Task Allocation in Teams for Launch and Range Operations

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Abstract

NASA's operations include many teams of people who must do their own individual tasks and communicate about those tasks to other team members to accomplish team goals. Team tasks are crucial in the Range Operations at Kennedy Space Center (KSC). Future systems to support such tasks may include software agents to alleviate heavy workload or time pressure by performing some tasks currently allocated to human operators. MORSE (Multi-agent Operation Range Simulation Environment) is an environment for three team members, encompassing some of the challenges facing Range Operations at KSC. The team must monitor incursions (e.g., aircraft or boats) that have entered the exclusion zone, an area bounded by launch impact lines. The human team has at its disposal radars that allow the team members to see incursions in the areas covered by the radars, and interceptor vehicles that can be appointed to intercept incursions. Radars and interceptor vehicles are shared resources that team members must acquire through coordination with each other and utilize for the performance of the team task. The overall team objective is to effect a safe launch where no incursions are left within the impact lines at launch time and resource consumption over the course of the task is minimized. In our initial experiment with this simulation environment we are comparing teams in which team members either have exclusive control over a resource type or control over an operating region.

1 Introduction

NASA's operations include many teams of people who must do their own individual tasks and communicate about those tasks to other team members to accomplish team goals. Team tasks are crucial in the Range Operations at Kennedy Space Center (Rabelo, Bardino, and Brown 2003). Range personnel must do a myriad of tasks to ensure the safety of the general populace during and immediately following launches from KSC. They must do so in an environment of heavy workload, time pressure, and uncertain data. Future systems to support such tasks will likely include software agents to alleviate heavy workload or time pressure by performing some tasks currently allocated to human operators, to deliver more task-appropriate information to human operators, to perform complex analyses of uncertain data, to aid team coordination or to aid the human operators in attainment of team goals.

MORSE (Multi-agent Operation Range Simulation Environment) is designed to be an extensible testbed for the study of aiding strategies using software agents. This initial experiment is intended to provide baseline data on task performance for future reference. MORSE is an environment for three team members, encompassing some of the challenges facing Range Operations at KSC. It is a distributed system that simulates a task performed by a team of three human operators, each being responsible for some aspect of ensuring that launching a space vehicle from KSC will not endanger the general populace. MORSE provides monitoring stations at Cape Kennedy (Figure 1), Antigua and the Ascension Islands, where human operators track the progress of the mission in the 15 hours (scaled to be 10 minutes of real time in the simulation) prior to launch, and decide whether to abort or go ahead with the launch.

To make this decision, the team must monitor incursions of aircraft or boats that have entered the exclusion zone, an area bounded by launch impact lines. The team objective is to effect a safe launch, where no incursions are left within the impact lines at launch time while minimizing the use of resources. The human team has at its disposal radars that allow the team members to see incursions in the areas covered by the radars, and interceptor vehicles (boats and planes) that can be appointed to intercept incursions. Radars and interceptor vehicles are shared resources that team members must acquire through coordination with each other and utilize for the performance of the team task, i.e. the safe launch, or abortion of a launch that is predicted to be unsafe.

