Computer Mediated Communication and Organizational Culture: An Agent-Based Simulation Model

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KEYWORDS
Agent-based modeling, organizational communication, organizational culture.

ABSTRACT

This paper examines the mutual relationship between the organizational use of Computer Mediated Communication (CMC) and organizational culture (OC). CMC supplements communication among members of an organization to maintain the culture, especially when those persons cannot communicate by other means. On the other hand, a strong OC allows a more effective use of CMC by providing members with some of the necessary common ground to better understand the information exchanged. These relationships are investigated using an agent-based model (ABM). Our ABM incorporates many partial theories into a coherent and fully defined model, which helps formalize and integrate those theories. Although we have empirically validated the ABM, our model allows us to go beyond what can easily be done using empirical research, such as analyzing non-linearities and interaction effects. Additionally, the ABM allows us to investigate dynamics and generate hypotheses that could then be tested using empirical studies. In this paper, we present some of the results of the ABM that show that OC can influence the effectiveness of CMC and that CMC can help maintain and stabilize a culture.

INTRODUCTION

Computer Mediated Communication (CMC) allows two or more persons who are not physically together to exchange information through a computer system. Many studies have suggested that CMC has the potential to provide tools for enhancing the flow of information in an organization (Fulk and DeSanctis, 1995). However, research aimed at analyzing the effective use of CMC in organizations has arrived to contradictory conclusions. Positivist studies of CMC based on the Information Richness Theory (IRT) (Daft and Lengel, 1986) have found that CMC is inadequate to handle ambiguous situations. On the other hand, interpretivist studies of CMC have shown that CMC can accommodate the exchange of information even in confusing situations.

For IRT the communication richness (CR) of a medium explains why this medium is more or less effective. CR refers to the ability of a communication system to transfer enough cues so that individuals can reach an understanding within a short time. For IRT, face-to-face communication is the richest media because it provides immediate feedback and allows the exchange of multiple cues through body language and tone of voice. Since CMC restricts the use of immediate feedback and/or the exchange of multiple cues, IRT views CMC as inherently a medium of low richness.

On the other hand, interpretivist studies have shown that organizational members can use CMC (e-mail) to effectively communicate under ambiguous conditions (Lee, 1994; Ngwenyama and Lee, 1997). These studies claim that the richness of any communication medium changes according to the organizational context in which it is used. The person who sends a message and the one who receives it are part of an organizational context, so they not only derive the meaning of the message from the information it provides, but also interpret it taking into account other information they have at their disposal, such as knowledge of the other person, of the situation at hand and of the organization.

As one can see, IRT-based studies focus mainly on the intrinsic characteristics of the communication medium and analyze them independently of individual and organizational context. For the interpretivist studies, the attributes of a communication medium are dependent on both the intrinsic and extrinsic characteristics of the medium. Those extrinsic characteristics originate from the individuals who use it and the organizational context.

HYPOTHESES

One way to succinctly incorporate organizational context into the analysis of CMC or any other communication system is in terms of OC (Zack and McKenney, 1995). One definition of OC states that it is "a pattern of basic assumptions, invented, discovered or developed by a given group, as it learns to cope with its problems of external adaptation and internal integration, that has worked well enough to be considered valid and therefore is to be taught to new members as the correct way to perceive, think, and feel in relation to those problems" (Schein, 1990). This definition of OC suggests that OC will contribute to enhancing the possibility of reaching a mutual understanding when members of the organization communicate. Common assumptions tend to homogenize how members handle their work-related problems, by contributing to a common

 ISBN 3-936150-25-7

understanding , which will facilitate communication, especially when using low to medium richness media (Clark, 1996). This beneficial effect of OC will depend on how widespread and strongly members hold the assumptions embedded in the culture. A variable that represents this attribute of OC is its strength (Denison, 1990). These points can be summarized in hypothesis ***H1****: The stronger the OC, the higher the CR of the communication system.* Since that hypothesis and the ones below are applicable to any communication system used in an organization all the propositions are stated using the generic term communication system.

