impact.

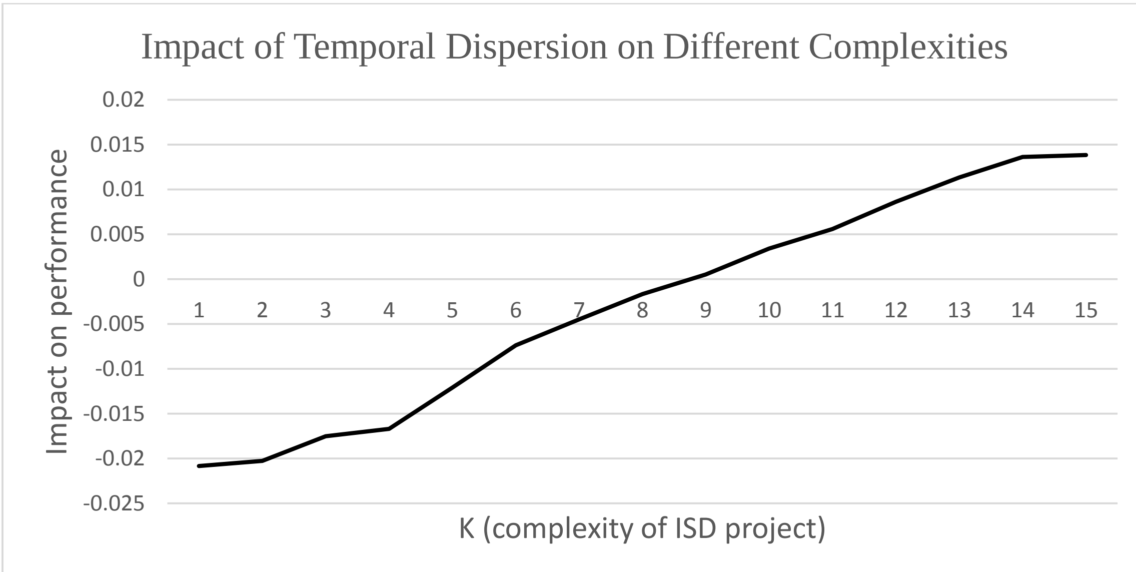


Figure 10

6.2.3. Impact of Other Variables against Different Project Complexities

From the table, we can get some findings about the other dependent variables.

First, the variable overlap has a positive impact on virtual teams' performance. However, overall the impact decreases as ISD projects become more complex. The explanation for this will be when two sites have overlapping working hours, they can use the overlapped time to discuss and get useful information from each other, which will increase the performance of virtual team. However, when projects become more complex, it will be harder to them to have very useful information during the overlapped working hours. This is because the work may be so hard that no site can make much progress on their work within the short overlapped working hours and thus it is difficult for each site to provide useful information to help each other.

Temporal dispersion and spatial dispersion does not only provide impact separately. They also have a joint impact when we put them together. This is often neglected in previous studies since they usually consider spatial and temporal dispersions as two separate variables and study them individually. Such joint impact is always negative and they are most significant when projects have moderate level of complexity.

6.3. The Impact of Trust Level on Virtual Team Performance

In our experiment settings, we mentioned that the team will give less consideration to the other team's decision factors when they are not working at the same time because of the lack of trust between different sites. In order to achieve that, for each site, we first assigned a trust level to the decision factors from the other site to show that they ignore the contribution from the other site to certain degree. Then we increase such weight from 0.2 to 0.6 and to 1 to see whether the different trust levels have a significant impact on the final result. From the results, it seems that the impact of spatial dispersion remain similar no matter how we vary the trust level. However, the impact of temporal dispersion is different for different trust levels.

From the chart (*Figure 11*), we find that such trust level will not have a significant impact on organizations' performance when there is no temporal dispersion. However, when there is temporal dispersion, the higher the trust level is, the better the virtual team's performance is. When the trust level is very high (e.g. when trust level is 1), the performance of the virtual team with temporal dispersion will be very close to the performance of the virtual team without temporal dispersion. This shows that organizations should be aware of the lack of trust among team members especially when the team members are in different time zones. If organizations pay more attention and make team members aware of the contributions and importance of each other's work and build the trust among team members, the performance of ISD projects will get increased. This is especially important for the virtual team located in different time zones.