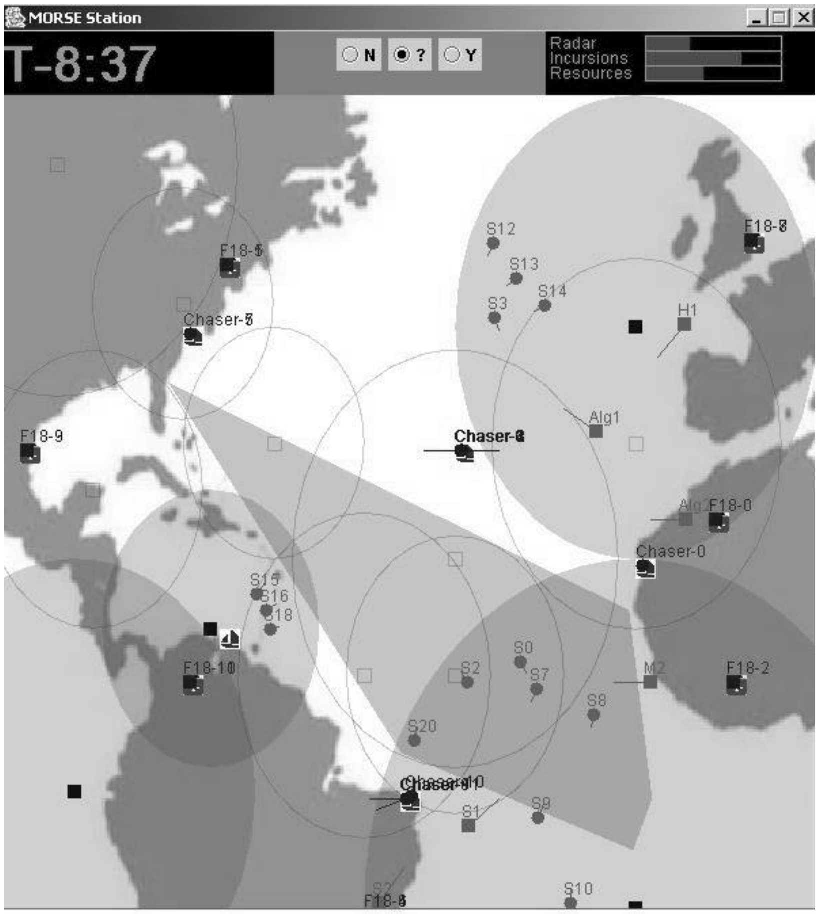

Figure 1: Standard full map MORSE display

2 The Control Task

Although MORSE was designed as a platform for studying agent aiding for teams, implicit human-agent coordination, and adjustable autonomy, our initial study is limited to unaided control and compares functional with geographic allocation of tasks to team members to provide baseline data for later experiments.

Under a *geographic allocation* each operator is responsible for detection of incursions and interceptions within the range of its station's radars and planes. The operators must cooperate to hand-off intruders, alert others of intrusions likely to affect their areas and negotiate coverage and responses for overlapping areas of operations. Under these conditions team members' actions are independent within their designated regions but they could improve one another's performance by sharing information. Their fisheye view provides higher detail for the region being controlled while preserving context needed to interact with the other operators.

In the *functional allocation*, each of the three operators is responsible for a single task, interception by boat, interception by plane, or radar control. These operators must communicate and explicitly cooperate to coordinate the activation of radars and interception of boats and planes but no hand-offs are required because a single operator retains control of a particular resource.

2.1 Task Requirements

Performing the MORSE task requires a number of coordinated activities. Radars must be turned on to detect incursions within their range but need to be turned back off after use in order to avoid consuming excess resources. Incursions are turned back by dispatching an appropriate interceptor which after reaching the intruder's location must escort the intruder outside the exclusion zone before it can return to duty. Boats and planes move at very different rates and can only intercept corresponding types of intruders. Planes can be dispatched from any of six airfields. Boats are stationed at two ports at each side of the Atlantic. Unlike radars which simply expend a metered resource, there are only finite numbers of planes or boats to be dispatched. If an airfield is exhausted, an interceptor must be summoned from someplace else, perhaps at a great distance. In this case, the greater time involved in the long distance interception increases the likelihood that a subsequent intruder also cannot be efficiently matched to an escort. These kinds of cascading effects increase the difficulties of the Range Operator's task particularly as resources are depleted and launch time approaches. To avoid unnecessary interceptions the operator must estimate projected locations for intruders at time of launch. Planes within the exclusion zone early in the exercise are likely to be well clear by launch while those just taking off may pose significant hazards. Boats near or within the zone, by contrast, are good candidates but will take significantly longer to reach and escort. This process of search, prediction, and tracking of resources makes MORSE a cognitively complex task particularly as the number intrusions increases.

3 Methods

3.1 Participants

Paid participants were recruited from the University of Pittsburgh and Carnegie Mellon University communities in 14 intact three person teams (42 participants). Twenty-six of the participants were male and 16 were female. The average age of participants was 25 with about half (19) having some graduate level education and about half (19) playing video games one hour or more per week.

3.2 Design

A between groups repeated measures design was used in this experiment. Task allocation (regional vs. functional) was the between groups factor with trial number as the within factor. Potential intrusions were generated at a constant rate at random positions and directions of travel across the three trials. Because an intrusion might first appear within or near the exclusion zone operators needed to periodically operate radars in this area even after clearing the region of known potential intrusions.

3.3 Procedure

The experiment was conducted using three networked pc's with 21" displays and standard mice and keyboards. As teams arrived they were assigned in an alternating fashion to the *geographic* or *functional* condition.

At the beginning of the experiment participants gathered around the first operator's workstation and were introduced to the MORSE display and task. They were encouraged to ask questions and queried until the experimenter was confident that the basic operations of the task were mastered. Participants then chose a workstation and completed an online demographic form. The first trial was begun after these forms were complete. Participants were requested to use a chat facility rather than talk during the experimental sessions in order to provide a clear record of their communication and communication patterns. Brief (2-3 minute) breaks were provided between the 1st and 2nd, and 2nd and 3rd trials. At the conclusion of the third trial participants completed a online exit survey with items addressing their strategies, hypotheses, and open ended comments about their experience in the experiment.

