Effective Team Interaction for Adaptive Training and Situation Awareness in Human-Autonomy Teaming

Conference Paper · February 2019

DOI: 10.1109/COGSIMA.2019.8724202

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***Abstract*—The aim of this exploratory paper is to underline the importance of coordination-based training for dynamic tasks in human-autonomy teaming. We address training solutions to distinct types of failures caused by either internal (the system) and external sources (the dynamic task environment). In order to accomplish this, we explore Human-Autonomy teaming communication and coordination with comprehensive scenarios drawn from the pilot tests and look at team needs to successfully overcome complex and dynamic failures. Findings from these two failure events are two-fold: (1) in order to adapt to dynamic environments and overcome unexpected failures, teams should receive role-related training (static and knowledge-based) as well as training about how to interact with one another (dynamic and coordination-based) and (2) designing synthetic agents with effective team coordination mechanisms will help future team training exercises. Current and future work is focused on additional experimentation on team training in the context of Human-Autonomy teams. Furthermore, future experimentation should highlight additional requirements needed for designing synthetic teammates and also dynamic task training necessary to produce effective teamwork.**

Keywords—Human-Autonomy teaming, team coordination, team training, malicious cyber-attack, team situation awareness, unmanned air vehicle.

I. Introduction

Due to recent advances in algorithmic and machine learning, there is a shift from simply seeing computers as tools used by humans to collaborating with technology as autonomous agents [1]–[4]. With that in mind, Human-Autonomy teams (HAT)s are becoming more common in dynamic task contexts where they may be able to serve a role in reducing workload and mitigating risk to humans. However, designing HATs is challenging in a dynamic task context which requires many different levels of interactions.

In a dynamic task environment, teams must effectively coordinate their activities under both routine and novel conditions in order to perform tasks in a more adaptive and robust manner. Therefore, individuals within a team need both role-related training (knowledge-based [5]) and training which focuses on coordination between team members [5], [6] in order to adapt to the task environment and complete common goals or tasks [7]. Training of HATs must include mechanisms of adaptation that allow teams to maintain and improve their metastable joint behavior (neither stable nor unstable) [8], [9], and subsequently their performance, under extreme time pressure [5], [6]. To adapt to novel events in dynamic tasks, this metastability is needed, and it can be adjusted in accordance with the interaction between team members and their dynamic task environment [8].

However, training teams within dynamic task contexts and with joint coordination present a number of challenges [7], [10]. One of the challenges is the number of individuals that are required to accurately simulate the task environment. Having a large number of team members (or stand-in confederates) present for training can be prohibitively expensive and logistically complex. One solution to this problem lies in the development of "synthetic" agents, which are able to stand in for missing team members. However, this solution addresses another challenge—that these synthetic agents may have difficulty understanding subtle behaviors of human team members and their needs to accomplish the team task [3]. Thus, the synthetic agents would need to possess an adequate level of intelligence in order to effectively communicate and coordinate with other human and synthetic agents in order to achieve the overarching goals [3], [7], [10].

This effective team coordination and communication within HAT is also essential for effective Team Situation Awareness (TSA). Based on previous HAT studies, we know that proactively providing information in anticipation of the needs of teammates [11] and demonstrating systems-level flexibility (with all human and technological factors) [12] is positively associated with TSA, and in turn, overall team performance in a Remotely Piloted Aircraft Systems (RPAS) context. In addition, teams with a highly-trained confederate as the pilot saw overall improvements in pushing and pulling information across the entire team [11]. This suggests that the insertion of a synthetic teammate who exhibits behaviors similar to a highly trained confederate may encourage this interaction and lead to improvements in TSA for HATs. In this exploratory study, focused on team training, we address coordination-based training solutions to distinct types of failures caused by either internal (system level) and external sources (task environment).

