Enhancing Team Performance through Effective Communication

Maaike Harbers
Delft Technical University
Mekelweg 4, 2628 CD, Delft
The Netherlands
M.Harbers@tudelft.nl

Catholijn Jonker
Delft Technical University
Mekelweg 4, 2628 CD, Delft
The Netherlands
C.M.Jonker@tudelft.nl

Birna van Riemsdijk
Delft Technical University
Mekelweg 4, 2628 CD, Delft
The Netherlands
M.B.VanRiemsdijk@tudelft.nl

ABSTRACT
Humans and intelligent software agents increasingly often work together in human-agent teams. To achieve a good team performance, the agents in such teams should communicate with the humans. Too much communication, however, will lead to a decrease in team performance due to an overload of information. This paper presents a simulation experiment that investigates the impact of different types of communication behavior on team performance. The results show that the communication of knowledge about intentions contributes more to team performance than the communication of world knowledge.

Categories and Subject Descriptors
I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence - *Intelligent agents, Multiagent systems.*

General Terms
Measurement, Design, Experimentation, Human Factors.

Keywords
Teamwork, Team Performance, Communication, Human-Agent Team, Multi-Agent System, BW4T testbed.

1. INTRODUCTION
Humans and intelligent software agents increasingly often cooperate in human-agent teams. In crisis situations, for example, humans and agents work together to solve incidents, see e.g. [10, 11]. Especially in crisis situations, where good team performance can make a huge difference in the outcome of the incident, maximal team performance should be achieved. To achieve good team performance in human-agent teams, agents should be equipped with teamwork capabilities. For example, agents should be transparent to other team members, and they should be able to coordinate their actions with others [1].

One of the requirements of good team cooperation is that team members communicate with each other [9]. A positive effect of communication is that it increases the shared of mental model of the team. A team's shared mental model consists of the knowledge that the team members share. This may include knowledge about the team goal, the tasks that need to be performed, the capabilities and activities of the team members, and the task environment [2]. When team members are dependent on each other for achieving tasks, i.e. they are *interdependent*, they need to coordinate their actions [6]. Higher sharedness of mental models facilitates the cooperation in a team.

A possible negative effect of communication on teamwork, however, is that it may lead to an information overload for humans [3]. Whereas software agents are able to send and perceive relatively large amounts of information without decreasing their performance, humans have a rather limited capacity of processing and memorizing information. For humans, in contrast to agents, communication takes a considerable amount of time and exchanging a lot of information may quickly become a burden.

We just described two possible effects of communication in teams. The first effect, higher sharedness of team mental models, generally has a positive effect on team performance. The second, information overload, usually has a negative effect on team performance. To balance the positive and negative effects of communication, it should be carefully considered how and how much information agents in a human-agent team should communicate to their human team members.

Not all information that can be shared in teams equally contributes to team performance [8, 12]. In this paper we will therefore describe an experiment that investigates the effects of the communication of different types of information on team performance. The experiment will be performed in BlocksWorld for Teams (BW4T) [7], a testbed for team coordination, and involves simulations with teams of agents that have different types of communication. The types and amount of communication of the different teams will be compared to their performance, and the implications of these results for designing agents that are to perform in human-agent teams will be discussed. The paper ends with a conclusion and suggestions for future research.

2. EXPERIMENT
In this section, we describe the setup of the experiment, present the results, and provide a discussion of the results.

2.1 Experimental setup
For our simulation experiment, we used the BlocksWorld for Teams (BW4T) environment, a testbed for team coordination [7]. The BW4T task is to deliver a sequence of colored blocks in a particular order. The virtual environment in which the BW4T task is performed contains rooms in which colored blocks are hidden, a drop zone where blocks can be delivered, and a status bar indicating which sequence of colored blocks should be delivered. To deliver a block successfully, a player has to find a block of the

right color, pick it up and drop it in the drop zone. The BW4T task can be performed by a single or multiple players, and players can be humans and/or software agents. Players cannot see each other, but they are informed by the environment when someone successfully delivered a block, and they can send messages to each other to coordinate their actions. Performance on the BW4T task is measured by the time needed to complete the task.

