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Jorge A. Colazo
Suffolk University, jcolazo@suffolk.edu

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Following the Sun: Exploring Productivity in Temporally Dispersed Teams

Jorge A. Colazo
Dpt. of Information Systems and Operations Management
Suffolk University
jcolazo@suffolk.edu

ABSTRACT
Dispersion in working teams has been addressed by earlier research mostly in terms of the physical distance that separated team members. In more recent work, however, the focus has been shifting towards understanding the influence of a newer construct: that of temporal dispersion (TD). The study of TD is so far constrained mostly to conceptual work, and the study of its association with distributed team performance is lacking. This paper attempts to explore that void by empirically investigating how TD relates to the team's productivity. Suitable hypotheses are developed based on coordination theory, and the analyses are performed on data collected from multiple archival sources comprising 100 open source software development distributed teams. The test of hypotheses is carried out using objective, non perceptual measures. Regression analysis is used to detect significant associations. Results show that temporal coverage is positively associated with productivity, and that the project's complexity moderates the relation between productivity and TD.

Keywords
Distributed Teams, Temporal Dispersion, Coordination Theory, Open Source Software.

INTRODUCTION
Scholars and practitioners agree that the proliferation and importance of distributed teams (DTs) will only increase, at least for the foreseeable future. Motivated by this, academia strives to improve the understanding of the factors that drive these teams’ performance. Managers, in turn, are eager to explore interventions that can make their DTs work more efficiently and effectively.

A trait that is germane to all types of DTs is that of the dispersion of their members. That dispersion has been addressed by earlier research mostly in terms of the physical distance that separated team members. More recently, however, the focus has been shifting towards understanding the temporal dispersion (TD), roughly defined as the variability in the different team members' working hours.

TD has been in principle seen as a consequence of teams that include members spread along geographical locations in different time zones. However, long considered as a given, recently many DTs purposely seek to be temporally spread. Especially in software development, some firms have tried a “Follow the Sun” approach by trying to place globally distributed team members in optimally placed, different time zones in such a way that their working times barely overlap and one sub-group of team members can pick up work where a previous subgroup left, supposedly increasing the overall productivity. To date, however, there is no hard data supporting whether that approach delivers any real improvement (Espinosa and Carmel, 2003).

Understanding the impact of TD on team performance not only is applicable to globally distributed teams. Conclusions could also be applied to multiple shifts working in the same location, to collocated but asynchronous work in the same nominal working hours, and to situations with telecommuters and / or otherwise flexible work schedules.

Coordination Theory (CT) serves as the theoretical lens for positing relevant hypotheses. The empirical research framework consists of a well-known kind of DT exhibiting various degrees of TD: open source software (OSS) development teams. The analyses were performed on panel data collected from multiple archival sources comprising 100 software developments DTs. Productivity was measured, together with TD and other controls, using objective, non perceptual measures. Regression analysis was used to test the hypotheses, with results showing that TD is positively associated with team productivity, and that task complexity moderates the strength of that association.
The following section of this paper reviews relevant research. Next, CT was used to motivate the hypotheses. The following section explains the analytical methods, including the research framework, sampling, data collection and analysis. After the results section, the last section contains the study’s conclusions, limitations and potential to engender future research.

LITERATURE REVIEW

At this point, a detailed definition of TD is called for. In this paper, temporal dispersion is defined as the lack of uniformity in the members’ working time, when starting and ending work times are expressed in a location-independent unit, such as coordinated universal time (UTC). For instance, a team with zero TD would have all its members starting and ending work at the same UTC.

Note that although in practice most geographically dispersed work teams will concurrently have some degree of TD, geographic dispersion (GD) is not a necessary condition for temporal dispersion. For example, consider members of a team doing a typical 9 to 5 work day but disseminated among locations in three distant cities: Toronto, New York and Quito. These three locations are indeed in the same universal time zone (in this case UTC-5) and there is no TD. Similarly, temporal dispersion does not imply geographic dispersion. For an example consider team members who work at the same physical location but distributed into three eight-hour shifts along a 24-hour work day.

But even though the concepts of TD and geographic dispersion are different, a review of the literature reveals that these two concepts were confounded in early research, and only recently the differences between the two were progressively recognized. Also the literature reveals that although TD is presently attracting scholarly attention by itself, the understanding of its influence on team performance is meager, and not supported by empirical research. In effect, following a cursory timeline of prior research on team dispersion is informative not only about key points for analyzing TD, but also gives an idea of how the concept of TD has developed, in due course differentiating itself from that of GD.