II. The Current Study

One of the goals of the Synthetic Teammate Project is to develop an ACT-R cognitive architecture [13] based synthetic teammate that is capable of operating as a team member for training [1], [7]. Previous experiments under this project have sought to evaluate and improve upon the synthetic agent's ability to participate as a member of the RPAS team. As part of this ongoing effort, the current study utilizes a Wizard of Oz (WoZ) paradigm in which a trained experimenter (located in a separate room) utilizes a script to imitate a synthetic teammate and communicate with participants in a limited scope [14], [15]. The focus of the current study is to understand the importance of training in overcoming failures in the HAT context. In order to accomplish this, we explore HAT communication and coordination with comprehensive failure scenarios drawn from pilot tests and look at team needs to successfully overcome these failures.

A. *RPAS Task Environment and Task Roles*

Teamwork aspects of RPAS operations are simulated in the Cognitive Engineering Research on Team Tasks RPAS Synthetic Task Environment (RPAS-STE). The task environment consists of seven hardware consoles (three for task roles, and four for experimenter roles) wherein communication between the task roles occurs by means of text chat [16]. The task environment consists of three heterogeneous and interdependent roles: (1) the *navigator*, who prepares the dynamic flight plan and sends information to the pilot including waypoint name and altitude, airspeed, and effective radius; (2) the *pilot*, who controls and monitors the remotely piloted aircraft (RPA)'s altitude, airspeed, as well as the effective radius of the current waypoint, fuel, landing gear, and flaps, and also negotiates with the photographer to attain the proper altitude and airspeed to take good photographs of the targets; and (3) the *photographer*, who takes target photos by monitoring and adjusting camera settings, and sends feedback regarding photo quality. The coordination sequence between the team members is referred to as Information-Negotiation-Feedback (INF [17]).

Participants are told that the pilot is a synthetic agent. In this particular task, the 'synthetic' pilot interacts with the navigator and the photographer following limited vocabulary "cheat sheets". The cheat sheets contain sample messages and message formatting guidelines in order to encourage clear communication with the synthetic agent [15].

B. *Experimental Design*

To understand and measure the system's behavior over time, we plan to impose the following six types of failures onto the missions in limited time range (see Table 1).

The experiment is split into one of three conditions: *automation, autonomy, and control*. Each of the separate conditions are defined by the manipulation of three elements of the pre-mission training: (1) variations in the interactive training slideshow, (2) differences in the behavior of the participant coaches during the hands-on training mission, and (3) changes in the behavior of the pilot during the hands-on training mission.

TABLE 1. Failure Type/ Duration and Description

Type	*Description*
Automation / 300-400secs	Applied to either the photographer or the pilot's simulated task screen (duration from 300-400 seconds), preventing the individual from seeing current and next waypoint information, remaining time, distance to the current target, bearing, and course deviation. In one example of an automation failure, the pilot is not able to access the current altitude, airspeed, remaining time, distance, and bearing to the current target waypoint. In order to overcome this failure, the pilot must communicate with other team members and get the proper information about the current waypoint, and in turn enable the photographer to take a photo of the target [12], [18].
Autonomy / 300-400secs	Applied to the synthetic pilot's limited capacity for understanding other teammates. When the human team members send information to the synthetic pilot, the pilot may continue to ask the same question several times. In order to overcome autonomy failures, team members must provide accurate information to the synthetic pilot in a timely manner, until it understands, and then they must continue to coordinate in order to take a good photo of the current target [12], [18].
Hybrid / 400-500secs	Applied as a combination of both automation and autonomy failures. The automation portion of the failure begins when the pilot loses access to indicators related to the maneuvering of the aircraft, such as altitude and airspeed. The aircraft continues toward the next waypoint, but before it is within range to take a photograph, the synthetic pilot experiences an autonomy failure and begins moving to a different waypoint of its own accord. In order to overcome this failure the human crew members must negotiate relevant flight information with the synthetic teammate and identify the synthetic teammate's goal misalignment.
System / 500-600secs	Applied by a gradual power-down and subsequent power-up of all six ground console interfaces over a period of 330 seconds. The sequence of power down follows the order of least to most vital, and is reversed during the power-up. During the system failure, chat communication between the team members is maintained, allowing a photograph of the target to be taken if the team coordinates effectively.
Communication / 300 -400secs	Applied as a one-way communication cut between the photographer and the synthetic pilot. The photographer is no longer able to send communications to the pilot, but the synthetic pilot remains unaware of the malfunction and is able to send communications to the photographer. In order to overcome this failure, the photographer must coordinate communication through the navigator, who serves as a "pipeline".
Malicious cyber-attack / 500-600secs	Applied on two fronts: the apparent hijacking of the RPAS, and the synthetic pilot providing false and detrimental information. The hijacking results in the redirection of the RPA to a hostile enemy waypoint and a warning to the navigator that the enemy has seized control of the RPA. The navigator or the photographer must identify that the RPA is headed towards an enemy occupied and contact "intelligence" (played by an experimenter) about this problem via the chat system. If the team is able to accomplish this, then they go back to the previous target and are able to take a good photo.

