# Viewing Air Battle Management Through the Lens of Interdependence

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Recent work has shown the importance of understanding and supporting interdependence relationships among agents engaging in complex, joint activities. Building on the Coactive Design Method of Johnson, the goal of this research was to determine the impact of providing operators with real-time information of team interdependencies. It was hypothesized that allowing operators to focus on maximizing the opportunities for team synergy would result in better planning in a dynamic environment. Operators in the Air Battle Management field used a decision aid that provided information on team interdependence during three combat scenarios. Effectiveness of the decision aid was measured by expert assessment of the operator's decisions. The results of this study could help to inform future training aids and interface design for command and control systems.

## Literature Review

Understanding the capabilities of a team requires an understanding of the interdependence relationships that may exist between the team members (Johnson et al., 2014). Interdependence relationships are often not obvious because they depend on the nature of the joint activities the team is conducting, which are often complex and subject to rapid change. A joint activity requires the support of interdependence relationships which "describes the set of complementary relationships that two or more parties rely on to manage [coordinate] required (hard) or opportunistic (soft) dependencies in joint activity" (Johnson et al., 2014 p.56).

These interdependence relationships occur anytime that team members must coordinate their activities to fulfill a common goal. The activity of coordination results in overhead costs including costs to diagnose and select coordination activities, communicate coordination activities, replan coordination activities and time waiting for other entities to complete prerequisite tasks (Klein et al., 2005). To relieve the individual actors of this overhead, many of these tasks are delegated to command and control (C2) structures. An example of how this plays out in a military setting is in Air Battle Management, which involves six core functions: 1) orienting shooters, 2) pairing shooters, 3) solving dynamic problems, 4) expediting decisions, 5) bringing order and 6) developing and disseminating assessments to operational command (Powers, 2018). The individuals responsible for performing these tasks are Air Battle Managers (ABMs), who must have the ability to maintain good situation awareness, perform resource allocation, and mission plan under extreme time pressure and uncertainty (Klein, 1998; Klinger and Gomes, 1993). However, this skill requires time to develop and can be difficult to master.

As part of the Coactive Design Approach for human-robot teams, a method termed Interdependence Analysis (IA) was developed to construct systems that can support the interdependent relationships that exist between human and robotic teammates (Johnson, 2014). This process uses an IA Table (IAT) that consists of a traditional hierarchical task analysis decomposition that identifies the tasks to be performed. Multiple teammates having capacities required for completion each task/subtask, including situation awareness information, knowledge, skills, and abilities; are assigned to each task. The table further provides an enumeration of viable team role alternatives along with an assessment of the member's capacity to perform and capacity to support the associated taskwork. The table employs a color code that helps identify potential interdependence relationships among a primary performer and supporting agents as shown in Table 1.

***Table 1*. Interdependence Color Scheme, adapted from (Johnson et al., 2014).**

| Team Member Role Alternatives | |
|---|---|
| Performer | Supporting Team Members |
| I can do it all | My assistance could improve efficiency |
| I can do it all but my reliability is < 100% | My assistance could improve reliability |
| I can contribute but need assistance | My assistance is required |
| I cannot do it | I cannot provide assistance |

While the IA method has proven to be an effective tool for design engineers when developing human-robot teams, this research seeks to extend this work and investigate the utility of an IAT as a decision aid, capable of supporting operator awareness and management of team interdependencies as they evolve in real time. Specifically, this work seeks to apply the interdependence analysis concept and an interdependence table-like representation to represent the interdependencies among aircraft within air battle management scenarios. The utility of this tool is then assessed by having newly trained ABMs perform the air battle management task both with and without the representation.

## Methodology

### Participants

Eight recent graduates of the Undergraduate ABM training course participated in the study. They had an average of five months experience post Undergraduate training as ABMs, but no experience with operational missions. Half of the participants were randomly assigned to either the control or experimental group.

### Scenarios

Three mission scenarios were developed in collaboration with a subject matter expert (SME). Each scenario presented the operator with unique challenges based on the nature of the task.

The first scenario was an offensive mission with a defended, stationary target. It was defined as a time critical target (TCT) with a limited window of opportunity to be destroyed due to the nature of the threat. Updates regarding the nature and number of defensive units were a major complicating factor as they could alter which aircraft was best suited to conduct the strike. Mechanical issues to certain assets also complicated the asset-target decision process. The second scenario was an offensive mission requiring a precision strike on a defended, moving target as it transitioned through areas of varying risk of collateral damage. Depending on the location, the number of strike options would vary. This scenario was also designed to trigger a call to abort the mission as a result of the last update. The third scenario was a defensive mission that focused on protecting a high value asset (airfield) against an unknown number of airborne adversaries. The evolving weather in the area had the potential to interfere with air operations and adversely impact sensor capabilities.

