Modeling Teamwork of Multi-Human Multi-Agent Teams

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Abstract
Teamwork is important when humans work together with automated agents to perform tasks requiring monitoring, coordination, and complex decision-making. While human-agent teams can bring many benefits such as higher productivity, adaptability and creativity, they may also fail for various reasons. It is important to understand the tradeoffs in teamwork. The purpose of this research is to investigate the process and outcomes of human-agent teamwork by running experiments and building quantitative simulation models. Preliminary results are discussed as well as future directions. We expect this research to deepen the under-standing of human-agent teamwork and provide recommendations for the design of teams and agents to support teamwork.

Author Keywords
Teamwork, Multiple Agents, Discrete-Event Simulation, Experiment.

ACM Classification Keywords
H.5.3. Group and Organization Interfaces: Computer-supported cooperative work

General Terms
Human Factors, Experimentation.

Research Steps

1) Human-in-the-loop Experiment: conduct experiment of human-agent teamwork.
2) DES modeling: build the model based on data and observations collected in the human-in-the-loop experiment.
3) DES model validation: compare DES model output with data from the human-in-the-loop experiment.
4) Hypothesis Testing: generate hypothesis on methods to improve team performance based on the DES model; test the hypothesis with another human-in-the-loop experiment.
5) Extension: generalize the model to other appropriate scenarios and provide recommendations on improving team performance.

Introduction

Advances in technology have enabled increasingly sophisticated automated systems to be applied to many fields. By releasing the operator from manual control, enhanced autonomy enables operators to work with multiple agents and do tasks requiring monitoring, coordination, and complex decision-making. However, the required cognitive load for working with multiple agents could easily exceed the capacity of a single operator, even with high levels of automation. Teams of humans are increasingly called upon to perform complex cognitive tasks that are less efficiently done or impossible to be done by an individual. Although teamwork may impose extra workload related to coordination and communication, teams have the potential of offering greater adaptability, productivity, and creativity than any one individual can offer.

However, the benefits of teamwork do not always occur naturally, and teams can fail for many reasons [7]. Factors such as poor combination of individual efforts, a breakdown in internal team processes (e.g., communication), and improper use of available information have been identified as potential sources of team failure [8]. When people collaborate with autonomous systems, system complexity inevitably increases, and automation can change the way people coordinate with each other [5]. Moreover, failure in human-agent teams can lead to severe consequences including loss of life, missing critical action time and monetary inefficiencies. To enable collaborative human-automation team interactions, we must therefore understand the nature of such teamwork, including outcomes, processes and dynamics.

Simulation models are valuable in capturing the process and dynamics of human-agent teamwork. With a valid simulation models, we can test and compare proposed changes to the current system, or new designs of the system at a lower cost than testing directly in the real world. Previous research [4, 6] has used queuing models for human-agent teams in which a single operator controls multiple robots. Human behavior and teamwork usually bring more complexity. Discrete event simulation (DES) can be used to model a complex queuing system that evolves over time by a representation in which the state variables change instantaneously at separate point of time [2].

Research Questions

My research objective is to investigate performance and workload in human agent systems, and model such teamwork quantitatively to capture the nature of team dynamics and guide the design of team and teamwork support tools. These objectives lead to the following three research questions.

- How should we design human teams to improve performance and reduce workload when working with multiple agents?
- Can we design agents to support the work of an individual human and how will it affect the performance of the team?
- Can we design agents to support teamwork?

To investigate these research questions, iteration between human-in-the-loop experiments and discrete event simulation (DES) modeling is used.

Independent Variables

Team structure

Sector: each participant controlled 12 robots individually

Shared Pool: the team shared the control of all 24 robots.

Search Guidance

Suggested: system provides a recommendation to switch to another robot when the operator spends thirty seconds on a robot.

Enforced: system provides a recommendation to switch at thirty seconds and switch automatically to another robot five seconds after the recommendation.

Off: system provides no recommendation.

Human-in-the-Loop Experiment

We conducted a human-in-the-loop experiment to investigate human-robot agent team structure as well as an agent supporting individual human team members' attention allocation.

