

Information Technology and Knowledge Distribution in C³I teams

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Abstract

This paper lays out a computational model for analyzing the relative efficacy of different C³I architectures for teams with access to different types of databases (ITT). Then using this model, a virtual experiment is conducted. Aspects of this virtual experiment are patterned off of behavior and technology surrounding the knowledge wall. Results suggest that bringing ITT in to traditionally structured teams may reduce their efficiency. Some guidance is provided for how to design C³I architectures for high performance and adaptive teams who are ITT enabled. Implications of these results for the knowledge wall are provided. This study, although preliminary, provides guidance for how to reason about team design in a network centric context.

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1. Introduction

As we move forward in the 21st century technologists suggest that there will be rapid changes in social and organizational activity due to advances in information and telecommunication technology (ITT). There can be little doubt that ITT is altering the way members of the armed services are trained, conduct operations, and coordination across forces (joint and coalition). Difficulties due to lack of inter-operability in the ITT, amassing and entering data in to the new databases, and lack of training on ever changing equipment are in some sense temporary though frustrating problems. As new ITT comes in to the forces new ways of organizing, of coordinating, of conducting operations should be possible. This is the promise of moving to network centric warfare. It is expected that computers will come to control, or be involved in the operation of, everything from utilization, operation and management of resources to the making strategic and tactical decisions. Yet, we have little understanding of how to coordinate and organize network centric teams.

A critical feature of network centric warfare is the use of integrated databases that enable access to more information more of the time and more types of information. In principle, rapid and universal access to more data more of the time is expected to enable more rapid and better decision making, a more comprehensive view, and increased common operational awareness. In this paper, we examine the way in which databases impact teams and ask whether these expectations are likely to hold. Our argument, and the underlying computational multi-agent network model, take in to account cognitive, social and technical factors influencing access to and use of information.

2. Transactive Memory

Individuals have a variety of different types of information. Some of this information is general – “we are attacking”; and, some specific “there is an aircraft carrier in location x,y”. Some of this information is about the task being done. Some of this information may have been articulated, in which case it is explicit. Whereas, other information may not have been articulated and so is tacit. General information typically imply a host of underlying tacit information. General queries often require access to tacit information. The more specific the information or query the less the reliance on tacit information. All this being said, there is still another type of information that has been shown to influence the ability of the individual and the team to work effectively – transactive [Wegner, 1986]. An individual’s transactive memory includes knowledge of who knows who, who knows what, who is doing what. Transactive memory is critical for group adaptivity and performance [Carley and Ren, 2001]. Information about who knows what and who is doing what is often referred to as referential information. The inclusion of such information in databases can improve group performance [Moreland, Argote and Krishnan, 1996].

3. Task and Referential Data

Databases can contain task data, referential data, or both. Task data are information related to the performance of a task or a solution to a problem. In most database applications, the user would search for specific information that is required to complete a task and receives the specific information the database has on the topic. Referential data

‘refers’ a user to an expert in the topic of interest. In most pure referential database applications, a user would search for a general or specific topic on which they need some information. The information needed could be for the performance of a task or a solution to a problem. The search would give the user a list of names of experts for that topic. The user could then contact the expert(s) and find the information that is needed.

In a task database, the task data has to be explicit in order to be in the database. Users must either contribute already explicit information or turn tacit information into explicit information before entry into the database. The latter often does not occur for many reasons, one being time consumption another being the need to pre-define areas of expertise. Hence, for some topics, databases may be incomplete. This is particularly likely to be the case for databases containing expertise rather than resource lists or resource characteristics, or for those pertaining to non-routine tasks. For such cases, it is unlikely to be the case that all the information known by C³I team will be captured in the databases.

In a referential database, the references are explicit. However, access to such references enables the user to then locate personnel with both explicit and tacit data. Since the user contacts the expert directly, there is an opportunity to access a greater range of expertise as the expert can directly convey explicit and tacit information. Of course, by conveying the tacit information the expert makes it explicit thereby enabling it to be entered in to a task database.