Note that if the initial strength of the OC is high, then members of the organization will have somewhat similar values, beliefs and assumptions. That common ground provided by a strong culture will facilitate the communication process. Thus, it will take the members a shorter time to reach a consensus than if the initial culture is weak, leading to hypothesis ***H2****: The stronger the initial OC, the faster the culture will stabilize.*

The previous hypotheses stated possible relationships between culture and CR. From a practical point of view, it is also interesting to see whether the mutually beneficial effects of a strong OC and high CR might be reflected in the effectiveness of the organization. Some case-based and empirical studies have suggested that a strong OC can enhance the performance of an organization (Denison, 1990 and references contained in that book). The main argument is that a strong culture establishes a common ground that facilitates the work among employees. Those beneficial effects might be reflected in the shortening of the time required to complete tasks. ***H3****: The stronger the OC, the shorter the task-completion time.*

Note that although these hypotheses plausibly follow from theory, because of non-linear interactions among variables and the general complexity of the phenomenon, it is not possible to determine a-priori that a particular formal model would generate results that would support those propositions.

THE MODEL

The model implements the conceptual ideas and mechanisms from the theory outlined in the introduction that bear on the hypotheses described in the previous section. There are many ways to implement those basic ideas. The present model is an attempt at a fairly simple implementation that captures the key mechanisms believed to be the most relevant. The following paragraphs describe the details of the model that are important for understanding the experiments carried out to test the hypotheses. For full details of the model, and for additional hypotheses and experiments see Canessa, 2002.

Organizational and Communicational Structure

The model assumes that an organization is a collection of groups of people that pursue some common goals. To reflect the relative difference in individual power in a firm, each agent has a number that represents its status. Members of a group can freely communicate. In the case of inter-group communication, only some members of a group may directly communicate with members of other groups. The capability of members to communicate outside their groups might influence their status. Since members who have a broader communication network have more influence, the status of the agents that can communicate outside their own group will be higher than the status of those who cannot (Krackhardt and Hanson, 1993).

Task Assignment and Completion

The organization assigns to each agent a task to complete. Each task consists of a given number of contacts that the agent must make with other members in order to complete the task. Some steps are sequential---the agent must wait until it receives a reply before advancing to the next step; other steps are non-sequential. Sequential task steps occur with probability 0.5.

If an agent is authorized to communicate outside its group, with probability 0.6 the organization assigns to it steps that involve contacting agents in other groups; otherwise, that probability is 0.3. When a task that requires inter-group communication is assigned to an agent that is not authorized to communicate outside its group, that agent must relay inter-group messages through the agents that are authorized to communicate outside the group.

Each time an agent completes a task the organization assigns a new one to it. With probability 0.5 the organization changes the identity of the agents involved in completing the new task and/or the sequence in which the contacts must be made. The rules that agents observe when completing their assigned tasks are:

a) An agent engages in completing one task at a time.
b) The number of steps of a task that an agent can perform in a simulation step is equal to the number of messages an agent can answer.
c) An agent processes messages that belong to its own task first. After that, if the number of already processed messages is smaller than the maximum the agent can process, then the agent processes messages from other agents. The order in which the agent processes those messages is dictated by the status of the senders, so that messages from high status agents are processed first.

Organizational Culture and Communication Effectiveness:

OC is represented as a list of dimensions (Axelrod, 1997) . For this study the number of cultural dimensions was ten. The initial values for each dimension are sampled from a normal distribution with mean zero and a given variance. This variance defines the starting variability of the OC and thus, the corresponding initial OC strength. The larger the variance, the weaker the initial culture.