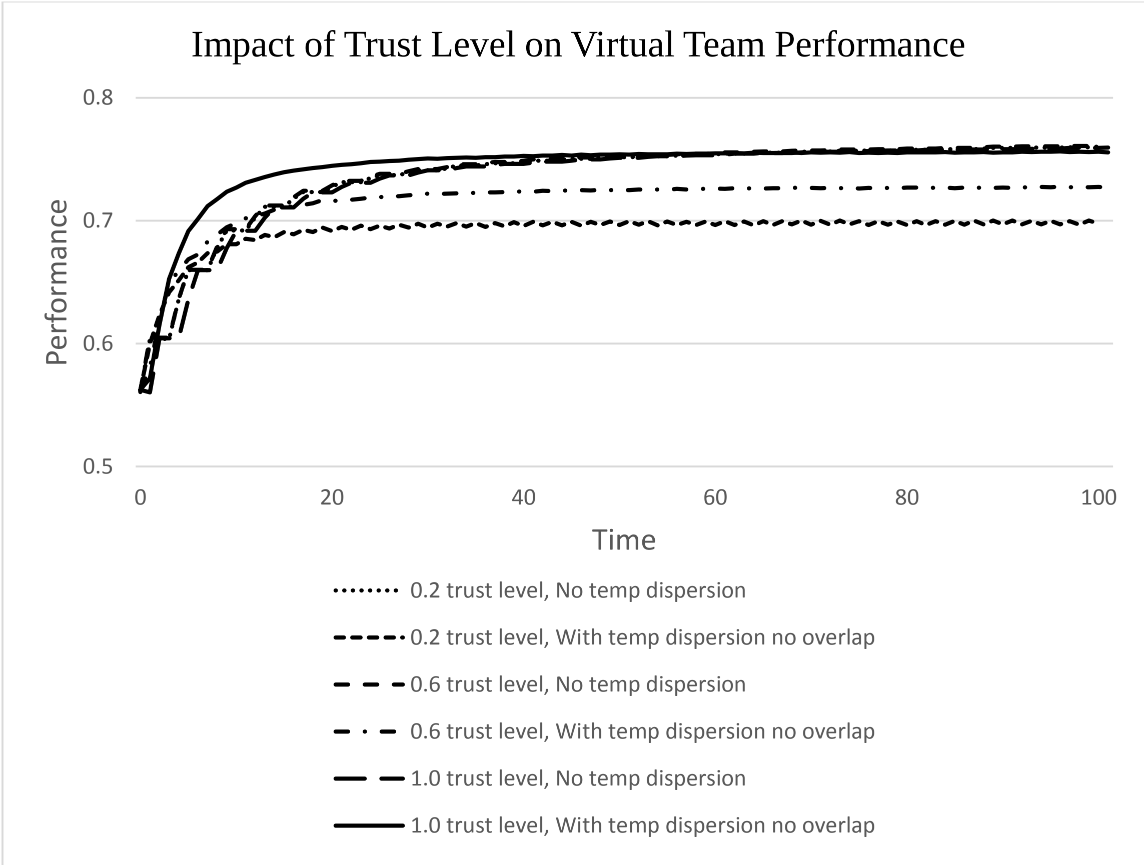


Figure 11

7. Discussion and Conclusion

7.1. Discussion and Implications of Results

Existing research on virtual team is mainly conducted in the form of empirical study. However, this approach has its limitation that every case is specific and therefore it is not easy to generalize the findings. Besides, many of the findings are based on qualitative analysis which lacks the support of enough examples. However, the information related to ISD project performance is rather hard to find and measure. Therefore, in order to verify whether the qualitative analysis is correct, simulation is a rather effective approach. Moreover, the impact of virtual teams with different settings is not quantified in previous studies. In this study, we explored the impact of virtual teams' temporal and spatial dispersion quantitatively with a simulation approach. Using the NK fitness landscape model, we explored the impact of various levels of temporal and spatial dispersion on the performance of virtual team in the ISD context. We also study the impact of temporal and spatial dispersion under different project complexity. Lastly, we also study the impact of temporal and spatial dispersion under different trust levels among team members.

Based on our analysis from experiment 1 and 2, we have several findings on the temporal and spatial dispersions.

First, spatial dispersion has a negative impact on virtual teams when the ISD projects are complex. However, as ISD projects become simpler, the negative impact become less significant and eventually it may even become positive when projects are very simple. In people's common sense, we may consider geographically dispersed team as an inefficient way of doing ISD projects. However, this may not always be true when the complexity of ISD projects change. Based on this findings, organizations can be reassured that they need not worry too much about the negative impacts of spatial dispersion for simple project. However, they need to be more mindful about how to manage virtual teams for more complex projects. From our study, we also know that the driver of spatial performance decay is a combination of information distortion and loss; so with more complex projects, organizations should be careful about mitigating information distortion and loss by adopting various practices. For examples, organizations can adopt cloud based platform to keep accurate records of the teams' work and ensure that team members can easily access these record.

We also find that temporal dispersion has a negative impact on virtual team when ISD projects are simple. However, such impact become positive when ISD projects become complex. For organizations which use virtual teams in information systems development, if the ISD projects are very complex, it will be a good practice for organizations to use virtual team located in different time zones. However, if the IS projects are simple, these organizations should consider using virtual teams located in the same time zone. These recommendations will be highly beneficial for big multinational companies because they usually have many virtual teams located in different parts of the world.

Moreover, we find that the overlapping working hours in temporal dispersion actually helps virtual team perform better because they can use the time to communicate and provide help to each other. With this finding, organization should give different sites of virtual teams the opportunities to have synchronous communications on daily basis. This is a good approach to improve the performance of virtual teams. For example, organizations can find a common time for different sites to have an online meeting on a daily basis. During the meeting, they can share their progress on their ISD projects and provide help to other site.