We implemented four BW4T agents in GOAL [5], a BDI-based agent programming language. These agents use the same strategy for solving the BW4T task, but differ with respect to their communication behavior. *Agent A* does not communicate at all. *Agent B* communicates only about world knowledge. World knowledge includes information about positions and colors of blocks, and information about the agent's own position and state, e.g. whether it is holding a block. *Agent C* only communicates about intentions. Intentions include information about where the agent is going to and which blocks it is going to deliver. *Agent D* communicates about both world knowledge and intentions. All agents are capable to process and use messages of other agents.

In the experiment we used two scenarios, one with a *high* level and one with a *medium* level of interdependence among the agents. In the high scenario, the agents need to deliver six blocks which each have a different color. Consequently, there is only one possible order in which the blocks can be delivered, and for an agent to select a useful action highly depends on what the other agents do. In the medium, scenario, the agents also need to deliver six blocks, but among those six blocks there are two pairs of subsequent blocks with the same color. This makes that the selection of an action depends less on what the other agents do. For instance, if there are two blue blocks that need to be delivered, two agents can go search and deliver a blue block, independent of what the other agent does. This is not the case when first a yellow and then a blue block needs to be delivered.

We performed eight BW4T simulation runs. In each run, a team of three agents of the same type played a particular scenario. There were four teams: team A, team B, team C and team D, where team A consisted of three agents of type A, team B consisted of three agents of type B, etc. The four teams each played two scenarios (medium and high), resulting in eight BW4T sessions. During the simulation runs, we logged the time of each block delivery, the time it took to complete the task, and the amount of communications.

2.2 Results

Figure 1 shows the times of each block delivery in the four teams for both scenarios. The results show that the team with full communication (team D) took the least time to deliver all blocks, teams with partial communication (team B and C) took intermediate time to deliver all blocks, and teams with no communication (team A) took the most time to deliver all blocks. Of team B and C, which both involved partial communication, team C (communication of intentions) took less time to complete the task than team B (communication of beliefs).

For team C and D there was almost no difference between performance in the medium and in the high scenario, but team A and especially team B performed much better in the medium scenario than in the high scenario. This can be explained by the fact that team C and D communicate about intentions and team A and B do not. In team C and D, agents know which blocks the other agents are going to deliver, so they will be searching for or delivering the right block in most cases, independent of whether there are pairs of blocks with equal colors in the goal sequence. In team A and B, however, it will not be unusual that two or three agents are trying to deliver a block of the same color, since they do not know that another agent is already intending to deliver that block. In that case, performance is not negatively affected when two blocks of the same color need to be delivered after each other (as in the medium scenario), but performance does go down when all blocks in the goal sequence have a different color (as in the high scenario).

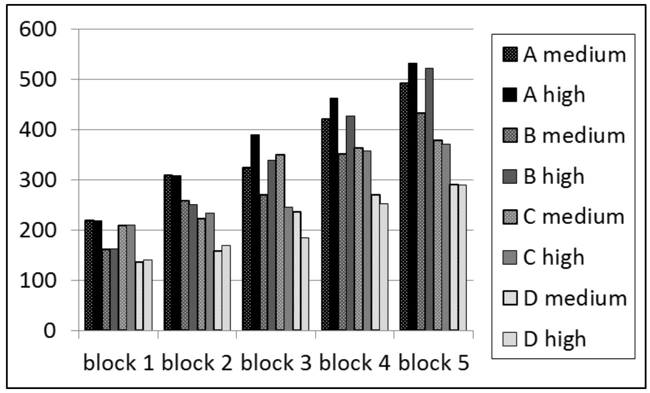

Figure 1. Time of block delivery.

The effect of not communicating about intentions in the high scenario is considerable. Namely, the performance of team B in the high scenario is even worse than team A's performance in the medium scenario.

Figure 2 shows the amount of communication in all conditions at the time of each block delivery. The graph is cumulative, and the bars indicate the total amount of communication until the time of that block delivery.