Testbed

USARSim, a robotic simulation performing Urban Search and Rescue (USAR) tasks [3], was used to provide the underlying simulation for the testbed, as shown in Figure 1. The human operators' tasks were to work as a team of two to explore the unknown environment and identify as many positions of victims as possible.

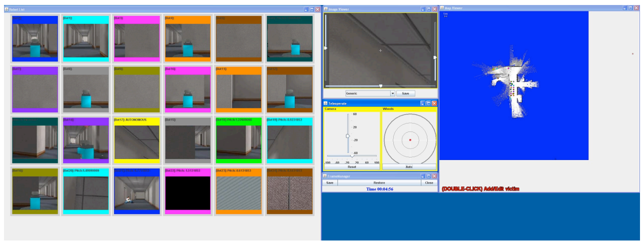

Figure 1. Interface for operating vehicles.

Independent and Dependent Variables

The experiment had two independent variables: *team structure* and *search guidance*. Team structure had two levels: *Sector* and *Shared Pool*. Search Guidance had three levels: *Off*, *Suggested* and *Enforced*.

Dependent variables included task performance metrics, subjective workload, operator measures and communication time as team measure. Task performance includes number of victims found, number of errors, number of victims missed and number of deletes.

Results

Pool team structure resulted in lower workload ratings than *Sector* team structure, but there was no significant difference in task performance. Further analysis on individual workload and performance suggests that a workload balancing process or back-up behavior occurs in *Pool* teams. *Pool* teams also communicated more while *Sector* teams teleoperated more. Further analyses on communication revealed that communication time was moderately negatively correlated with errors ($r=-0.309$, $p=0.008$) for *Pool* teams, suggesting that operators in *Pool* teams may correct each other facilitated by communication.

Automated search guidance did not improve or decrease performance, but had an influence on working process. In *Sector* teams, *Suggested* search guidance helped operators mark victims faster when they appeared in the cameras as measured by mean display-to-mark time ($p=0.024$). Detailed results can be found in a previous paper [1].

Modeling

A DES model was built based the data and observation from the human-in-the-loop experiment described in the previous section. Operators function as servers in the queuing model and serve the events generated from the robot agents. The overall framework of the model is shown in Figure 2. Four aspects are modeled using DES: arrival process of agent-generated events, service process of human operators, task assignment in teams and communication.

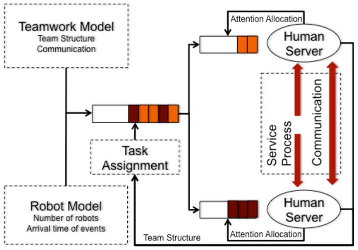

Figure 2: Discrete Event Simulation Model for Multi-robot Multi-operator Teaming.

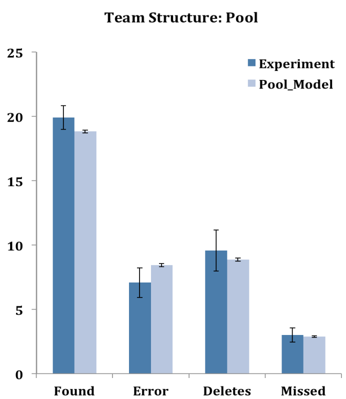

Figure 3: Comparison between DES Model and Experiment for Pool Teams with No Search Guidance.

Several data sets were recorded in the experiment and used to fit probability distributions used in the model. We compared the outputs from the DES model with experiment results. Under all the conditions, the DES model could replicate the experiment results. Figure 3 presents the results for *Pool* teams with *Off* mode for search guidance.

Future Work

Future work will include further validation using an independent data set and extend the model to another scenario of ground control of unmanned aerial vehicle or mixed vehicle teams. Ultimately, we hope to make predictions using the DES model, test them using another human-in-the-loop experiment and generate recommendations.

Potential contributions of this research have three aspects. Theoretically, it could deepen the understanding of teamwork of human-agent teams by looking at team processes and dynamics instead of strictly focusing on team performance. Methodologically, we investigate and analyze teamwork of human-agent teams using a quantitative model. Practically, the quantitative model can be used to guide the design of human-agent teams. It could also inform the design of agents to support individual humans as well as the team as a whole.

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