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Effect of Temporal Patterns on Task Cohesion in Global Software Development Teams

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Abstract. This work focuses on the analysis of temporal measures and their ability to predict *task cohesion* within global software development projects. Messages were collected from three software development projects that involved students from two different countries. The similarities and quantities of these interactions were computed and analyzed at individual and group levels. We proposed *pacing similarity*, *pacing rate* and *synchrony*, a set of temporal metrics measuring frequency and rhythm of team member's interactions. Results showed a statistically significant negative correlation between *pacing rate* and *task cohesion*, which suggests that frequent communications increases the cohesion between team members. The study also found a positive correlation between *synchrony* and *task cohesion*, which indicates the importance of establishing a communication rhythm within members a team. In addition, the temporal models at individual and group-levels were found to be good predictors of *task cohesion*, which indicates the existence of a strong effect of frequent and rhythmic communications on cohesion related to the task.

Keywords. Virtual groups, cross-culture communication, teamwork, task cohesion.

1 Introduction

Group cohesion is an important factor that affects collaboration behaviors among members of global software development teams. Previous research found that using communication technology often causes delays in the development of the group cohesion construct in virtual teams. As a result, global teams tend to have much lower group cohesion levels than co-located groups [10]. An important reason to examine group cohesion levels is that it seems to affect how a team deals with different obstacles during a project development. In addition, the relation between group cohesion and other constructs (e.g. trust) has been shown to have a significant relationship to team performance [6].

There have been a number of approaches used to measure group cohesiveness; ranging from paper-based individual surveys to the more automatic process of following a team's communication trails [4]. Such methods have shown the significance of examining factors that affect cohesion at the team process level. Despite they usefulness, an important drawback is that they fail to capture temporal aspects of group processes and how they relate to task cohesion. A failure to utilize temporal information naturally reduces the power of the analysis, which may, in turn, limit the validity of a study's conclusions.

In an effort to gain a better understanding of group's temporal factors and their effect on task cohesion, we introduce three temporal measurements to predict a group's overall task cohesion levels. In particular, we focus on the analysis of features capturing temporal factors such as *pacing rate*, *pacing similarity*, and *synchrony* within medium-sized global software development teams and show how they can be used to predict cohesion levels within a group.

The goal of this paper, therefore, is to examine temporal features of global virtual teams and determine whether these measures relate to *task cohesion*. The measures are also used to create a learning model to predicts *task cohesion*. The main hypothesis of this paper is that the communication activities within distributed teams are cyclical in nature and oscillate between discussions and individual work.

2 Methodology

We began the study by asking students from institutions in the US and Mexico to work in teams on mid-sized software development projects. Once the projects were completed, we extracted temporal patterns from a team members' interactions. We then determined the relationship between temporal variables and *task cohesion*. A more detailed description of the teams' composition and the assigned projects now follows.

2.1 Teams

The data used in this study was obtained from three student global software development projects that occurred between 2014 and 2015. Students who participated in these projects were enrolled in Computer Science courses at the University of North Texas and Universidad Politécnica de Altamira –located in the United States of America and Mexico, respectively.

While each of the three projects addressed aspects related to the software development process, the actual assignments often varied in terms of team size (4-8 members), and specific task.

Two of the projects consisted of redesigning a non-profit website, including the redesign of the home page, the events page, and the contribution page sections as well as implementing a database that could support the various operations that were needed to maintain the different pages.

A third project consisted of creating a learning website about an optimization algorithm. The various elements of the website included a section where users could read information about the algorithm, as well as a section where users could test the algorithm. The length of the project also varied between 6-7 weeks. The software development methodology was defined by each team.

2.2 Software

Students who participated in the three projects were asked to communicate with one another using Redmine, a project management web application. This application platform included several collaborative tools such as chat, forums, wikis, and document sharing. Moreover, the application software was enhanced so that it recorded and time stamped all interactions among group members and transferred this information to a centralized database.