## Apparatus

All participants were provided with all of the information that is normally available during a mission to make decisions on assigning assets to mission tasks, such as the mission objectives, physical map of the area of operations indicating objectives, position of friendly and known adversaries, the fuel and weapons status and current assignment of each asset. In addition to this, the experimental group also received the IAT decision aid as shown in Figure 1.

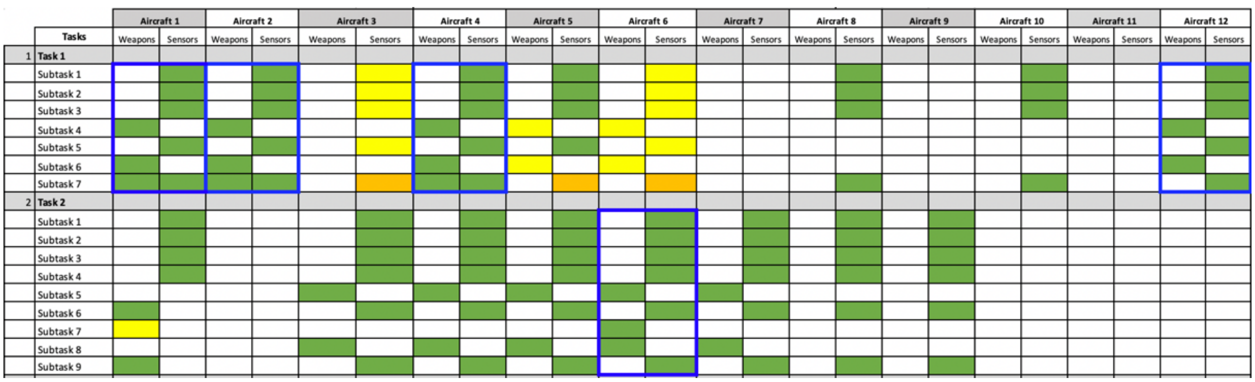

***Figure 1.*** **Except of the IAT Decision Aid with generic entries for tasks and aircraft.**

The IAT was designed as a decision aid to support the operator by highlighting team interdependencies in real-time, specifically those for resource allocation and planning purposes. It was developed from the use of several Excel macros. There were five main parts to developing the decision aid: 1) dissecting the mission objectives into subtasks, 2) identify assets and their capabilities, 3) color-coding the IAT based on the most recent mission update, 4) restricting the capabilities of assets based on the mission timeline and 5) recommending the most capable asset to the operator. The color of a cell mapped the ability of the current asset weapons load out and sensor status to the selected task. To ensure an operator could not assign an asset to two mission objectives occurring at the same time, the macro would grey out the other mission objective rows if the asset was assigned to a task. This feature helped the operator keep track of their resource allocation. Lastly, the IAT made recommendations to the operator by outlining the most capable assets to fulfill a mission objective in a dark blue. The goal of this feature was to help the operator save time during assignment of resources to address a time critical target.

## Procedure

The experiment was conducted through Microsoft Teams and took approximately 90 minutes, including a 15 minute briefing, a 60 minute simulation, and 15 minute debriefing. The experimenter acted as the Air Commander and provided additional information or clarifications as needed. Each scenario contained ten mission updates designed to trigger critical decision points around the status of enemy and friendly forces, weather, and other decision factors. The participants were asked to verbalize their thought process while making any necessary adjustments to aircraft assignments or ordering the mission to be aborted if deemed necessary. A debriefing followed to provide further insight into the decision-making process and situation awareness of the mission scenario.

# Results

The performance errors among the results were classified into four categories: 1) *Mission Asset Pairing* in which the ABM assigned a mission objective to an aircraft that was better suited for another aircraft, 2) *Crew Coordination* in which the ABM did not properly utilize the interconnected capabilities of assets 3) *Knowledge Gap* in which they made an inadequate decision due to a knowledge gap of necessary information, and 4) *Assumption Error* in which the ABM assumed inaccurate information. The performance of the experimental and control group were analyzed for common errors and compared against the correct predicted response from a SME ABM. No one participant made more than three errors per scenario. The results revealed that the control group made more errors of all types in total and across each mission.

Figure 2 shows the results from scenario one, which involved an offensive mission with a stationary target. No one in the control group completed the mission. Three of four participants aborted the mission by Update 9. The final participant was unable to successfully select an aircraft to perform combat assessment of the target during the tenth update. In comparison, all four of the participants in the control group successfully completed the mission. These results highlight the utility of the decision aid to help the participant keep track of their assets as the mission evolves.