The movement of information between the explicit and the tacit has been defined as the SECI process [Nonaka, Toyama and Konno, 2000]. Nonaka defines knowledge creation as a continuous dynamic interaction between tacit and explicit knowledge. There are four factors that establish the knowledge conversion process:

1. Socialization – tacit to tacit
2. Externalization – tacit to explicit
3. Combination – explicit to explicit
4. Internalization – explicit to tacit

From a database perspective, whether the user has a specific or general query affects where in this process the user enters. With either a task or referential database, knowing you can use the database to get information is step 1, the formation of a general query is step 2, while the formation of a specific query is step 3. In both cases, the retrieved data is part of step 3. Whereas the use of such data in making a decision is step 4. Now, if the user is utilizing a task database this is where the process stops. If the user is utilizing a referential database then the decision (step 4) is about whether to ask the expert referred to for information. If the decision is positive that moves the user back to step 1. The process of asking the expert for information and then using it moves the user through steps 2-4 a second time this time for task information. With the task database is that the user goes through the SECI process once to make a decision; whereas, the user goes through the process twice with a referential database. Hence, task databases have the potential to enable faster decision making. With the referential database, the user is potentially exposed to more information that was initially tacit and held only in the mind of the expert. Hence referential databases have the potential to enable more accurate decision making and greater levels of knowledge creation.

When referential databases are used, there is a need for increased interaction among the personnel. Consequently, the key communication can occur over a variety of

communication medium. Personnel are able to hold a ‘conversation’ whether it be by telephone, e-mail or face-to-face. Any of these possibilities provide the user with the opportunity to not only access more information but also to strengthen understanding through a ‘stream’ of communication. For instance, the expert may be able to provide the information requested and provide valuable contextual advice. This may help the user in knowing how to ‘apply’ the information. Also, if possible, the users may choose to have a face-to-face discussion. The face-to-face meeting is a much richer communication medium than either telephone or e-mail and since any of these allow for a ‘conversation’ to take place, they are all richer than simply receiving a specific entry from the database.

Another difference between the two data types resides in the process of obtaining information. The meta-network [Carley, forthcoming; Krackhardt and Carley, 1998] provides the framework on which to analyze this process. In Table 1 the portion of the meta-network connected personnel, knowledge and tasks is shown. Accessing the task data enables the user to learn data associated with the information, needs, or precedence network. Given this information the user’s own knowledge has increased (i.e., the user’s own knowledge network has increased). If the user is assigned to the task for which information is being sought, then the overall knowledge congruence in the organization has improved thus enabling better performance [Carley and Ren, 2001]. This is a two-step process where the agent queries the database and then receives the information to fulfill the need.

Table 1 –Task and Referential Data and the Meta-Network			
	People	Knowledge	Tasks
People Relation	Social Network Who knows who	Knowledge Network Who knows what	Assignment Network Who does what
Data	REFERENTIAL	REFERENTIAL	REFERENTIAL
Knowledge Relation		Information Network What informs what	Needs Network What information is needed to do that task
Data		TASK	TASK
Tasks Relation			Precedence Network Which task must be done before which
Data			TASK

Accessing a referential database is different. This access enables the user to learn data associated with the social, knowledge or assignment network. Accessing this information creates, at least, a weak link between the user and the expert referred to. This is a change in the social network (who knows who). The user can then contact the expert, strengthening the link, and can obtain new information, thus increasing the user’s own knowledge (and possibly altering the expert’s knowledge). If the user or the expert is assigned to the task for which information is being sought, then the overall knowledge congruence in the organization has improved thus enabling better performance [Carley and Ren, 2001]. This is a three-step process and forces the user to interact with other users as a resource.

From a security standpoint, databases can be compromised and the information recovered by the enemy; but reduces risks in terms of personnel and communication. Whereas, the increased communication and increased flexibility in mode of communication for referential databases increases channel and personnel risks. Specifically, communications can be tapped. Experts may become unavailable.

4. Performance and Adaptation

We have argued that accessing task and referential data are distinct information retrieval processes. The question before us is how does that difference affect the team's performance and adaptability. Performance in the context of knowledge distribution is task accuracy and timeliness in response. Adaptivity means that as the C³I structure or the task changes, the level of performance is maintained or improved.