2.3 Measures

In order to analyze interactions among team members, we developed three temporal measures (*Pacing similarity*, *Pacing rate*, and *Synchrony*), which we believed to be good predictors of a team's task cohesion levels within a global software development context.

These measures were calculated at the individual-level as described below. Additionally, we calculated these measures at the group-level by averaging their values i.e. *group pacing rate*, and *group synchrony*. We also measured *task cohesion* at the individual and group level.

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2.3.1 Pacing Rate and Pacing Similarity

The *pacing rate* (pr) was defined as the average number of seconds between messages from participants in the same team. *Pacing similarity* was obtained by averaging the similarity between the *pacing rate* of team participant i and the *pacing rate* of each of the other team members (see Equation 1):

$$pacing\_similarity = 1 - \frac{|pr_i - pr_j|}{pr_i + pr_j}. \qquad (1)$$

2.3.2 Synchrony

This temporal measure captures the synchrony of messages sent between two team participants; where the messages from each participant are defined as a time series, and then their frequencies are compared to one another, one at the time [7].

Figure 1 (top) shows an example of the obtained time series and the number of messages sent by a team consisting of 4 participants.

We estimated the spectral density from each data series by creating a periodogram, a diagram of frequencies by amplitude, using the Fast Fourier transform.

Figure 1 (bottom) shows the resulting periodogram for the time series in our previous example. From this information, we calculated the coherence between two time series, which was the correlation between paired members of each frequency.

As a result we got a coherence series for each combination of pairs within a team ($c(2, n)$), see Figure 2. This calculation results in a vector of coherence values (each value representing coherence in a specific frequency) between two subjects.

To provide a unique temporal value between two individuals, we took the highest coherence score. Finally, for each participant in a team, we obtained the highest coherence scores of a participant as compared to the rest of the team members and averaged those scores.