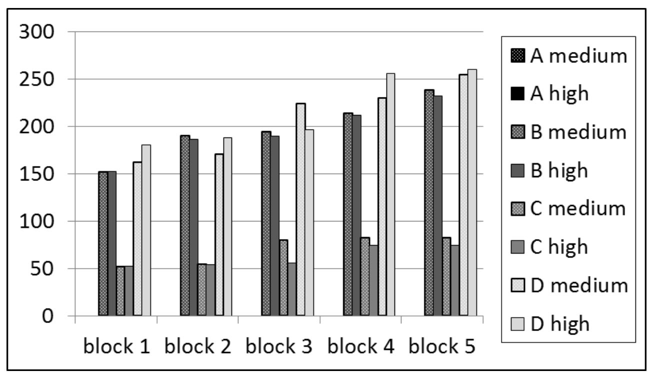

Figure 3. Number of sent messages.

It can be seen that in team A there was no communication at all, in team C there was relatively little communication, and in team B and D there was a large amount of communication. It thus can be concluded that communication about world knowledge involves much more communication actions than communication about intentions. The figure also shows that most communication actions occur before the first block is delivered, and that there are no big differences in the amount of communication between the two scenarios. Note that though for team B and D the amount of communication actions per block delivery is only slightly larger for team D than for team B, the time between each block delivery is less for team D than for team B.

Figure 3 shows a combination of the amount of communication and time of task completion in one graph. For all conditions in the experiment, the total amount of communication is plotted against the time of task completion.

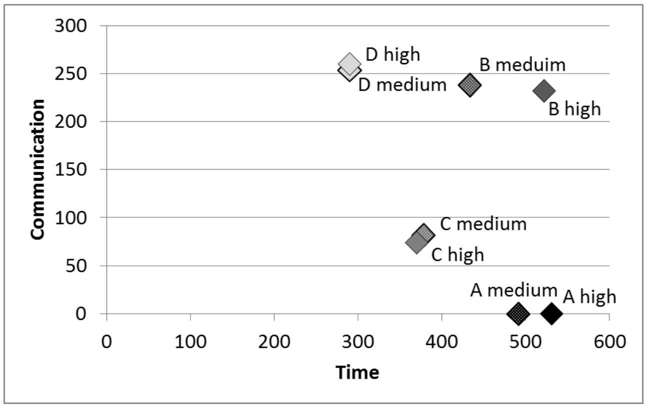

Figure 3. Task performance and amount of communication.

An efficient team delivers blocks as quickly as possible while keeping the amount of communication low, and would be positioned close to the null point. The figure shows that team B (communication of world knowledge) and team C (communication of knowledge about intentions) are positioned farthest from and closest to the null point, respectively. In comparison to the other teams, team B needs relatively much and team C relatively little time and communication to solve the task.

2.3 Discussion

The results showed that sharing knowledge about intentions contributed more to team performance than sharing world knowledge, even though the former involved much less communication actions than the latter. Based on these results, it seems better to restrict agents in human-agent teams in their communication of world knowledge than their communication of knowledge about intentions in order to avoid information overload of the human team members. Before this conclusion can be drawn, however, several factors need to be considered. We discuss five of them.

First, in this experiment we have only used the amount of messages to determine the cognitive load of communication. It should be checked whether all types of communication cause an equal amount of information overload.

Second, in this experiment we studied teams with only agents. When using these results for developing agents for human-agent teams, it should be investigated under which circumstances these results are transferable to human-agent teams.

Third, we performed the experiment in the BW4T environment. When applying the results to a new domain, it should be checked if the tasks in that domain are sufficiently similar to the BW4T task to transfer the results.

Fourth, communication can contribute to the trust of humans in agents, which can also have a positive effect on team performance. In this experiment we did not consider which types of information contribute more to trust.

Fifth, in this experiment team performance was the only outcome measure. Satisfaction of human team members can also be influenced by communication type [4]. For several applications of human-agent teams, user satisfaction is also an important criterion.

3. CONCLUSION

In this paper, we investigated the effects of different types of communication behavior on team performance in a multi-agent simulation in the BW4T testbed. We found that communication of knowledge about intentions contributes more to team performance than communication of world knowledge. Based on these results and considering the fact that humans have limited capacities to process communication, priority should be given to communication of intentions over communication of world knowledge when developing agents for human-agent teams.

Additional research can reveal to what extent these results are transferable to other teams and domains. In future work, we aim to repeat this experiment with human-agent teams instead of only agents. Furthermore, we want to investigate to what extent these results are transferable to other team tasks. In particular, we will focus on the application of these results to human-agent teams in the domain of crisis management.

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