As Kiesler and Cummins noted in their review (2002), early studies on team dispersion focused on geographical distance and addressed relatively short distance spans, considering mostly Euclidean distance as measure of dispersion. To this point, no reference to temporal considerations appeared or could be presumed in the literature. However, as researchers approached situations where physical distance among members was bigger, that was not the case anymore.

In fact, later studies targeted relatively more (geographically) dispersed teams, for instance those working in the same building or business unit. These studies found that although distance generally affected team performance negatively, once a distance of approximately 30 meters was reached between team members, the influence of physical separation on performance levels out, with further separation bearing relatively little additional effect (Kiesler and Cummins, 2002). Contrasting the two groups of studies makes possible to begin fleshing out an incipient influence of TD.

In fact, researchers agreed that the prime difference between the mentioned earlier and later groups of studies is that in the latter there was a significant decrease in the frequency of face to face communication, considered the main motive for the observed performance deterioration (Hoegl et al., 2007). Interestingly, a principal problem of this lack of face to face contact was a big drop in the frequency of spontaneous communication. Due to this, information that would have been transmitted immediately between members got forgotten or discarded, and sometimes modified, but more importantly, delayed.

This difference between spontaneous and delayed information transmission hints to a need to untangle the influences of geographical and temporal nuisances in the performance of dispersed teams. In reality, that concern was at that point in our timeline not explicitly acknowledged, but the advent of newer organizational forms such as DTs was going to amplify the evidence of dissociation between space and time, and prompt scholars to reconsider their assumptions.

Progressing now to the last two decades, enter the DTs. With members dispersed along the world spanning several time zones and working from very diverse geographical locations, the importance of Euclidean distance in construing team dispersion seemed to fade even more (and that of TD increase). With the use of technologies that allow remote collaboration, the importance of face to face contact diminished, even for teams working at close physical range. In fact, in many instances even collocated team members preferred the use of communication technologies instead of resorting to a totally feasible face to face contact (Griffith et al., 2003). This evolution made temporal effects become more transparent, and geographical distance started to be questioned as to its importance in defining DTs.

In fact, recent research suggests that the concept of geographic dispersion is becoming outdated and needs to be dropped from future definitions of DTs (Kirkman and Mathieu, 2005). Kiesler et al. (2002) when discussing highly dispersed DTs operating in technologically intensive contexts, suggested that geographic proximity might be becoming largely irrelevant and will be superseded by the concept of “virtual proximity”, which is enabled and altered by the use of different
communication technologies in all their potential combinations. However, these researchers did not suggest which construct, if any, should come to fill that void.

This paper suggests that at least in part, TD is the answer. This suggestion seems to have been at least implicitly shared by some. In the last few years the appreciation of a decreased importance of physical distance for distributed team work spawned a stream of research that yet embryonic, decidedly started concentrating on time-related issues in DTs. Some articles incorporated temporal considerations into the discussion of other matters such as team virtuality or team dispersion (O’Leary and Cummins, 2007, Kirkman and Mathieu, 2005, Cummins, 2004). Other researchers pointed to contextual influences that could interplay with time-related issues in their potential relation to DT performance. Some of those are task complexity and “task granularity”, a concept loosely comprising task size, complexity and interdependence (Labianca et al., 2005).

Of course, an empirical study such as the present faces the task of actually measuring TD. Only a few past attempts directly or indirectly related to TD that can potentially inform this task. Knoll (2000) measured the mean and standard deviation of the team members’ working hours, taking as center of the distribution Greenwich Meridian Time. McDonough et al. (2001) divided teams into three ordinal categories related to their degree of TD: co-located, virtual, and global. In a theoretical paper, O’Leary et al. (2007) considered TD as an important dimension of geographical dispersion, and besides furthering the theoretical discussion they argued that a measure of TD should include some temporal variance metric. In the mentioned recent and rather modest body of research there are no empirical studies observing the association between TD and team productivity. In that sense, it sounds true that “at least empirically-, there is still “practically no research on the nuances of time separation” (Espinosa and Carmel, 2003, p. 249).

Yet from the practical aspect, one can see that those nuances have been recognized as substantive by DT managers (Saunders et al., 2004). The consequences of temporally dispersed DTs that collaborates asynchronously include work flow disruptions (Perlow, 1999), problems for conflict management (Montoya-Weiss et al., 2001), difficulty to assimilate atypical work hours with related problems with meeting deadlines (Labianca et al., 2005), and perhaps more importantly a substantial decrease in the attainability and effectiveness of leadership control over the team (Jarvenpaa et al., 1998).