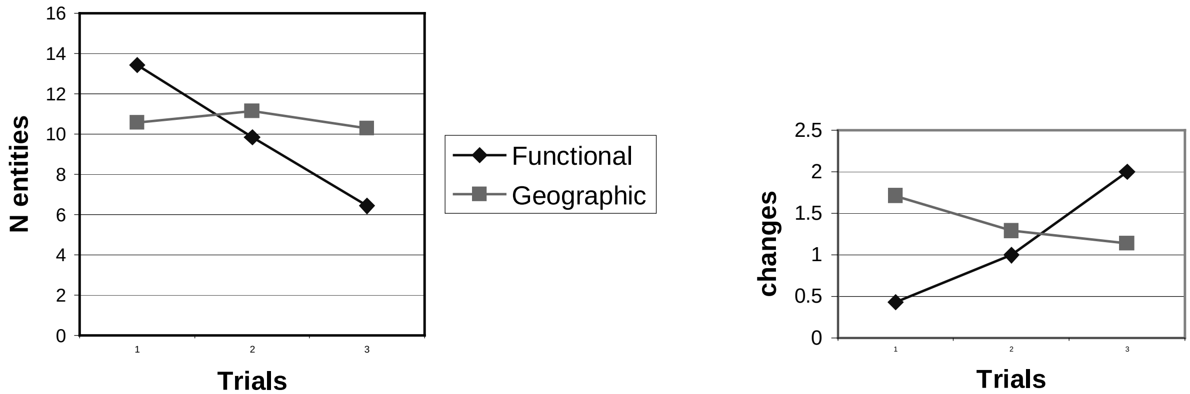

Figure 2: Remaining incursions (left), Changes in launch status (right)

4 Results

4.1 Trials 1-3

Test of the multivariate Wilk's Lambda statistic, $F(22,28)=3.309$, $p < .002$, showed a strong learning effect across the three trials for the full set of dependent measures. Effects due to task allocation were less pronounced. Significant interactions were found between trials and the number of remaining incursions at session's end, $F(1,12)=7.975$, $p=.015$, (Figure 2, left) and number of changes made to the mission's go/no-go status, $F(1,12)=7.031$, $p=.021$ (Figure 2, right). The interaction between trials and escort ships remaining in the launch zone failed to reach significance ($F(1,12)=3.902$, $p=.072$). No significant effects were found for task allocation, however, the number of ships in the exclusion zone at session's end, the total time spent by ships in the exclusion zone, and the time escort ships spent away from port without being tasked all approached significance.

4.2 Trials 2-3

Because the impact of task allocation was observable primarily through its interaction with learning and there appeared to substantial changes in performance between the first and second trials we chose to examine data from trials 2 and 3 separately. While effects across the three trials were limited to ships or aggregates of ships and air craft, interactions were found for trials 2 and 3 for intercepting aircraft within the exclusion zone, $F(1,12)=8.854$, $p=.012$, and transit times for unassigned aircraft, $F(1,12)=7.006$, $p=.021$.

4.3 First and Last Trials

In the first trial the number of changes made to the mission's go/no-go status differed between groups, $F(1,12)=5.786$, $p=.04$. Effects for escort ships remaining within exclusion zone, time spent by ships within the exclusion zone, and time spent by escort ships without assignment approached significance ($p=.058$-$.084$). On the final trial a difference was again found for the number of ships remaining within the exclusion zone.

4.4 Exit Survey

Participants in the Geographic allocation condition reported greater difficulty in coordination but similar levels of task difficulty compared to Functional allocation participants. All small majority in each group thought the allocation they had not experienced would be better. Half of the participants in the Geographic allocation condition thought that the task might be easier to perform alone while only two from the Functional allocation group held this opinion.

5 Discussion

Although Geographic allocation groups performed better on many measures for the first trial, their performance remained relatively stable over succeeding trials while Functional allocation groups improved in performance. The interactions shown in figures 2 are typical of much of this data although several measures including time spent by ships within the exclusion zone, and time spent by escort ships without assignment have parallel slopes with better performance accruing to Functional allocation groups from the start. The most difficult of the tasks appears to be intercepting and escorting ships. Because the ships move very slowly, the operator must plan well in advance to task an interceptor then turn attention elsewhere while the ship is in transit. Since success at this task depends on accurate estimation and monitoring strategies, the ship operator in a Functional allocation team can acquire more experience at intercepting errant ships and should develop better models of ship behaviour. The Functional allocation ship operator also has attentional advantages because the ships he is directing and monitoring operate on similar time scales allowing periodic monitoring strategies. Operators responsible for geographic regions, by contrast, must suspend their monitoring to respond to interruptions from rapidly intruding aircraft or to update radar images.

Difficulties in teamwork are also implicated in the observed differences. Functional allocation groups only need pairwise coordination between the radar operator and the ship or aircraft operator. The radar task could conceivably even be performed independently although a good operator would be expected to follow what others are doing and backup teammates (Cannon-Bowers & Salas 1998). Geographic allocation groups, by contrast, require three-way coordination across all three tasks to effect handoffs of tracks and coordinate radar in neighboring regions. This difference in difficulty is reflected in the Exit Survey where most Geographic allocation participants rate coordination as difficult while most Functional allocation participants feel it to be easy or at least not difficult.

This initial test of MORSE has shown that it provides a sufficiently difficult team task to be potentially useful for studying strategies for operator aiding. As Figure 2 shows the average performance does not approach complete success (an empty exclusion zone) under any of the conditions. In its present form difficulty in MORSE is primarily a result of the rate at which incursions are introduced, making it similar to other demand based team simulations such as DDD (Kleinman & Song 1994) or Tandem (Smith-Jentsch, Johnson, & Payne 1998). With continued development we hope to introduce progressively more of the characteristics of the actual NASA Range Operations tasks to provide an environment in which to study human interruptability, adjustable autonomy, and transfer of control strategies.

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