In the *automation condition*, participants will be trained to push and pull information in a timely manner in order to improve team coordination, and in turn team performance and team situation awareness [11]. During the interactive team training, each participant is shown information that their teammates have access to (e.g. altitude, airspeed, etc.) and is encouraged to expediently push and pull information. During the hands-on training mission, the pilot subtly influences the team coordination patterns by requesting relevant information whenever a team member fails to send it in a timely manner.

For instance, when an automation failure occurs, the synthetic agent cannot access altitude and airspeed information, so it needs to pull the information in a timely manner from other team members. Then, at least one of the team members (navigator or photographer) will respond to this request (see Fig. 1). This condition is based on findings from two previous studies that outlined effective team interaction: in the first study, the pilot was able to subtly influence the team coordination patterns by requesting relevant information whenever a team member failed to send it in a timely manner, resulting in a more timely pushing and pulling of information for the entire team [11]. In the second study, the importance of metastable team coordination [9] and team flexibility to maintain effectiveness during failures [18]-[20] was observed.

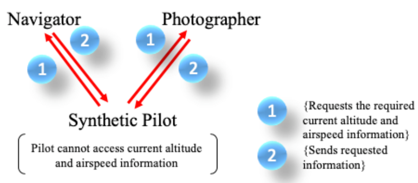

Fig. 1. Team interaction between Synthetic Teammate and Human Teammates for Automation Condition

In the *autonomy condition,* the training is designed to help calibrate participants' expectations of the synthetic teammate's abilities, limitations and also trust. Previous research has brought to light the necessity that human operators understand an agent's strengths and limitations in order to maintain appropriate levels of trust, and that an agent's past performance is one of the strongest predictors of operator trust [19]. During the interactive training slides, participants are informed that the synthetic teammate is an imperfect computer program which is still under development, and that it may experience occasional malfunctions related to misunderstandings and goal misalignments. This is intended to calibrate their expectations of the synthetic teammate's capabilities and reduce the probability that participants over trust it. Furthermore, during the hands-on training mission, the synthetic teammate experiences minor performance decrements in the form of intermittent delays in responding to the human teammates. When these delays occur, the participants are encouraged by the coaches to be persistent when interacting with the synthetic agent, and that it may be failing. Thus, it is expected that participants will be less prone to over trust the synthetic teammate and also be primed to recognize failures related to its autonomous abilities (i.e. decision making, inference) in follow-on missions.

We consider a three-step interaction mechanism for overcoming autonomy failures (see Fig. 2): (1) human teammates recognize the abnormal behavior of the synthetic agent and demonstrate a supervisory control action due to lack of response of the synthetic agent, (2) they persist if it still does not work, and if it still does not understand, (3) then the resolution can come from an outside resource, or intelligent agent (intel/ experimenter).

