Geographically Distributed Teams in a

Collaborative Problem Solving Task

by

Michael Champion

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Graduate Supervisory Committee:

Nancy Cooke, Chair
Bing Wu
Steven Shope

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ABSTRACT

As technology enhances our communication capabilities, the number of distributed teams has risen in both public and private sectors. There is no doubt that these technological advancements have addressed a need for communication and collaboration of distributed teams. However, is all technology useful for effective collaboration? Are some methods (modalities) of communication more conducive than others to effective performance and collaboration of distributed teams? Although previous literature identifies some differences in modalities, there is little research on geographically distributed mobile teams (DMTs) performing a collaborative task. To investigate communication and performance in this context, I developed the GeoCog system. This system is a mobile communications and collaboration platform enabling small, distributed teams of three to participate in a variant of the military-inspired game, "Capture the Flag". Within the task, teams were given one hour to complete as many "captures" as possible while utilizing resources to the advantage of the team. In this experiment, I manipulated the modality of communication across three conditions with text-based messaging only, vocal communication only, and a combination of the two conditions. It was hypothesized that bi-modal communication would yield superior performance compared to either single modality conditions. Results indicated that performance was not affected by modality. Further results, including communication analysis, are discussed within this paper.

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To anyone else that I may have forgotten, I'm sorry but thank you.

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

In today's society we are faced with a multitude of technologies that affect our daily communications. A number of these technologies are having a profound influence on the manner in which we interact with one another, both in one-on-one and team levels. These changes in communication are likely facilitating the performance of distributed teams (e.g. Serçe et al., 2011). Research emphasis on distributed teams has commonly been placed on the communication and performance aspects of such teams. However, this effort has not taken into account the communication modality effects on task performance of distributed teams that do not have a stationary location. Examples of these teams include military infantry, large-scale construction crews, and emergency response. In this paper, I examine the effects of varying methods of communication (modalities) on team performance in a collaborative task in geographically distributed mobile teams (DMTs).

Distributed Mobile Teams

A distributed team can be defined as a team that operates with a remote connection to either another team or members within the same team that are not, or normally not, able to have face-to-face communication (e.g., Fiore, Salas, Cuevas, & Bowers, 2003; Funke, Galster, Nelson, & Dukes, 2006) and are mobile in nature. This method is sometimes utilized by companies, with one such application being to conduct research and development (García Guzmán, Saldaña Ramos, Amescua Seco, & Sanz Esteban, 2010). University students also employ such strategies when it comes to projects that require a team effort. Whereas some communications on projects are likely to happen face-to-face, some are likely to occur through other communication means (telephone, text messages, emails, etc.) creating a distributed collaboration situation.

Implementations of distributed teams also share a commonality in that typically individuals will occupy an established location to work from. These locations are sometimes geographically distributed and can include offices, conference rooms, libraries, home offices, and so forth. The underlying theme is that during distributed communication in these locations, team members are in stationary, non-moving, locations.

Although distributed teams have team members occupying geographically distributed locations, what happens if team members do not, or cannot, occupy stationary distributed locations? Distributed mobile teams (DMTs) can be thought of as a distributed team in which some, or all, team members do not maintain a stationary location and are nearly-constantly changing locations. This is not a newer phenomena, but rather old. For instance, systems that rely on radio dispatch, such as military infantry, police and other emergency responders can be considered DMTs. Although a centralized command center may be established in each implementation, the team members are typically mobile throughout their service. Even though members of these teams often carry some form of personal radio device, larger systems required for job performance and function are installed in vehicles that accompany team members.

However, it is not always possible, nor desirable, to carry around large pieces of equipment. There are some instances, such as in military applications, in which team members are often required to carry large and heavy packs of equipment up to 40lbs (Burgess, 2004), and much more, according to unpublished reports. Adding any substantial weight to this pack for the purpose of communicating in a mobile environment may not seem appealing, or realistic. Additionally, each piece of equipment added for the purpose of maintaining communications will need to be adequately powered by batteries thereby additionally increasing the already cumbersome packs. These limitations may produce complications when considering the types of equipment that team members could utilize in distributed mobile situations, but must also be balanced based on the level and type of communication that DMTs will require.