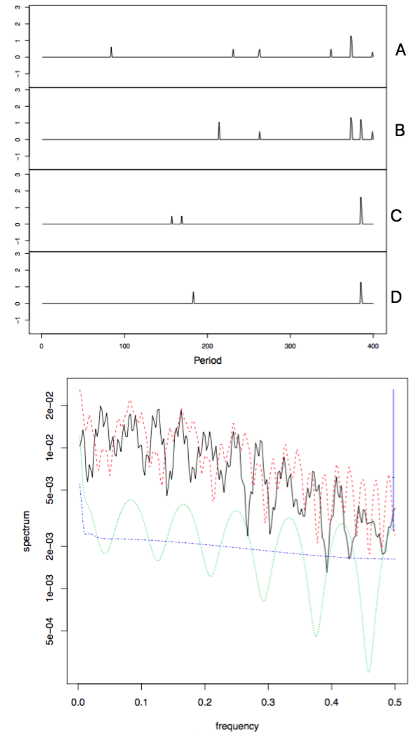

Fig. 1. Frequency graph (top) and periodogram (bottom) of 4 team members

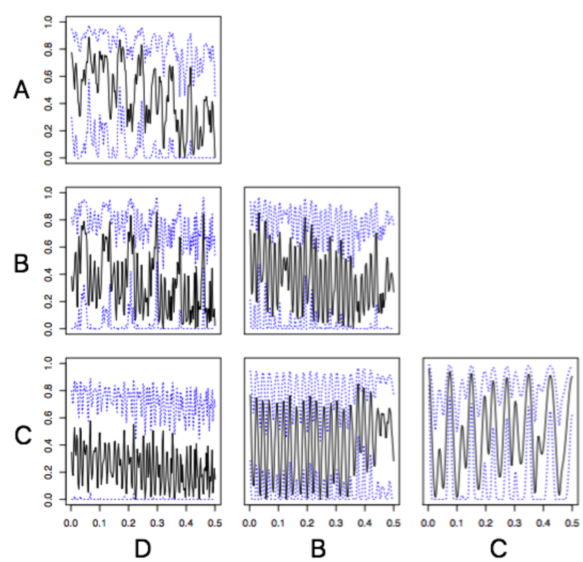

Fig. 2. Coherence graphs for each pair team members

2.3.3 Task Cohesion

Task cohesion is a construct that measures the degree to which team members are working together. To calculate the value of this construct, we used an individual survey approach because it seemed more appropriate for a distributed virtual team context [8]. The survey, intended to capture a participant perception of their team, included questions from the *task cohesion* section of the Group Environment Questionnaire (GEQ) [3]. A group's cohesion measure was then obtained by averaging each team's individual responses to the survey.

2.4 Linear Model

We conducted a set of experiments to assess the performance of temporal features as predictors of task cohesion. The data, collected from the three global projects, was then used to determine which set of variables were most successful at predicting individual task cohesion. We examined the relationship between *task cohesion* and the three temporal measures of *synchrony*, *pacing similarity*, and *pacing rate*. We also conducted comparative experiments between *pacing similarity* and *pacing rate* to choose the best pacing representation for the linear model.

3 Results

3.1 Sample Characteristics

A total of 5,583 messages were transmitted during the three projects. A total of 167, out of a possible 180, task cohesion surveys were collected. Since we had 27 missing surveys, we decided to include only messages sent by students who had completed the questionnaire; thus, we had a total of 5,446 messages in the final dataset.

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Table 1. Task cohesion values by culture *$p < 0.05$

Country	Mean	India	US
India	8.01		
US	6.21	1.8057*	
Mexico	6.48	1.5310*	0.2746

Table 2. Temporal metric statistics

Project	Instances used	Avg. Pacing Similarity	Avg. Pacing Rate
A	94.52%	0.56	4d 02h 52m
B	82.97%	0.54	4d 01h 09m
C	88.33%	0.53	6d 03h 38m

3.2 The Culture Effect

Due to the multicultural composition of our teams, we obtained cohesion surveys from people who were born in eleven different countries. However, the majority of the completed surveys came from students born in India, the US, and Mexico (i.e $n > 20$), while only a few surveys came from students born in other countries (i.e. $n < 4$). As a result, we reduced the data set even further by only keeping responses from students born in India, the US, and Mexico; thus, ending up with a final count of 4,849 messages sent by 153 individuals. We then compared the task cohesion mean values between countries and found that students from India tended to have higher Task cohesion perceptions than either US or Mexican students (see Table 1). Considering these findings, we used the culture factor as a control variable in our analyses.

3.3 Pacing at Project-Level

In addition, analyses conducted on the pacing metric measured at project level excluded data points from students who posted only one message during their interactions as the pacing similarity measure cannot be calculated for single messages. The final percentage of messages used for each project is shown in Table 2.

Results obtained in the remaining subjects suggest that pacing similarity has a similar value across all three projects; however, a comparison of the pacing rate shows that the communication rhythms within the three projects were dissimilar. More specifically, the rate of student replies was much slower in the last project i.e., Project C.

3.4 Temporal Measures and Task Cohesion

Using the final dataset, we calculated the correlation between *pacing similarity* and *task cohesion* and between *pacing rate* and *task cohesion* at the individual-level. Table 3 shows that *pacing similarity* has no effect on task cohesion. On the other hand, *pacing rate* has a weak, but statistically significant effect on *task cohesion*. This correlation, albeit weak, suggests that frequent communication tends to lead to an increase of individual's perception of Task cohesion.

The lack of a relation between *pacing similarity* and *task cohesion* suggests that individuals prefer frequent, although erratic, communication (*pacing rate*) with team members, over a more uniform, but less frequent, rate of communication.

Moreover, the *pacing rate* metric consists of 2 components: 1) Duration of communication (time between first and last communications), and 2) Number of communications. As a result, we analyzed the relation of these two components to *task cohesion*. Table 4 shows that both components have a statistically significant relation to *task cohesion*. The relation of the number and duration of communications to *task cohesion* may represent the communication engagement by each participant. Therefore, participants who are engaged in the project will perceive a greater team cohesion than those who are not.