In the *control condition (baseline)*, standard RPAS-STE training procedures which were used in previous synthetic teammate studies [9] are utilized: the standard synthetic teammate behavior during the hands-on training mission.

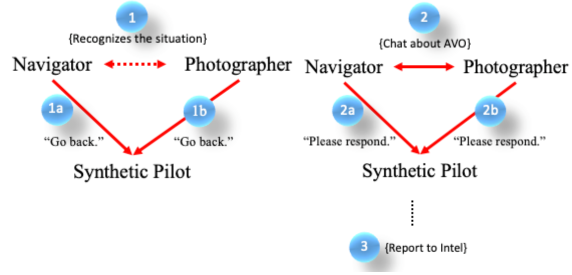

Fig. 2. Team interaction between Synthetic Teammate and Human Teammates for Autonomy Condition

III. Experimental Procedure

In this experimental design, a trained confederate is assigned to the pilot role (WoZ paradigm). The other two team members are participants who are randomly assigned to the roles of navigator and photographer. The participants are told that the pilot is a synthetic teammate, not a human mimicking one. To maintain the veracity of the scenario, the pilot was located in a different room than the other two participants, who were also separated with a partition. During the five 40-minute missions, the navigator's job is to guide the pilot to the waypoint locations in accordance with restrictions and the photographer is responsible for adjusting camera settings and taking good photographs of critical target waypoints (see Table I). Each mission consists of 11-40 targets and there will be a 15-minute break between missions.

Before the task, each team conducts 70 minutes of role-related training (30-minute interactive PowerPoint slides and a 40-minute hands-on training mission). During the hands-on training mission, the experimenters use a checklist to ensure that the participants are comfortable with their roles and that the condition-based training manipulations are conducted. The first 40-minute mission following the training is used as a baseline and contains no failures. Missions 2 through 5 contained two failures each (see Table 2).

TABLE 2. Experimental Sessions with Failure Order

	Failure I	*Failure II*
Training	No Failure	No Failure
Mission 1	No Failure	No Failure
Mission 2	Automation	Autonomy
Mission 3	Autonomy	Automation
Mission 4	Hybrid	Comm. cut
Mission 5	Systems	Malicious cyber

In this experiment, three performance measures are obtained: a mission level team performance score (a composite score calculated based on the overall RPAS team), Target Processing Efficiency (TPE: based on the timely and accurate processing of the target), and team situation awareness (TSA: based on whether or not they successfully overcame the failures) [20]. Additional measures include team communication processing (message count and flow), a verbal behavioral checklist, team coordination, process ratings, a post-experiment questionnaire, the NASA-TLX workload, and a trust and anthropomorphism questionnaire. The aim of this exploratory study is to highlight and discuss team interaction mechanisms in order to assist in overcoming complex and dynamic failures.

IV. Recommended Interaction Mechanisms under Degraded Conditions

For adaptive team training, the recommended interaction mechanisms in this study are introduced in light of a human-systems integration perspective since HATs are considered sociotechnical systems [21]. In this case, a sociotechnical system is a system of interdependent, multilevel, technological, and human factors which also interacts with the environment at the individual-systems level. The interactions in these sociotechnical systems convert inputs to outputs, based on individual-system relationships where the system is more than the sum of its parts [21]–[23]. That is, system-level performance outcomes are considered to arise as functions of the complex interaction patterns between a system's human and technological factors [24]. In order to demonstrate team interaction (communication and coordination) in overcoming complex and dynamic failures, we present the following two comprehensive scenarios: team interaction during a hybrid failure and team interaction during a malicious cyber-attack.

A HAT faces *hybrid failure* in two phases during the coordination sequence in the RPAS task context (INF: see Table 3).