For the current study, I have chosen to use cellular smartphones. Currently, nearly 40% of all cellphones in the United States are smartphones (Kellogg, 2011). The majority of these devices are capable of GPS location and navigation, web browsing, and data access. Various other services have been developed for these devices, such as: location-based online sharing networks (Li & Chen, 2010); empirical real-world data collection(e.g., Raento, Oulasvirta, & Eagle, 2009); traffic data collection (Herrera et al., 2010); medical applications (e.g., Boulos, Wheeler, Tavares, & Jones, 2011); and military applications (e.g., Heite, 2011; McCluney, 2010; Rosenberg, 2011). These functions make the smartphone an ideal compact mobile device with a small footprint. And with the high level of pervasiveness, the probability of a user having experience with a smartphone is relatively high.

Team Cognition in Distributed Mobile Teams

Team cognition is defined as cognitive activity that occurs at the team level through interaction. Although some research has proposed that team cognition is the aggregation of individual cognition, recent work defines team cognition as an emergent property of a team (Cooke, Gorman, & Winner, 2007a). Theoretically, the majority of methods by which a team could interact might aid in enhancing team cognition (Cooke, Gorman, Myers, & Duran, in press). However, DMTs only have limited direct methods in which they may interact and thus may limit the growth of team cognition.

There are two main theories within team cognition. The first is shared mental models (SMMs). This theory postulates that teams form mental representations of the task, and any related information such as procedures, rules, expectations, and goals. These individual representations can overlap or be similar to different extents across team members (Cannon-Bowers, Salas, & Converse, 1993). The underlying concept is that teams with well-formed SMMs will be able to anticipate other team member’s needs and react accordingly. Under stressful events and high workload periods, high SMMs would become beneficial to a team by eliminating the need to interact (Entin & Serfaty, 1999).

There is mixed support regarding shared mental models. In a meta-analysis conducted by DeChurch and Mesmer-Magnus (2010), 23 studies on SMMs were analyzed and showed support for the benefit of SMMs on team performance. However, Cooke, Gorman, Duran, and Taylor, (2007b) found that in simulated unmanned aerial vehicle (UAV) tasks, SMMs could not fully account for the results indicated by the data. They found that teams were able to recover from experimental roadblocks that altered the task parameters beyond the original implementation. Teams were able to adjust by communicating and reacting according to those communications to navigate through the roadblock. Such responses and actions are only somewhat ambiguously accounted for by SMMs.

Subsequent studies and research by Cooke and her colleagues led to a divergence from SMMs and to the formation of the second main theory in team cognition: Interactive Team Cognition theory. This theory states that team cognition is an emergent property of teams based on the interactions of the team (Cooke, et al, in press). This theory accounts for the interactions uniquely formed and maintained by a team over time that allows for behaviors like adaptation. This continuing adaptation allows a team to interact and navigate a task that may deviate from the original task, its parameters, or even navigate through a novel task over time.

Both shared mental models and interactive team cognition may be utilized within distributed teams. An important aspect of any task, planning, helps form shared mental models. Klein and Miller (1999) found that planning played an important role within the performance of a task. Though, Klein et al. pointed out that often plans might not be utilized fully, or completely scrapped. One argument is that the constructs from the plans may help maintain an active shared mental model to aid in the formation of a new plan. The contrasting argument is that through continuing interactive team cognition, teams may be able to adapt plans, formulate new ones, or account for unforeseen variables as they happen.

Although distributed teams and distributed mobile teams are closely related, consideration must be given to the limitations of DMTs. With the only form of communication in DMTs being through electronic interaction with little to no face-to-face interaction, any number of factors could mediate the formation of ITC.

Communication Modalities

With distributed teams, consistent face-to-face communication is nearly impossible leaving only communications mediated by various technologies (e.g., Bayerl & Lauche, 2010; Fiore et al., 2003; Funke et al., 2006; Nurmi, 2010; Walker, Stanton, Salmon, & Jenkins, 2009). A concern with limited modalities is whether or not the available modalities are sufficient for DMTs. Even then, there may be no consistency in which modalities would suffice for the range of types of DMTs. To illustrate this, Bordia (1997), showed in a meta-analysis that generally those teams that used various technologies to interact indirectly were slower and performed less effectively than those in face-to-face interactions. In direct contrast, Funke, et al. (2006) found that teams did not suffer any negative effects from utilizing only text-based communications compared to face-to-face communication in a goal oriented task environment. Although both studies utilize only distributed teams in static locations, these contrasting findings illustrate that a generalization of distributed communications may not be wise.