4.1 Building of Social Ties

Task data has the potential to build social ties due to homophily. As users learn more information outside of their domain they become more similar to others. As one individual's relative similarity to another increases, they are more likely to interact. Hence accessing task data leads, eventually, to new ties in the social network. The speed of this process depends on a variety of factors including the degree of training or knowledge held by the individual's involved, the size of the group, ability to actually access the other individual, and so on. Referential data has a more immediate impact on interaction. As users learn who has information outside their domain they then will interact. However, it is possible, that when a user knows that another is an expert in some topic, the user then may choose to "learn and forget"; i.e., to go to the expert when information is needed but not try to learn on their own. As such, although the referential data may lead to a faster increase in the number of social ties and the density of the social network it may actually slow the rate of task learning and lead to slower development in knowledge ties and so the density of the knowledge network. Previous results have shown that network density and connectivity are positively correlated with adaptation [Carley, Ren and Krackhardt, 2000] but negatively related to performance; whereas, overall density (social plus knowledge network) is positively related to performance [Lee and Carley, 1998].

4.2 Building of Transactive Memory

Task data on its own has no way of building transactive memory because the information is not attributed to an agent. On the other hand, referential data does provide a link between knowledge domain and agent thereby creating an instant tie for transactive memory. When the user contacts the expert referred to this reinforces this transactive memory tie and adds to it. Through richer communication, the agent learns more about what and how much the agent actually knows. The entire process of receiving a reference and retrieving information directly from an expert produces a more accurate transactive memory for the agent. Work has shown that stronger transactive memory networks are related to increased performance [Moreland, Argote and Krishnan 1996]. With a strong transactive memory system, agents of a team can specialize in different tasks because they know who specializes in the other tasks that are needed to complete the operation. Specialization leads to rapid, narrow learning. Previous work has indicated that factors promoting rapid, narrow learning increase performance [Carley and

Ren, 2001]. In this way, referential data might increase performance. The relationship between referential data and performance is complex at best. It can increase social ties and decrease performance but at the same time increase transactive memory and increase performance. The non-linearity of this relationship is one of the reasons we use a computational model of this process to explore the impact of databases on the performance and adaptability of C³I teams.

4.3 Increased Diffusion

Diffusion occurs when information is conveyed from one entity (person, database, team) to another. Rapid diffusion can facilitate performance [Carley and Krackhardt, 1999], unless it leads to excessive rework [Lin and Carley, 1994]. In principle, without a database information is more distributed throughout the C³I and it takes longer for people to find specific information. Simply adding a database to a C³I architecture should increase the rate of diffusion. Further, task databases should increase the rate of diffusion of task knowledge more than referential databases as there are more steps with a referential database to get acquire new information. This becomes especially important when time is of the essence and a quick decision has to be made. Under time pressure, referential data may be too slow in providing information. Task data, because it has one less step in the process, will be more advantageous toward gaining timely information and rapid learning. Previous work has demonstrated that rapid learning improves performance [Carley and Ren, 2001]. Both task and referential data should increase the rate of diffusion and increase performance. Task databases should have the highest rate of diffusion and the largest increase in performance.

5. Model

Prior work has shown that C³I architectures can be usefully characterized in terms of the meta-network people, knowledge (resources), tasks and the relationships linking them together [Carley, Ren and Krackhardt, 2000]. Given this formalization it is possible to study both the performance and the adaptability of alternative C³I architectures using multi-agent network models. In these models, such as ORGAHEAD and Construct-O, the agents are adaptive information processing agents with constraints on their capabilities. In this work, we expand this work to include an analysis of databases – both task and referential. We represent a database as an intelligent artificial agent with distinct information processing capabilities from people. As such the database can be an integral part of the C³I architecture. By representing the database as another agent, we can account for the interactions that occur between the technology and the human agents, the impact of learning or adding information to the database on the behavior of the team, and the impact of databases to ameliorate for personnel unavailability on the team. In this way, we gain a better understanding of how to coordinate and organize network centric teams.