TABLE 3. Team Interaction during Hybrid Failure

INF	Team Communication Sequence	Corresponding Events
Information	**Pilot → Navigator and Photographer** "What is the current status of the RPA for M-STE?"	***Phase I:*** *Synthetic pilot loses access to altitude and airspeed information and informs teammates.*
	Navigator or Photographer → Pilot "The current altitude is 2900, the current airspeed is 200, the distance from the target is 6."	Human team members become aware of the failure and coordinate with pilot.
		Phase II: *Pilot initiates movement to the next waypoint prematurely.*
	Navigator → Pilot "Go back to M-STE."	Pilot returns to the proper route.
Negotiation	**Photographer → Pilot** "Increase altitude to 3100 for M-STE."	
	Pilot → Navigator and Photographer "What is the current status of the RPA?"	Automation failure continues, and the pilot continues to request RPA status updates.
	Navigator or Photographer → Pilot "The current altitude for M-STE is 3100, the current airspeed is 200, and the distance from the target is 4.5."	
Feedback	**Pilot → Photographer** "Do we have a good photo of M-STE?"	
	Photographer to Pilot and Navigator "Got a good photo. Let's go!"	Failure is overcome.

In the first phase, an automation failure is imposed onto the system which is more explicit. That is, at least one team member is aware of this failure and starts coordination with the other members to overcome the automation failure. This failure requires interaction in a constructive and timely manner among the team members. In the second phase (while the automation failure is still happening), the HAT experiences a more implicit autonomy failure. The autonomy failure may cause the autonomous agent to provide misinformation or demonstrate incorrect action which may or may not be the result of the initial automation failure. In this case, the team members may not be aware of the autonomous agent's failure and may only deal with the initial (automation) failure. When one of the human team members notices that the agent has failed and is headed to the wrong target, the human teammate may communicate with the agent: "Go back to M-STE". This action from the human team member may be considered as supervisory control and less coordination, but it can still result in success. Therefore, in the hybrid failure, team members need to know how to effectively coordinate with each other and remain aware of autonomous agent's limitations and potential to fail.

During the *malicious cyber-attack*, the failure occurs from external and internal sources: externally, the synthetic agent is hijacked via cyber-attack; internally, the RPA is also out of control because the synthetic agent is the one who controls the RPA. This failure is implicit like the autonomy failure but has the addition of indirect automation failure because the RPA is also not responding, and coordination among team members looks like supervisory control (i.e. "Go back to R-STE"; see Table 4).

TABLE 4. Team Interaction during Cyber-Attack

INF	Team Communication Sequence	Corresponding Events
Information	**Pilot → Navigator and Photographer** "What is the next waypoint after R-STE?"	Synthetic pilot is hacked, gives misinformation to team members and initiates movement to enemy territory.
	Navigator or Photographer → Pilot "Go back to R-STE."	
	Pilot → Navigator and Photographer "The current waypoint is R-STE."	Human team members become aware of a failure and attempt to correct it.
	Navigator → Photographer to Pilot "Go back to R-STE."	The synthetic agent continues to enemy waypoint and while providing misinformation.
	Navigator or Photographer → Intel "There seems to be a problem with the synthetic pilot. The RPA is moving to a hazardous enemy waypoint."	After several attempts to correct the pilot, the human team members contact outside support.
	Intel → Navigator and Photographer "We are aware of the issue and we will work to reboot the synthetic agent."	The RPA is reset, thwarting the cyber-attack, and the pilot initiates movement to the correct target when prompted.
	Navigator or Photographer → Pilot "Go back to R-STE."	
Negotiation	**Photographer → Pilot:** "Increase altitude to 3100 for R-STE."	
	Pilot → Photographer "The target altitude for R-STE is 3100."	
Feedback	**Pilot → Photographer:** "Do we have a good photo of R-STE?"	
	Photographer → Pilot and Navigator: "Got a good photo. Let's go!"	Failure is overcome.