In an effort to combat the limitations of communications in distributed teams, tools have been developed and tested. These include: software tools (e.g. García Guzmán et al., 2010; Serçe et al., 2011), online tools (e.g., Weil et al., 2008), video and interactive video (e.g., Walker et al., 2009), and wireless PDA and tablet computer systems (e.g., Luyten, 2006). However, very few of these tools exist past the experimental phase.

Walker, et al. (2009) utilized several common communication configurations of tools by comparing the modalities of streaming video and/or data against no information streaming while text-based communications were conducted in a distributed environment. They found that performance drop-offs could be directly mediated through the use of technology. Funke, et al (2009) developed a similar study in which they directly manipulated the modality of communication among dyads in a simulated capture-the-flag task. There were four within subject levels of communication: no communication, text only, vocal only, and text/vocal combination.

Media richness theory (MRT) states that people will seek out the media source that provides the most relevant and rich information while reducing the overall amount of information (D'ambra, Rice, & O'Connor, 1998; Daft & Lengel, 1986; 1986; Vignovic & Thompson, 2010). In effect, the quality of the information is more important than the quantity. In Walker et al. (2009) teams within the video-only and data-only conditions required more communications than teams within the video-data condition. In Funke, et al. (2009) teams within the oral-only or oral-text condition required less communication than the teams within no communication or text-only modalities. Although no significant differences were found between the modalities in Funke, et al., participants did prefer vocal and vocal-text modalities above text only and no communication. With regards to MRT, the combination modality required less communication than the vocal modality and should be the predicted, and accurately was, preferred modality of participants. According to MRT, this combination of modalities provided enough information to reduce the overall communications required to complete the task.

With the current study placing DMTs in real-world environment tasks, extra measures must be considered. Funke et al. (2009) found workload performance differences among modalities. The lowest self-reported workload was from teams within the vocal and vocal-text communication modalities. This suggests that vocal communication may relieve workload compared to text communication. Although not investigated within these studies, a likely reason for this workload addition within text communication is the time to formulate, type, and send text communications compared to vocal communication.

Extra workload, not associated with communication may be endured by participants due to the required and constant monitoring of the ever-changing surroundings. This extra workload could have a damaging effect on the communication capabilities of teams by overloading working memory systems.

This overload would cause extra processing by individuals and increase the time of comprehension, processing, and output (Kane, Conway, Hambrick, & Engle, 2007). If communication from individuals becomes affected, team cognition could suffer.

Evidence from aforementioned studies shows support for vocal communication above text communication. However, text communication can allow for permanence of the communications in storage on the communication device. This is a form of external storage and could allow for the formation of a transactive memory system (TMS) (Wegner, 1986). Lewis and Herndon (2011) found that in teams with an increased TMS, performance improved. In Walker et al (2009) the addition of a data stream to the video modality it is arguable that a transactive system could be formed with the data stream explaining some of the improvements those teams had.

With the current mixed support for distributed team communications, it is unclear what communication modality would benefit DMTs. Previous literature shows that adding more information into communications can aid in the ability to complete the task. However, it is not necessarily the quantity of the information, but quality and richness of the information. With proper information and methods of communication, teams may communicate effectively and aid in forming team cognition. Both team cognition and transactive memory systems would also enhance the capabilities of teams. However, all of this must be accomplished in equipment that is small, mobile, and easily deployable.

This study's goal is to examine communication modalities in DMTs. This will be accomplished by utilizing a real-world environment and teams of participants communicating through mobile devices in a capture-the-flag task. In this study, the modalities of communication will be counter-balanced within subjects design examining text-only, vocal-only, and text-vocal bi-modal modalities. In the analysis, team performance is compared across these different modalities.

Hypotheses

In order to study DMTs, the current study is modeled after Funke, et al. (2009). Three modality conditions have been selected based on the literature: text-only, vocal-only, and vocal-text combination. This study advances that of previous literature on distributed teams by introducing participants into a semi-controlled outdoor environment. This addition will allow for the testing of two main themes: the similarity to results from previous lab studies, and the effects of a real-world environment on distributed teams' performance and communication.

Based on the studies conducted by Funke and his colleagues, and Walker and his colleagues, a preference for the vocal and vocal-text modalities emerged. Supporting these findings is the media richness theory stating that the richness of data is preferred to quantity of data, leaving people to pick the more rich modalities of vocal and vocal-text conditions. Because of this, I assert my first hypothesis:

Hypothesis 1: Teams in vocal and bi-modal modalities will show higher preference for modality, and satisfaction for the task compared to teams in the text-only modality.