Communication effectiveness (CE) is defined as the probability that two agents can communicate without problems. CE is a function of the difference in culture

between two agents, based on the sum of the absolute value of the differences in values between corresponding dimensions for the two agents. A sigmoid curve is used to calculate CE:

$$CE_{jk} = \frac{1}{1 + e^{\left(\sum_{i=1}^{N} |Tij - Tik|\right)\alpha - \beta}} \quad (1)$$

where Tij is the ith dimension of the culture of agent "j" and Tik is the ith dimension for agent "k" and N equals the number of cultural dimensions. The constants α and β adjust the shape of the sigmoid curve. In this study, α was set to 0.25 and β to 5.0. The value of CE between two agents specifies the probability that the receiver of a message understands it. If the receiver understands the message, then it processes the message. If the receiver does not understand it, then the receiver replies with a clarification message. The sender of the first message responds to this clarification. Upon receiving the answer to the clarification from the sender, the receiver decides if it now understands the new message. This process continues until the receiver understands the message or the receiver or sender quits sending/answering clarifications. The receiver or sender quits sending/responding clarifications when the number of clarifications exceeds three. If the sender quits answering clarifications or the receiver notifies the sender that it quit sending clarification messages, then the sender selects a new receiver for the message. This change of receiver occurs only once. If after changing receiver, the message is still not understood, then the communication fails, and the organization discontinues the corresponding task and assigns a new task to the agent.

Communication Richness and Organizational Culture Change

Different communication channels exhibit varying capacities for transmitting different types of cues. Therefore, when agents communicate using a channel, this channel will allow them to transfer some ("visible dimensions") and will block the transfer of other dimensions. The visible dimensions will be the ones that can change during the simulation. The model allows establishing the number of visible dimensions for communications among agents that belong to the same group (intra-group communication) and for communications among agents that belong to different groups (inter-group communication). The reason for distinguishing between the richness of intra and inter-group channels is that the members who belong to the same group will have more opportunities to communicate through rich channels (for example face-to-face meetings) than members who belong to different groups (Olson and Olson, 2000).

The OC change between agents takes place every time two agents communicate. The message receiver will change its culture toward that of the sender in an amount proportional to the CE and the difference in status between them. When agents s (sender) and r (receiver) communicate, r's culture will change according to:

$$\forall \text{ Visible Dimensions "i" between agent "s" and "r"}: \quad T_{t,i,r} = T_{t-1,i,r} + CE_{sr}(T_{t-1,i,s} - T_{t-1,i,r})\frac{Status_s}{Status_s + Status_r} \quad (2)$$

where $T_{t,i,r}$ is the value of dimension i at time t for r. The quotient of the statuses represents the asymmetrical nature of the influence that persons of different status can exert on each other (Salancik and Pfeffer, 1974). The bigger the difference in status between two persons, the higher the influence the person of higher status can exert on the person of lower status and, and vice versa.

The effect of CE reflects the influence a person might have on the culture of another if they can understand each other (Axelrod, 1997). Note that the change in OC is unidirectional; that is the sender influences the culture of the receiver and not vice versa. Since the receiver acts as sender when responding to the message and the original sender acts as receiver, the effect becomes bi-directional but not synchronous.

Sequencing of Events and Updating of the Model

The simulation is updated asynchronously (to avoid artifacts---cf. Huberman and Glance, 1993), as follows:

a) Select at random without replacement agent A.
b) Allow A to send messages for its current task.
c) Process incoming messages for A and change its OC.
d) See whether A's task is complete. If the task is complete:
   i. Compute measures pertaining to the task.
   ii. Assign a new task to A.
e) Repeat steps a) through d) for all agents.
f) Compute the measures and outputs of the model.
g) Repeat a) through f) for as many steps as specified.

Measures and Outputs of the Model

The following measures are used in this paper:

a) Average task-completion time for the organization (ATCTO). For all the completed tasks calculate the time it took to finish those tasks. Calculate an average time for the entire organization. This time reflects only the time agents spend communicating, so it applies only to assessing how long it takes members to carry out the communicational part of their jobs.
b) Overall OC strength (OOCS) measures the strength of the OC by calculating the variance for each of the dimensions of the culture for the entire organization, combining them using:

$$OOCS = \frac{1}{1 + \sum_{i=1}^{N} \sigma_i^2} \quad (3)$$

where σ^2_i is the variance of cultural dimension i and N (=10) is the number of cultural dimensions. Note that the stronger the culture, the smaller the variation and thus the closer OOCS will be to one.

c) Organizational average culture (OAC) is the average value of the culture computed over all cultural dimensions and agents. The time series corresponding to