However, successfully overcoming this failure is not as simple as the previous one. For instance, supervisory control over the synthetic agent does not work here, because the synthetic agent is hacked from an outside source, so its information is not trustworthy. Failures in dynamic interaction among the team members (hijacking the synthetic agent and untrustworthy information) also constrain other interaction possibilities among the team members to overcome the failure. The complexity and dynamics of this failure require contacting an outside entity to repair the synthetic agent. Thus, this failure requires awareness of the agent's abnormal behavior and also awareness of internal and external resources which the team can access to fix this unusual behavior. From both of these sample complex and dynamic failure scenarios, we understand joint coordination is dependent upon constructive and timely communication between the synthetic teammate and human teammates. These examples illustrate the importance of both communication and coordination on the part of the synthetic teammate for adaptive team training.

V. Conclusion

In order to adapt to dynamic environments and overcome unexpected failures, teams must receive role-related training (static and knowledge-based) as well as training about how to interact with one another (dynamic and coordination-based). The aim of this exploratory paper is to underline the importance of coordination-based training which is drawn from two complex and dynamic failure events (hybrid and malicious cyber-attack). In this paper, we present recommended interactions to successfully overcome two complex failures, both of which are comprised of explicit and implicit failure phases: hybrid and malicious cyber-attack.

From hybrid and malicious attack failure test scenarios and recommended interactions, we understand that team coordination depends on constructive and timely communication between the synthetic and human teammates. Through these scenarios we understand teams need to have training which contains metastable and flexible team interaction for effective TSA. Based on these findings, we propose that moving beyond knowledge-based training and consider more dynamic and coordination-based training as a supplement for training HATs.

Another finding from this exploratory study based on manipulations of the synthetic pilot's coordination behavior underlines development of future synthetic agents. Even if current synthetic agents are not yet capable of adequately adapting to dynamic task environments and interacting as full-fledged teammates, it is anticipated that one day synthetic agents will have these capabilities, allowing them to serve as teammates in large scale team training exercises. Eventually, team training may be able to be conducted via virtual network, without the cost or logistical demands of full-scale training exercises. Therefore, designing synthetic agents with effective team coordination mechanisms will help future team training exercises. Current and future work is focused on additional experimentation on team training in the context of HAT (either WoZ paradigm or real ACT-R based synthetic agents). Furthermore, future experimentation should highlight the additional requirements needed for designing synthetic teammates and also dynamic task training necessary to produce effective teamwork.

Acknowledgment

This research is supported by ONR Award N000141712382 (Program Managers: Marc Steinberg, Micah Clark).

References

[1] J. Ball *et al.*, "The synthetic teammate project," *Comput Math Organ Theory*, vol. 16, no. 3, pp. 271–299, Sep. 2010.

[2] J. Y. C. Chen and M. J. Barnes, "Human-Agent Teaming for Multirobot Control: A Review of Human Factors Issues," *IEEE Transactions on Human-Machine Systems*, vol. 44, no. 1, pp. 13–29, Feb. 2014.

[3] N. J. McNeese, M. Demir, N. J. Cooke, and C. Myers, "Teaming With a Synthetic Teammate: Insights into Human-Autonomy Teaming," *Hum Factors*, vol. 60, no. 2, pp. 262–273, 2018.

[4] E. J. de Visser, R. Pak, and T. H. Shaw, "From 'automation' to 'autonomy': The importance of trust repair in human-machine interaction," *Ergonomics*, Mar. 2018.

[5] E. E. Entin and D. Serfaty, "Adaptive Team Coordination," *Human Factors*, vol. 41, no. 2, pp. 312–325, Jun. 1999.

[6] J. C. Gorman, N. J. Cooke, and P. G. Amazeen, "Training Adaptive Teams," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 52, no. 2, pp. 295–307, Apr. 2010.

[7] C. Myers *et al.*, "Autonomous Intelligent Agents for Team Training Making the Case for Synthetic Teammates," *IEEE Intel. Systems*, 2018.

[8] M. Demir, N. J. Cooke, and P. G. Amazeen, "A conceptual model of team dynamical behaviors and performance in human-autonomy teaming," *Cognitive Systems Research*, vol. 52, pp. 497–507, 2018.