But TD may not only have negative connotations. Managers have in fact identified that a proactive intervention on the patterns of TD in DTs may have very important practical implications. For instance, globally distributed DTs have been trying to take advantage of a “follow the sun” approach, where work started in a given location is taken over by other team members located several time zones later, supposedly increasing the overall team’s productivity.

Although this “follow the sun” approach is an interesting idea, to date, studies confirming its efficacy were called for but are still lacking (Carmel, 1999, Espinosa and Carmel, 2003). Presumably, research linking TD to team performance will, -besides filling an academic void- better inform managers on which interventions are more promising to make the strategy effective, or under which conditions such strategy can be expected to be effective.

In brief, from the analysis of extant literature it appears that temporal differences do matter, and, such as Espinosa and Carmel (2003) suggest, “future empirical research … needs to [either] control for time differences within teams, or [else be] conducted with teams that are not separated by time.” In general in academia, the notion of TD is gaining momentum as a factor that clarifies and expands the idea of team dispersion. Also, from theoretical and practical evidence an association of TD with DT productivity in not only plausible but worth looking into.

It can be then concluded that given the cited groundwork laid out by previous research and the relevance of the topic, a logical next step is to empirically explore the association between TD and team productivity.

HYPOTHESES

To develop the hypotheses the theoretical grounding is coordination theory (CT) (Malone and Crowston, 1990, Crowston et al., 2006, Malone et al., 1999, Malone and Crowston, 1994, Malone and Crowston, 1991), which is in turn based on Thompson’s (1967) typology of functional dependencies. Thompson (1967), mainly preoccupied with dependencies among departments or functions in an organization, posited that the tasks that shape the work flow among functional departments of an organization have three different types of dependencies: pooled, sequential, and reciprocal. In the first case tasks could in principle develop simultaneously but depend on and are constricted by the same pool of resources from which the tasks draw. In the second case a given task requires an antecedent task be completed before it can begin. In the third, tasks are mutually dependent, and each task requires the incremental progress of the others to incrementally advance. In complex systems, all three modes are expected to coexist.

CT extends Thompson’s typology by breaking down coordination into underlying processes such as group decision making and communication, and more relevant to this paper, by considering different layers of interdependent entities such as tasks,
and resources, as well as suggesting different coordinating mechanisms that may apply to different types of interdependencies.

CT indicates that teams spend their effort in two different activities: goal-oriented activities and coordination activities. For instance, in software development teams the goal is to write useful source code towards the completion of a functioning program. Coordination activities are required when there are dependencies to manage. CT posits that there are three types of dependencies that imply some sort of coordination activity: Task-Task, Task-Resource and Resource-Resource (Crowston, 1997). This framework is useful to explore how these dependencies should affect overall team productivity in temporally dispersed teams.

As per CT, the necessity of Task-Task coordination arises from the existence of a set of task precedence relationships that is unique to a given project, much in the same way as many readers have learned the critical path method for project management. In this paper “project” is the set of tasks that the team is expected to complete within a given timeframe or towards a certain goal.

Assuming that team members have a finite set of skills that do not cover all skills needed to complete all the tasks in the project, if a team were not temporally dispersed, or “concentrated”, with all members amassed in a given working time, there would be a substantive chance that one or more team members might be at some point idle waiting for the completion of a preceding task. The resulting idle time could be minimized if the team members were temporally dispersed in such a way that their allocation is exactly aligned with the task sequencing that derives from the task precedence relationships. Since tasks have positive durations, the latter case would require some amount of temporal dispersion in the team. If temporally dispersed teams can be expected to have a smaller amount of idle time, then it follows that those teams should be more productive than concentrated teams. It could also be expected that the higher the complexity of the project (and the intricacy of the precedence relationships) the effect of temporal dispersion should be more pronounced.

CT indicates that a second case of task-task interdependence is given when lack of coordinating mechanisms or an inadequate coordinating mechanism results in the generation of tasks that are conflicting, i.e. only one out of a two or more tasks will eventually be selected for completion, rendering the others useless. In a team setting, and especially in larger teams, maintaining a certain communication level gets exponentially more difficult with the size of the team (e.g. Blau, 1970). It follows that concentrated teams, forcibly larger than a succession of temporally dispersed subgroups of team members, should be more prone to generating conflicting tasks, for instance producing task duplication. Conflicting tasks require the solution of the conflict by analysis of the merit of the conflicting tasks and decision making processes, both of which are coordinating activities and subtract from the available goal-oriented effort. From this point of view it can be expected that concentrated teams should be less productive than their temporally dispersed counterparts. When the project complexity increases, with more tasks and more intricate interrelationships, it can be expected that solving task-task conflicts will be more onerous than in simpler projects, because the analysis of conflicts needs to account for the impact of potential alternatives on a greater number of interfaces with other tasks. This reasoning also suggests that the complexity of the project should moderate the relationship between TD and team productivity.