OAC will reflect the dynamics of the culture of the organization. When this time series remains unchanged, the system is in equilibrium.

d) Average communication effectiveness for completing tasks for the entire organization (ACETO). Calculate the CE for each assigned task, even if it was not completed. The average CE for a task is calculated as the geometric mean of all the CE's between senders and receivers. For example, if agent 1 needs to communicate with agent 4 and to do so needs to go through agents 2 and 3 for completing the task, then:

$$CE_{task} = (CE_{12}\ CE_{23}\ CE_{34}\ CE_{43}\ CE_{32}\ CE_{21})^{1/6}$$

where CE_{12} = CE between agent 1 and 2, CE_{23} = CE between agent 2 and 3, and so on. Using the CE_{task} of all the assigned tasks, compute the average, which corresponds to ACETO. This measure reflects how well agents are communicating due to the intrinsic and extrinsic CR of the medium. If the intrinsic richness is high (i.e. the communication channel allows the transfer of many cultural dimensions), the culture is able to homogenize well and that increases the similarity among the agents' cultures. If the extrinsic richness is high (i.e. the agents' culture is already similar), the difference between the cultures of agents is low. In both cases, the CE_{task} will be high (close to one) and, correspondingly ACETO will also be high.

RESULTS

Before running experiments, we carried out extensive verification and validation of the program. Details are in Canessa, 2002. Table 1 shows the parameter values used in the experimental runs.

Table 1: Combination of Parameters Changed for Experimental Runs

Para-meter	Value	Experimental condition label
CIR	6 visible cultural dimensions within group 4 visible cultural dimensions between groups	Low intrinsic communication richness (LICR)
	10 visible cultural dimensions within group 8 visible cultural dimensions between groups	High intrinsic communication richness (HICR)
IOCS	Variance of normal distribution = 5	Strong initial culture (SIC)
	Variance of normal distribution = 10	Weak initial culture (WIC)

CIR = Communication channel intrinsic richness
IOCS = Initial organizational culture strength

We used four different numbers of steps per task (10, 20, 30 and 40), which were matched up with the corresponding number of messages an agent could process per time step; e.g., for a 40-step task, each agent has the capacity to process 40 messages per step. These four pairs of values were combined with the two scenarios for CR and for initial strength of OC, for a total of sixteen combinations. Each of these combinations was simulated for 600 time steps and replicated thirty times using different RNG seeds. Other parameters kept fixed were: the organization had 8 groups, each of 30 agents; three agents of each group were authorized to communicate directly with agents of other groups; these agents had a status of two, whereas the rest had a status of one.

Hypotheses Testing

The results for the 10, 20, 30 and 40-step tasks are very similar and thus we will report the outcomes for the 40-step tasks only. Tables 2 and 3 show the data gathered from the experimental runs, which we will use in testing the hypotheses and making other analyses. Specifically, Table 2 presents the OC strength (OOCS) and its standard deviation computed over the thirty replications using the last sixty data points of each run, where the system was in equilibrium.

Table 2: Organizational Culture Strength for the 40-step task

	SIC	WIC
LICR	0.0472 (0.0018)	0.0239 (0.0009)
HICR	0.7311 (0.0695)	0.5215 (0.0914)

(mean over the last 60 data points, std. deviation in parentheses, N = 30 replications)

Similarly, Table 3 presents the overall organizational CR and its standard deviation computed under the same conditions. Note that this overall organizational CR corresponds to the average communication effectiveness (ACETO), which encompasses both the intrinsic richness that does not change (due to the established number of visible cultural dimensions) and the extrinsic richness, which changes (because the culture of agents becomes more similar as time advances).

Table 3: Overall Organizational Communication Richness for the 40-step task

	SIC	WIC
LICR	0.8476 (0.018)	0.5792 (0.026)
HICR	0.9889 (0.0002)	0.9799 (0.0008)

(mean over the last 60 data points, std. deviation in parentheses, N = 30 replications)

If hypothesis H1 is true, we expect to see that the higher the value of OOCS in Table 2, the higher the corresponding value of ACETO in Table 3, which is the case. Table 4 shows the differences in ACETO, all of them significant. Thus, we conclude that H1 is supported.