[9] M. Demir, A. D. Likens, N. J. Cooke, P. G. Amazeen, and N. J. McNeese, "Team Coordination and Effectiveness in Human-Autonomy Teaming," *IEEE Transactions on Human-Machine Systems*, 2018.

[10] W. Zachary, T. Santarelli, D. Lyons, M. Bergondy, and J. Johnston, "Using a community of intelligent synthetic entities to support operational team training," in *Proceedings of the 10th conference on comp. gen. forces and beh. rep.*, Orlando, FL: UCF, 2001, pp. 215–224.

[11] M. Demir, N. J. McNeese, and N. J. Cooke, "Team situation awareness within the context of human-autonomy teaming," *Cognitive Systems Research*, vol. 46, pp. 3–12, Dec. 2017.

[12] D. Grimm, M. Demir, J. C. Gorman, and N. J. Cooke, "The Complex Dynamics of Team Situation Awareness in Human-Autonomy Teaming," in *CogSIMA*, Boston, USA, 2018.

[13] J. R. Anderson, *How can the human mind occur in the physical universe?* Oxford; New York: Oxford University Press, 2007.

[14] M. Demir, N. J. McNeese, and N. J. Cooke, "The Impact of a Perceived Autonomous Agent on Dynamic Team Behaviors," *IEEE Transactions on Emerging Topics in Computational Intelligence*, vol. 2, no. 4, 2018.

[15] M. Demir, N. J. McNeese, N. J. Cooke, J. T. Ball, C. Myers, and M. Freiman, "Synthetic Teammate Communication and Coordination with Humans," in *Proc. of the HFES Ann. Meeting*, 2015,vol.59,pp.951–955.

[16] N. J. Cooke and S. M. Shope, "Designing a Synthetic Task Environment," in *Scaled Worlds: Development, Validation, and Application*, L. R. E. Schiflett, E. Salas, and M. D. Coovert, Eds. Surrey, England: Ashgate Publishing, 2004, pp. 263–278.

[17] J. C. Gorman, P. G. Amazeen, and N. J. Cooke, "Team coordination dynamics.," *Nonlinear Dynamics Psychol Life Sci*, vol.14, no.3, 2010.

[18] D. Grimm, M. Demir, J. C. Gorman, and N. J. Cooke, "Systems Level Evaluation of Resilience in Human-Autonomy Teaming under Degraded Conditions," in *2018 Resilience Week*, Denver, CO, 2018.

[19] P. A. Hancock, D. R. Billings, K. E. Schaefer, J. Y. C. Chen, E. J. de Visser, and R. Parasuraman, "A Meta-Analysis of Factors Affecting Trust in Human-Robot Interaction," *Hum Factors*, vol. 53, no. 5, 2011.

[20] N. J. Cooke *et al.*, "Acquisition and Retention of Team Coordination in Command-and-Control," Jul. 2007.

[21] J. C. Gorman, M. Demir, N. J. Cooke, and D. A. Grimm, "Evaluating Sociotechnical Dynamics in a Simulated Remotely-Piloted Aircraft System: A Layered Dynamics Approach," *Ergonomics*, Dec. 2018.

[22] G. J. M. Read, P. M. Salmon, M. G. Lenné, and N. A. Stanton, "Designing sociotechnical systems with cognitive work analysis: putting theory back into practice," *Ergonomics*, vol. 58, no. 5, 2015.

[23] L. J. Hettinger, A. Kirlik, Y. M. Goh, and P. Buckle, "Modelling and simulation of complex sociotechnical systems: envisioning and analysing work environments," *Ergonomics*, vol. 58, no. 4, 2015.

[24] A. Zwaan, "The sociotechnical systems approach : A critical evaluation," *Inter. J of Prod. Res.*, vol. 13, no. 2, pp. 149–163, 1975.