The need for task-resource coordination derives from the use of shared resources by more than one task simultaneously. When tasks do share a resource, CT explains that the resource is either completely shareable or non-shareable but reusable. If the resource were completely shareable, there would be no conflict and no need for coordination, and hence no idle resource. However, if the resource is non-shareable but reusable, the only coordination mechanism possible, as suggested by CT is scheduling the use of the resource. In simple terms, that means that one task should wait until some other task (which may or may not be linked by a formal precedence relationship) finishes making use of that resource. One of the interdependent tasks needs to use the resource first, and the other must wait until the resource is available. Obviously, this situation will impede the simultaneous completion of both tasks, and manpower scheduled for working on the successor task might be idle waiting for the completion of the predecessor task. Thus in the presence of non-shareable, reusable resources concentrated teams would be more likely to generate idle manpower and then be less productive than temporally dispersed teams.

The need for resource-resource coordination arises when the availability of a given resource depends on the previous presence of another resource (e.g. the availability of a computer may depend on the presence of electrical power). This is the case when one resource is produced by a process in which some other resource is needed. Much in the same way as there is a set of task precedence relationships, resources will have their own set of resource precedence relationships. And following a similar argumentation as the one used for task-task coordination, the consequent temporal sequencing of resource availability would indicate that concentrated teams would be less productive than temporally dispersed teams, which can be temporally allocated in such a way that members are ready to make use of the resource only when the resource is available once its own resource precedence relationships are met, and not before, in the latter case requiring coordination efforts which are detrimental to productivity. And here again, the more complex the project, it is plausible to say that the corresponding
resource precedence relationships will also be more complex, and optimally temporally dispersed teams should achieve a higher level of productivity.

In brief, CT consistently indicates that temporally dispersed teams stand to be more productive than concentrated teams, and that project complexity should moderate the relationship between TD and productivity. Relatedly, Espinosa and Carmel (2003) suggested —without empirical test— that a "follow the sun" strategy would be more effective for ‘low granularity’ tasks. Although granularity is not explicitly defined in that work, in the context of software development (their research framework) granularity is "the size and complexity of the units of code under consideration" (Raymond, 1996). Given the arguments above:

**H1: Temporal dispersion is positively associated to productivity**

**H2: Task complexity positively moderates the association between temporal dispersion and productivity**

**METHODS**

**Research Framework**

The research framework for the empirical test of the hypotheses consists of open source software (OSS) project teams. OSS is software produced under licensing terms that make the complete source code (i.e., instructions coded in a programming language) of the product publicly available. Notable examples of OSS are Linux and Apache. OSS teams are distributed, (often globally) and their members can span several time zones (Crowston and Scozzi, 2002). The consequent temporal dispersion of these teams makes OSS teams a natural research framework to empirically study team dispersion. Additionally, the public availability of data on OSS — including the product (source code) itself and all of the work records in artifacts such as files and modules — pose a great opportunity for empirical researchers, which this study attempted to tap into.

**Sampling, Data Collection, Measurement and Analysis**

The unit of analysis was the team. OSS project team information is hosted in web-based repositories which have been used repeatedly as sources of archival data for empirical studies (c.f. Mockus et al., 2002). In line with the majority of these studies, this paper uses Source Forge (SF) (www.sourceforge.net). The programming language of the projects was restricted to ‘C’ because it is the most popular programming language in SF, and because the use of a single language is preferred when using code-based metrics (Jones, 1986). To limit the time spent in the collection of data, only the biggest teams were considered. In accordance with previous empirical research on OSS, projects with six or more team members were selected (Crowston and Howison, 2003).

The sampling was non-probabilistic (see limitations), and all the projects that matched the definition of the sampling frame were considered. In the repository, there were 276 software projects being developed by six or more team members and using ‘C’ as the sole programming language. These projects constituted the sampling frame for this paper. The final sample was reduced to 100 projects (36% of the sampling frame) since only that number had archived full data on all development activities. All measures were taken in quarterly intervals from the first date they were created until 12 quarters of data were obtained. The projects’ source code files were downloaded and parsed with custom-written software analyzer programs to obtain both product size in source lines of code (SLOC) as well as other static metrics such as code complexity and number of lines added for each time period. These metrics were confirmed using at least two different off-the-shelf code analyzers.

Productivity was measured using a well-established –albeit basic- empirical metric for software development productivity: average source lines of code per team member, per unit of time (Fenton and Neil, 1999).