The particular model we use is construct-tm. This is a multi-agent network model in which agents interact, communicate, learn, and make decisions in a continuous cycle. Agents may interact because they are relatively similar (have things in common) or one agent thinks the other knows things they need to know (relative expertise). Each agent has both task and transactive knowledge. The transactive knowledge include knowledge of who knows what. The transactive knowledge is initially incomplete and can change over time as the agent interacts with others or use a database. When agents communicate

they communicate either task knowledge or transactive knowledge. Note, the transactive knowledge they communicate is not necessarily correct. Agents can also forget.

Databases are agents. However unlike the human agents they cannot initiate an interaction. Further, while only one agent can update a database at a time (for congruency control); multiple agents can access a database and query it at one time. There are two types of databases, task and referential. The task database contains information only on the task and the referential contains information only on who knows what.

Outcome measures include performance (accuracy in making decisions) and timeliness (ability to acquire the necessary information). In addition, since the agents can be wrong about who knows what, for their transactive memory we can capture the accuracy of their transactive memory and the quantity of information in their transactive memory.

6. Virtual Experiment

At global, each sub-group has a particular responsibility and expertise that is broadly known. This can be thought of as knowledge about role. Most individual's know which group to go to for general information. However, there is a lot of detailed expertise that is known within each group. Most individual's do not know who to go to for such detailed data if they need it. The majority of databases used at global are task databases. Many times, these task databases contain detailed data. Additional detailed data is tacit or has not yet been put in databases. Typically, the more complex situations have more data that is not in the database. These databases are often used primarily within the sub-unit assigned to that task – such as weather.

Most referential data is retrieved by asking those one is talking to “who knows about x” or through sneaker-net – sending an aid to the area where the information is thought to be to locate an expert – the individual who knows the needed detailed data. There are two problems with this approach. First, the sender may be wrong about in which group the detailed data resides. Second, the group may not have the detailed data even though they are the correct group to have such expertise. The knowledge wall plays an interesting role in this situation. By virtue of its construction, the knowledge wall displays both referential and task data. Using simulation we examine how this might affect behavior and how adding additional referential databases might affect the group.

At global, not all personnel were present continuously. This personnel movement might affect performance. Further, personnel although trained in their own specialities often had little experience with specific technology or with the entire group (although members of a sub-unit had often been engaged in joint projects previously).

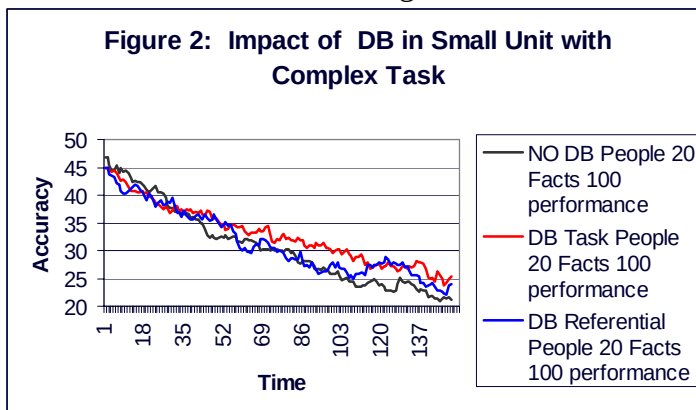
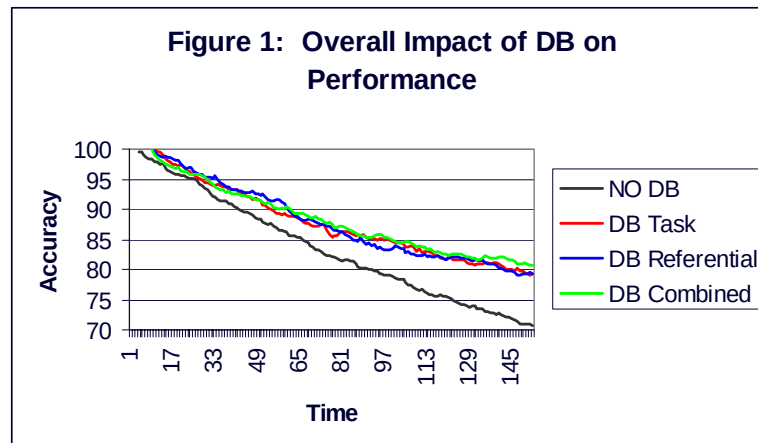
To examine these factors a virtual experiment was run in which the we examined small and large units, in simple and complex knowledge situations, with access to either no database, a task database, a referential database or a combined database. This is a 2x2x3 design. Further, we reflected the movement of personnel by having individual agents in the virtual worlds leave the group periodically. Additionally, to reflect the distribution of knowledge we created databases with more expertise than the specific users and all agents other than databases as having more expertise in their area and less in others.