Table 4: Differences in Means of Communication Richness corresponding to the four different values of organizational culture strength for the 40-step task

	Final Culture Strength	Comm. Richness	Difference in Comm. Rich.
Strongest final culture	0.7311	0.9889	
Moderately strong final culture	0.5215	0.9799	0.010
Weak final culture	0.0472	0.8476	0.1323
Weakest final culture	0.0239	0.5792	0.2684

(all differences significant at least at the 0.01 level)
For example: 0.010 = 0.9889 – 0.9799 and so on

To test hypothesis H2 we compute the steps required for the mean of the organizational average culture (OAC) to reach equilibrium (defined as starting when the time series of organizational average culture remained unchanged). Table 5 presents these figures.

Table 5: Mean Stabilization Time for Organizational Culture for the 40-step task

	SIC	WIC
LICR	20.5 (4.93)	34.3 (11.27)
HICR	18.0 (4.48)	19.3 (3.92)

(standard deviation in parentheses, N = 30)

If hypothesis H2 is true, we expect that the differences between the times corresponding to an initially weak and strong culture should be positive and significant.

Table 6: Differences in Stabilization Time of Organizational Culture between initially strong and weak cultures

	LICR	HICR
40-step task	13.80 (<< 0.001)	1.30 (0.237)

(p-values in parentheses)
The figures correspond to the difference in stabilization time between an initially weak and strong culture: stabilization time for initially weak culture - stabilization time for initially strong culture: 34.3 – 20.5 = 13.8 (see figures in Table 5)

From the figures of Table 6, one can see that for low intrinsic CR, hypothesis H2 is consistently supported (the difference is positive and statistically significant), whereas for high intrinsic CR it is not (difference is relatively small and non-significant). Note that the decrease in stabilization time between an initially weak and strong culture is much more pronounced for low intrinsic CR than for a high one. This happens because a low intrinsic CR prevents some cultural dimensions from changing. Thus, if these unchanged dimensions are initially similar, as when an initially strong culture exists, then the extrinsic CR among agents will be always higher than when these unchanged dimensions are initially dissimilar, as when an initially weak culture exists. Since extrinsic CR dictates how much the culture between agents will homogenize per step, the higher the extrinsic richness, the faster the culture will homogenize. Hence, the impact of an initially strong or weak culture on stabilization time of the culture will be higher when intrinsic CR is low than when it is high.

Table 7 presents the means and standard deviations of the task-completion times for the entire organization (ATCTO).

Table 7: Task-completion Time for the 40-step task

	SIC	WIC
LICR	23.054 (2.307)	61.406 (12.221)
HICR	16.894 (0.059)	16.947 (0.068)

(mean over the last 60 data points, std. deviation in parentheses, N = 30 replications)

If hypothesis H3 is true, then we should see that the task-completion times for strong final cultures (situations where OOCS is high in Table 2) would be shorter than the ones for relatively weak final cultures. To asses that, we computed the difference in task-completion time at equilibrium for strong and weak final cultures, using the times of Table 7. Table 8 presents these differences. All the differences between these times are statistically significant. One can see that the task-completion times are shorter for strong cultures than for weak ones. Thus, hypothesis H3 is supported.

Note that the impact of an initially strong or weak culture is more pronounced for low intrinsic CR than for high (see Table 7). This interaction effect of CR on the relationship between culture and task-completion time occurs because a low intrinsic CR prevents some of the cultural dimensions from homogenizing. Under that condition, the initial similarity of the dimensions that an initially strong culture produces is more important than when a high intrinsic CR exists. In this latter case, almost all of the cultural dimensions will homogenize and thus will decrease the impact of an initially weak culture on task-completion time at equilibrium.