Temporal dispersion was measured as the ratio, in percentage, of the number of worked hours to the total number of elapsed hours. An hour was considered as worked when at least one team member (software developer) was active during that hour. Activity was observed from two different sources: timestamps in the concurrent versioning system log files and from time stamps recorded in the developers’ e-mail exchanges. Those two sources were parsed with custom-made scripts written in PERL (Practical Extraction and Report Language) to extract activity times.

Project complexity was measured using the project's average McCabe's cyclomatic complexity factor (McCabe, 1976), a widely used metric for assessing the intricacy and understandability of software projects.
The sampling design naturally controlled for programming language to eliminate inconsistencies in the metrics based on source code, such as productivity or complexity. Project tenure was measured by the number of days between the first known addition or change to the source code repository. Project size was measured in total lines of code.

The hypotheses were tested using ordinary least squares (OLS) regression. OLS was selected because it is well suited for studies in a preeminently exploratory stage, and it allows the study of interaction effects between variables by regressing on their standardized cross-products. All variables were log-transformed to increase linearity. Temporal dispersion and task complexity were also standardized in order to alleviate potential colinearity problems with their interaction cross-product.

RESULTS

Table 1 shows the results of a basic OLS regression model where the dependent variable is team productivity. H1 was supported. Temporal dispersion was positively associated with productivity (p < 0.0001). H2 was also supported. Task complexity moderates the relationship between temporal dispersion and productivity. The positive sign of the interaction term indicates that an increase in complexity will increase the regression coefficient for temporal dispersion, i.e. the more complex the tasks at hand, the higher the positive influence of temporal dispersion on productivity. Variance inflation factors (VIF) are close to one, which confirms that no substantial colinearity problems existed.

<table>
<thead>
<tr>
<th>B</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.635 ****</td>
</tr>
<tr>
<td>Team size</td>
<td>1.264 **** 1.2</td>
</tr>
<tr>
<td>Team tenure</td>
<td>-0.175 1.0</td>
</tr>
<tr>
<td>Temporal Dispersion</td>
<td>0.107 **** 1.2</td>
</tr>
<tr>
<td>Task Complexity</td>
<td>0.088 *** 1.0</td>
</tr>
<tr>
<td>TD x Complexity</td>
<td>0.064 ** 1.0</td>
</tr>
</tbody>
</table>

N = 698  
F = 31.4 ****  
R² = 0.125  
** p< 0.01  
*** p < 0.001  
**** p < 0.0001

Table 1: Regression, Productivity

CONCLUSIONS

This basic study intended to explore whether an empirical relationship can be expected between the degree of temporal dispersion in a team and the team's productivity, and what role, if any, task complexity plays in such relationship. Based on coordination theory, results of a basic regression model using open source software development team data suggest that temporal dispersion of a team can result in higher levels of productivity, and that the more complex the project, the greater the effect.

This study offers several academic contributions. The first is the identification for the first time of a suitable comprehensive theoretical framework (CT) to analyze the temporal dispersion of teams. The second contribution is that (to the authors’ knowledge), besides several anecdotal accounts and suggestions from previous research, the present is the first empirical analysis encompassing a good number of teams of different sizes and task complexities that looked into the association between temporal dispersion, task complexity and team productivity. Another contribution is the simple operationalization of temporal dispersion, which can be easily replicated in other settings. As well, the data used is objective, and the covariates were measured using metrics with a long history of reliability and internal validity.
From the practical perspective, these exploratory results yield support to a “follow the sun” work strategy, and suggest that the mentioned strategy will be more efficient as the task complexity increases. Given the expense and difficulty of setting up a globally dispersed team, the present results should be informative to project managers who are considering spreading a team's members across several time zones. The results, however, should not be only applicable to globally dispersed teams: they should also apply to shift-based work in the same geographical location and to other flexible work time arrangements, pretty much independently of the geographical location of team members.

Undoubtedly, this exploratory study should be further extended by considering more complex analytical models that may incorporate behavioral and task characteristics that were not available in time for the present study. Other research frameworks should also be analyzed to assess the external validity of these results.

Future work under way is developing a more complex structural model of temporal dispersion vs. team productivity, and incorporating data from interviews with temporally dispersed team members in several different industries. Another interesting question to pursue is whether TD could influence other team outcomes such as product quality or team viability. Also, aligning the number of team members with the project complexity is a dynamic problem (project complexity changes with the degree of completion of the project). How to find the optimum temporal dispersion of a team needs to be further studied in such a dynamic environment. Analytical models of TD in teams could also yield rich insights.

REFERENCES