Based on our findings from experiment 3, we find that the impact of temporal dispersion is different for different trust levels. When there is temporal dispersion, the higher the trust level is, the better the performance is. When the trust level is very high, the performance of the agent with temporal dispersion will be very close to the performance of the agent without temporal dispersion. This shows that organizations should be aware of the lack of trust among team members especially when the team members are in different time zones. If organizations pay more attention and make team members aware of the contributions and importance of each other's work and build the trust among team members, the performance of ISD projects will get increased. This is especially important for the virtual team located in different time zones. One example of improving the trust level is to send people abroad from one site to spend some time with their colleagues in the other site. This method can be seen in some modern multinational organizations and it is proved to be an effective way to let team members better know each other. With such opportunities provided by organizations, virtual team members can build more trust with their colleagues in a remote site and the performance of the virtual team will also get increased.

7.2. Limitations and Further Study

For this study, we conceptualize the team to be in an ISD context and the project is assigned to a virtual team with two geographically dispersed sites. Even though this study addresses the characteristics of spatial and temporal dispersions in virtual team, we realize that there are some constraints. Firstly, real ISD projects are usually more complex than their simulated versions because they may have more decision factors and there will be more variances such as cultural difference, leadership styles, which may have impact on the process and performance. Secondly, the study does not focus on the impact of configurational dimension (number of sites) of virtual teams, which is also an important factor for virtual team. To find out more about the impact of configurational dimension, the experiment of this study can be extended by considering 3 or more sites. Thirdly, we do not separately test the impact of information loss distortion in this study. We treat them as a bundled effect created by spatial dispersion. We can do further studies on the impact of information loss and distortion separately so that we can know the impact of spatial dispersion at a more micro level (e.g., how much is due to info loss and how much is due to info distortion).

7.3. Conclusions

Despite these potential limitations, the results of this study produce important theoretical insights into ISD and the use of virtual teams in ISD. In this study, the ISD process is conceptualized as a process of search within a design space. The NK Fitness Landscape model enables us to well model the process. We develop a theoretical / computational model to explore the impact of temporal and spatial dispersion of global virtual teams. The study extends prior research on the impact of virtual teams on organizational performance by rigorously modelling the phenomenon and combining different experimental conditions. In this study, we explored the impact of temporal and spatial impacts at different complexity levels and the impact of trust levels among virtual team members. The findings of this study allows us to offer practical recommendations for organizations who need to adopt distributed virtual teams for collaborative tasks. Another objective of this study is to derive new theoretical insights about the influence of virtual teams on ISD performance. The findings of this study will inspire further practical application of virtual teams in organizations and further empirical studies on virtual teams.

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Appendix

Result of Linear Regression for Experiment 2

	K0	K1	K2	K3	K4	K5	K6	K7
(Intercept)	1.00E+00	0.952637	0.918388	0.895779	0.8773672	0.8603483	0.845188	0.831039
Temporal	1.66E-15	-0.02083	-0.020246	-0.0174939	-0.016695	-0.012065	-0.00737	-0.00448
Spatial	1.66E-15	0.006621	0.017092	0.0185099	0.0113786	-0.00117	-0.02017	-0.03838
Overlap	-1.29E-29	0.021717	0.032388	0.0349003	0.035018	0.0336841	0.029978	0.027793
Temporal x Spatial	-1.66E-15	-0.00914	-0.017889	-0.0231447	-0.03578	-0.046396	-0.0595	-0.06024
Adjusted R-squared	0.4961	0.3681	0.584	0.748	0.8757	0.9441	0.98	0.9859
F-statistic (on 5 and 594)	1.19E+02	70.79	169.2	356.6	845.1	2023	5857	8354

	K8	K9	K10	K11	K12	K13	K14	K15
(Intercept)	0.8189623	0.807488	0.7959022	0.7849714	0.7736376	0.7637314	0.75243	0.741299
Temporal	-0.0016722	0.000521	0.003422	0.0055935	0.0086375	0.0113473	0.013621	0.013831
Spatial	-0.0593387	-0.07655	-0.094048	-0.1060344	-0.116203	-0.123251	-0.12762	-0.1311
Overlap	0.0251488	0.022889	0.019895	0.017737	0.0146727	0.0121109	0.010213	0.00976
Temporal x Spatial	-0.0596356	-0.05161	-0.04796	-0.0417487	-0.038901	-0.035462	-0.03238	-0.02842
Adjusted R-squared	0.9909	0.9917	0.995	0.9953	0.9948	0.9965	0.9958	0.9198
F-statistic (on 5 and 594)	1.31E+04	1.43E+04	2.37E+04	2.54E+04	2.31E+04	3.46E+04	2.84E+04	1374

- The underlined value means the impact of its related variable under its related complexity is not statistically significant (with p value less than 0.05). In this case, we can say this variable does not have a significant impact on the performance of virtual teams.
- For adjusted R-squared, we regard the model with R > 0.5 as a good model. Therefore, when k=0 and 1, the model is not very good.