Table 8: Differences in Means of Task-completion Times corresponding to the four different values of organizational culture strength for the 40-step task

	Final Cult. Strength	Task completion time	Difference in Task-completion Time
Strongest final culture	0.7311	16.894	
Moderately strong final culture	0.5215	16.947	-0.053
Weak final culture	0.0472	23.054	-6.107
Weakest final culture	0.0239	61.406	-38.352

(all differences significant at least at the 0.01 level)
For example: -0.059 = 13.897 – 13.956 and so on

In addition to allowing testing the postulated hypotheses, the runs showed another interesting aspect of the system's behavior. In one of the runs, task-completion time exhibited a different dynamic from the rest of the runs. In general, task-completion time increases at the beginning of the simulation reaching a maximum and then it begins to asymptotically decrease toward a lower equilibrium value. This happens because the first completed tasks among all the tasks that the organization assigns are the ones that take agents a shorter time to complete. Since those short tasks are the ones the model includes in the first calculations of the mean task-completion time, that figure remains low. As time advances, agents complete the more complicated tasks, which increases the mean task-completion time. However, at the same time, the OC begins to homogenize, making it easier for agents to understand each other. This shortens the task-completion times, which in turn, decreases the mean value of that variable. Finally, the culture homogenizes as much as the conditions allow and the system reaches equilibrium. At this stage, the task-completion time reaches its equilibrium value.

However, in one run, the dynamics of task-completion time changed. At the time when that variable was reaching its equilibrium value, suddenly it jumped to a higher value, interrupting its asymptotic decrease. After that abrupt variation, the dynamic of task-completion time went back to

normal, i.e., it began to decrease reaching an equilibrium value. Examining the run, we found that the organization had assigned tasks to agents involving almost no change in the identity and sequence of contacts, from the beginning of the run until the moment the change in dynamics occurred. At that moment, the organization (by chance) drastically changed the identity of the agents involved in each step of the tasks and somewhat the sequence of contacts. Examining the culture of the agents, we saw that because the tasks were initially so stable, the agents had fine-tuned their culture to accomplish such tasks, creating very strong local cultures. These local cultures significantly differed from one another. Thus, when the organization changed the contacts for completing the tasks, the agents had to communicate outside these local cultures. Since these cultures were strong but different, agents could not immediately adjust to their new communication partners. This caused an increase in task-completion time. Eventually, as the local cultures homogenized, that measure improved.

DISCUSSION

As one can see from the results of the experiments, in general the postulated hypotheses were supported. This is not surprising since the model embeds part of the corresponding theory that supports such hypotheses. However, the interaction effects discovered were not postulated a priori based on the theoretical background. Although a close examination of the model helped explain why these interaction effects occurred, our intuition regarding the outcomes of the model was not completely right. Thus, the agent-based model served the purpose of enhancing the understanding of the phenomenon under study. The usefulness of this approach in this study agrees with similar ones reported in other papers (Axelrod, 1997).

The new relationships discovered have some useful implications. First, the results showed that the difference in the stabilization time of a culture between high and low intrinsic CR media for an initially strong culture is small. On the other hand, for a weak initial culture, the stabilization time is significantly shorter for media of high richness than for low ones. This might suggest that the use of low richness media, such as CMC, is appropriate for stabilizing a culture when it is already strong. However, when the culture is weak, one should favor the use of high richness media. Second, the interaction effect of CR on the relationship between task-completion time and the initial strength of a culture suggests that a modest increase in the strength of the culture might significantly increase organizational performance. This conclusion is important for virtually collocated work, which involves persons geographically separated working on common tasks through CMC.

The major part of the work on CMC has been conducted using experiments and survey or field research. This study took a different approach to analyzing the bi-directional link between the use of CMC (or any communication system) and OC. In addition to the results presented, the ABM described here contributes to the CMC research in two other ways. First, the model may be used in future studies to help pinpoint some questions to be answered and consequently design experiments, surveys or field studies. Since the latter approaches generally cannot be easily repeated, it is very useful to have a means of anticipating the possible areas to focus on, leading to better design of experiments, surveys or field work. Second, the translation of some social science theories related to CMC that have been stated in words to a very precise operationalization, as required in ABM, helps formalize the theories. This assists in enhancing the mutual understanding among researchers and the transfer and accumulation of knowledge in the field.

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