7. Results

Using this model previous research has demonstrated that databases are not always beneficial to the organization. Sometimes, performance will degrade when a database is present. The reason is that individuals spend more time interacting with the database than each other and so never learn key novel information. In this study, we move beyond this initial result to look at cases where the databases are still under construction and where we contrast task and referential databases.

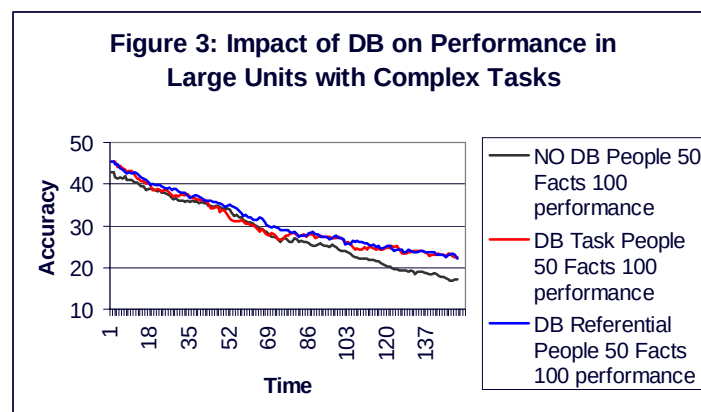
These results indicate that on average, even though incomplete, databases can improve performance – but the impact is more pronounced in the long run. On average, in the short run there is a small advantage to referential databases and in the long run there is

a small advantage to a combined database. In Figure 1, we see that on average the difference across types of databases is not particularly pronounced. There are several reasons, the primary one being that even the largest of the groups examined may still be too small for the effects of cognitive limitations to emerge.



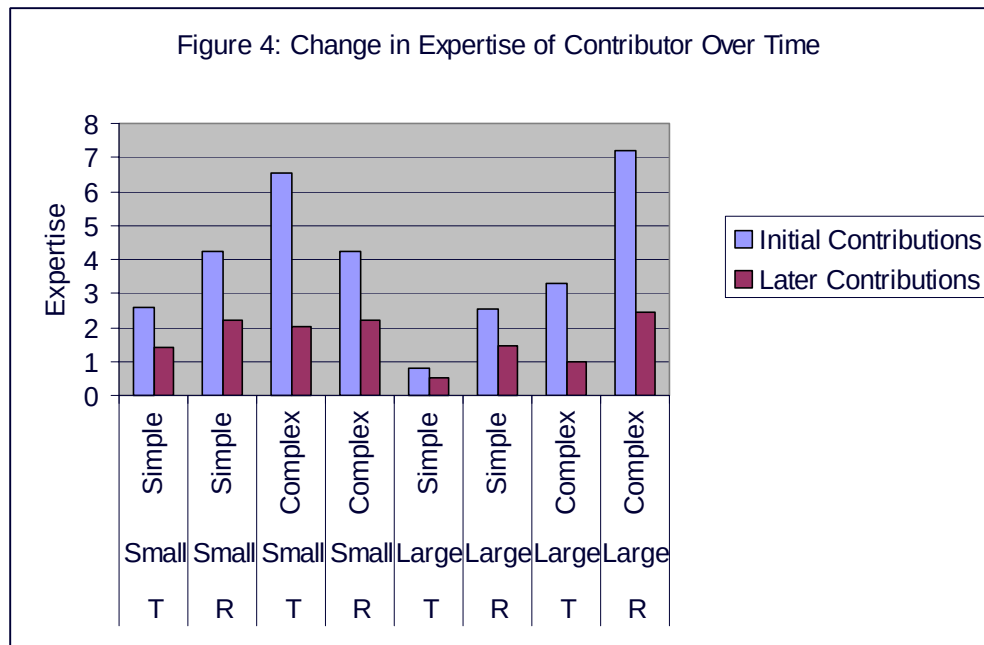
The situation, however, varies based on the complexity of the problem and so the wealth of information. It also varies based on the size of the unit. In Figure 2 a small faced with a complex task is shown. Note, here the database actually degrades performance, particularly in the short run. Whereas, in the long run, the task database is more beneficial. Basically, the smaller