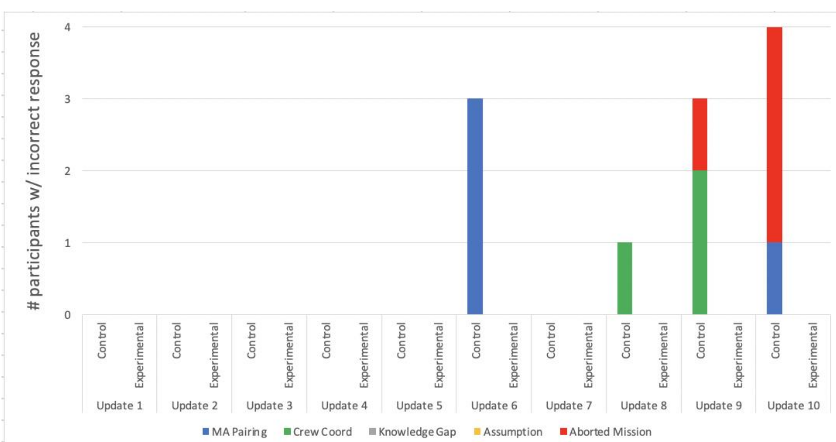


***Figure 2.*** **Participant's Errors during each mission update for Scenario One, color indicates error type.**

During the second scenario, involving the precision strike on a moving target, all participants performed well until the last update. No errors were made by the experimental group. However, three of four participants in the control group made a knowledge gap error on Update 10. This update changed the capabilities of assets due to inclement weather. The Air Commander informed all participants that the target was unable to be detected by any aircraft. Participants in the experimental group were able to use the decision aid to recognize the environmental effects on their asset capabilities. This led to four of four participants making a decision that aligned with the SME's assessment. However, three of four participants in the control group left aircraft hovering over the target in extreme weather conditions due to knowledge gap of aircraft weather capabilities. The responses to this update emphasize how the decision aid can be useful for novice trainees with knowledge gaps from training when making operational decisions.

The third scenario, which focused on defense of an airfield, resulted in the most performance errors. During this scenario, as the updates occurred, the participants were presented with more and more enemy aircraft in the airspace, eventually leading an overwhelming large number of enemy aircraft to be tracked and targeted. The experimental group was able to quickly recognize which assets were able to perform air-to-air defense, while most control group participants were hesitant and made inaccurate assumptions. These results suggest the decision aid was helpful for resource allocation in a task saturated environment.

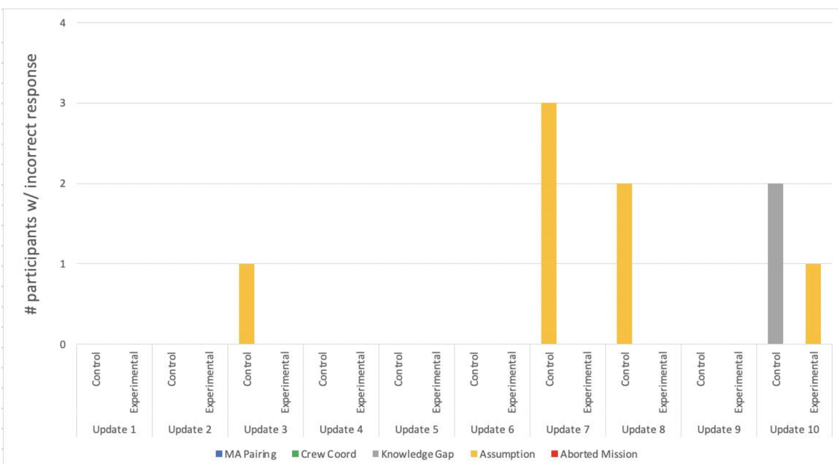


**Figure 3.** ***Participant Errors during each mission update for Scenario Three, color indicates error type.***

## Discussion and Conclusion

As shown in Figures 2 and 3, participants in both groups generally performed well initially in all of the scenarios, however, as the missions continued, more participants in the control group struggled to keep track of their asset capabilities, perform efficient resource allocation, and mission plan. For example, in scenario one, as the number of updates increased so did the number of errors for the control group. It became very difficult for these individuals to keep track of their asset capabilities, which resulted in aborted missions. In scenario two, the Air Commander had more control of assigning aircraft to tasks, which led to fewer errors. However, on the last update, three of the four participants in the control group lacked knowledge of asset weather capabilities and made poor decisions. Lastly, on scenario three, several assumption errors occurred due to the defensive mission type. Students are trained to target enemy aircraft when they reach a particular area of engagement. These participants made inaccurate assumptions about enemy locations and aircraft weapon capabilities. These results highlight how the decision aid was able to support all of these decisions.

Feedback from the participants suggested that having the information on how team interdependencies were changing over time improved their situation awareness, enhanced their resource allocation decisions and ability to plan missions. They also stated that the aid helped them understand how their time critical decisions can have cascading effects on the ability to accomplish competing tasks, ultimately saving time, resources, and increasing resilience.

## Future Work

While the results showed some promise for this approach, it was limited to a specific domain and a small subset of AF operators. Future work should focus on increasing the fidelity of the interface, incorporating more complex scenarios, including multiple participants, and potentially artificial agents.

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