Results for the *Synchrony* metric, presented in Table 5, suggest that *synchrony* is a very good predictor of *task cohesion*. Hence, this metric seems to capture the synchrony of collaborations among team members, regardless of the frequency of when those communications occur (e.g. communications every 12 hours, versus communications every 24 hours, etc.).

We also created an additional model to predict *task cohesion* (coh) that use the *Pacing rate* (pr) and *synchrony* (sy) (while controlled by *team size* (ts) and *culture* (cu). The top row in Table 6 shows that the temporal model is a good predictor of the variability of the *task cohesion* variable (r=0.358). These results suggest that temporal-based measures at the individual-level are helpful for understanding the perceptions of *task cohesion*.

Finally, we also evaluated the predictive power of temporal metrics measures at the group-level and built a model using *team size* (ts), *group pacing rate* (gpr), *group synchrony* (gsy) and *group task cohesion* (gcoh). Results shown in the last row of Table 6 indicate that group-level temporal measures are also good predictors of *task cohesion*.

Table 3. Pacing correlation with Task Cohesion *$p < 0.1$

Project	Correlation
Pacing Similarity	0.049
Pacing Rate	-0.129*

Table 4. Relation of components of Pacing rate to Task cohesion *$p < 0.1$, **$p < 0.05$

Component	Task cohesion
Duration of communication	0.137*
Number of communications	0.161**

4 Conclusion

The major goal of this study was to determine which temporal features can predict *task cohesion* for individuals and teams who were engaged in global software development projects. The motivation for this work was the expectation that information about the cohesion levels among individuals and teams in global software development projects could lead to better interactions among team members, and ultimately better group performance. Although many researchers have explored relationships between certain collaboration variables [11, 2, 9], few have examined the effects of temporal factors of pacing and synchrony.

Table 5. Effect of coherence similarity to *task Cohesion* $^{**}p < 0.05$

Measure	Correlation
Coherence Similarity	0.170**

Table 6. Linear temporal models to predict *task cohesion* $^{***}p < 0.01$

Model	R
$a_0+a_1\cdot ts+a_2\cdot cu+a_3\cdot pr+a_4\cdot sy = coh$	0.358**
$b_0+b_1\cdot ts+b_2\cdot gpr+b_3\cdot gsy = gcoh$	0.733**

For example, previous research has indicated that linguistic similarity, information exchange, and message content can help determine cohesion levels within groups [5, 12, 1]. However, we felt that just-in-time and abrupt communications require new methodologies to measure temporal phenomena that are more complex than simple linear patterns. For example, current research has not captured the effects of communication cycles spiraling up, down or intensifying.

Thus, this work herein proposes a methodology for describing the temporal narratives of distributed team processes over time and determining whether they could be used to predict Task cohesion. The three measures that were developed for this study were *pacing similarity*, *pacing rate*, and *synchrony*. Each of these factors was examined at both the individual and group levels.

Results showed a statistically significant negative correlation between the *pacing rate* and *task cohesion*, which suggests that frequent and perhaps sporadic rhythmic communications about different social and work themes increases the cohesion among team members. On the other hand, *pacing similarity* was not found to be related to *task cohesion*, which suggests that a minimum (although not equal) participation is necessary for individual's to perceive that their group is cohesive.

Thus, *pacing similarity* is not relevant to Task cohesion. We also found a positive correlation between *synchrony* and *task cohesion*, which suggests the importance of establishing a rhythm within a team. Finally, the temporal models constructed at individual and group-levels were found to be good predictors of *task cohesion*, which indicates the existence of a strong effect of frequent and rhythmic communications on cohesion related to the task.

Knowledge obtained from this study should provide insight into current empirical research on global virtual teams by defining the different temporal patterns that occur in these projects and how this can affect a team's perception of their cohesion levels.

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