group the more likely that personnel have good transactive memory and so the referential database is actually more of a hindrance than a help. Also in a small group it is faster to go talk to someone than to look up information in a database. As the group size grows,



databases increase in value. In particular, the value of referential databases increase in value.

We also find that, in general, in larger groups the individuals who contribute to the database are more expert than in smaller groups. This is due to the fact that by chance there are more expert experts in larger groups. It is also due to the fact that in larger groups, the database can accumulate information faster making it a more compatible place for the expert to send his or her information to. We also find that the average expertise of those who contribute to the database is greater in the short term than in the long term. That is, even without specific rewards, experts are more likely to initially contribute to databases.



8. Limitations

There are several limitations to this study. First, the computational model is limited in that it treats all information as equally timely, valuable, and interpretable. Ignoring timeliness probably advantages referential databases as use of such databases might make it take longer to get to any information. In contrast, ignoring interpretation might advantage task databases as there are likely to be fewer errors when most explicit information, rather than tacit, is communicated. Further work is needed to determine if the access of tacit knowledge with referential data has any benefits above or in addition to those described. In other words, can referential data access additional information that is not captured within a database and that would be of benefit to the operation?

From the perspective of the technology used in war games, such as the knowledge wall, perhaps the main limitation of this study is the fact that we treat all information as equally presentable. However, there may indeed be types of information that are better presented on a universally visible medium, such as the knowledge wall, and others that are best presented only when asked about. It is likely that referential information, particularly detailed referential information of the form “Joe knows x” rather than general

referential information “Space command knows x” is most valuably presented when queried.

From a socio-cognitive standpoint, the agents in these simulations are “too smart.” Although they forget, there are no limits on their transactive memory. This may be depressing the value of referential databases. In addition, the agents although heterogeneous in expertise, that expertise is spread uniformly throughout the organization; whereas, we observed some units with on-average higher expertise.

9. Conclusions

We have described a model for beginning to explore systematically the impact of ITT on enabling new forms of organizing. The results herein suggest that databases in general are not a panacea and that the gains in organizing proposed by technologists may not accrue, at least in the short run. Clearly such systems will speed the flow of information. However, they will not necessarily lead to better decisions. Thus, ITT enabled teams may make more timely decisions but not necessarily more accurate decisions. These results also suggest that referential databases will be of most use in larger groups. In particular as the groups get large enough that individual’s ability to remember what who knows is swamped, the referential databases will be of greater value. In general, in the short run, databases will have little if any impact. Over time, however, databases improve performance, particularly in large groups. This is true in part the fact that personnel leave and they forget. More critical, particularly to this study, is the fact that over time information is added to the database making it an increasingly valuable resource.

It is likely that there are C³I architectures, whose form is different than traditional architectures, which will be able to take advantage of this technology and to ensure accuracy in the face of this technology for small units and in the short run. Future work should address this issue. Models such as the one used herein can help address this issue.

With respect to the ITT we observed at the various games, this research makes the following recommendations. For large units, or where there is a need to move information between units who have little or no contact, effort should be focused on creating referential or combined task and referential databases. Users should not expect to see major performance improvements from using databases in the short run. When there is a situation when personnel leave, having databases will not prevent the loss of information. Performance will still degrade due to attrition in an ITT enabled team. In the case of referential data it may well be that as attrition accrues and the database gets out of date the time to make decisions will decrease leading ultimately to less timely decisions.

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