Utilizing the interactive team cognition theory, team communication is team interaction. Given this, it is expected that teams not communicating effectively will have lowered team cognition and therefore lowered performance. Previous literature shows that vocal conditions are higher performing than text conditions. Any combination of the two modalities shows an even further increase. However, text communication may foster a transactive memory system that could lead too less unique communications compared to vocal conditions. Therefore,

Hypothesis 2: Teams with less communication will display lower levels of performance than those with more communication.

Hypothesis 3: Teams in the vocal and bi-modal conditions will display more, and qualitatively better, communication than text-only condition.

Hypothesis 4: Teams in the vocal and bi-modal modalities will display superior performance compared to teams in the text-only conditions.

Lastly, evidence shows that workload measures are lower for vocal conditions compared to text conditions. However, because of environmental factors, this may change. The advantage of a formed transactive system with text communications could lower workload. Therefore,

Hypothesis 5: Teams in the vocal and bi-modal modalities may report higher levels of workload compared to text-only modality teams.

Chapter 2

METHODS

Participants

Eighteen participants were selected from a participant pool and through word of mouth from Wright-Patterson Air Force Base through Wright State University. Individuals were assigned to teams of three, and then randomly assigned to one of six different run-orders to randomize presentation of conditions through a Latin-square. Each team participated in each condition only once. A total of 18 trials were collected.

Procedure

The experiment lasted for an approximate total of 5 hours, spread across two days. Two teams completed all exercises in one day. The first 15 minutes included training on the first condition, followed by an approximately 30 minute practice trial. After the training and practice trial, participants were asked to complete the first of three exercises followed by a 15-minute administration of the TLX survey. Before each subsequent exercise, a 15-minute training session was provided on the condition specific changes. This training was followed by the 1-hour exercise and 15-minute TLX administration. (Figure 1).

Figure 1. *Procedure of experiment.*

Training consisted of acquainting the participants with the smartphones and the programs they were to use during the exercise. Training was administered using a printed PowerPoint presentation to ensure the consistency of training across teams. At the end of training, participants had the opportunity to familiarize themselves with the functions of the smartphone and ask questions before starting the exercises. At the conclusion of the participants' training, they were asked to go outside and spread out by at least 15m and maintain this distance throughout the exercise.

The training exercise consisted of 5 flags and the full exercise consisted of 40 flags that must be "captured". The training task was conducted in an identical fashion to the full exercises aside from the number of waypoints (i.e., flags). The modality of the training exercise was dependent on the modality of the first full exercise. Therefore, if the text-only modality was the first exercise, training was conducted in a text-only modality, and likewise for the vocal-only and bi-modal modalities. In order to capture a flag, the participant must complete the given task at the flag's location, described in the following section. At commencement of the exercises, participants are given information on the first five flags and continued the task for the entire 1-hour period. During this time, participants were allowed to devise their own strategies and methods for completing the task. At the conclusion of the one-hour period, an exercise termination message was sent out and requested all participants to return to the laboratory. Once they arrived, they were administered a TLX questionnaire. When they completed the third exercise, they were given a demographics survey followed by a debriefing statement. Any remaining questions about performance or the task were answered.

Capture – the – Flag Exercise

Capture-the-Flag is a popular military-inspired strategy game that has been utilized in everything from augmented reality (Cheok, Sreekumar, Lei, & Le Nam Thang, 2006) to popular video games (e.g. Halo series, Modern Warfare series, Unreal series, etc.). The use of this style of exercise introduces two aspects useful to the current study, while simultaneously engaging the participants. The first is an oriented goal that the participant or team of participants must attain. In this style of game, this goal is called a "Flag". These flags can either be a single or multiple physical flag(s) or a goal location. The use of the flags could be considered representational to a variety of tasks that one must complete at either a given location, or in a series of locations. The second is the commonality and simplicity of the game itself. The game is easily explained within a few minutes time and it is likely that the majority of people have *some* knowledge of the game and its execution.

The common variant of this game type is a Red versus Blue (opponent) structure. However, a less common variant requires relying on one side capturing as many flags as possible. At this time, I am not interested in the performance of competing teams and therefore chose the latter variant.

Target Zone. The target zone within this study is a select portion of a University campus. The area was 550 meters by 500 meters at the widest points and contained 22 buildings ranging from a single story to five stories tall.

Flags. This study consists of 40 flags located in the target zone. Each flag location was determined with a handheld GPS device and walking around the target location. Three flag location datasets were developed from a set of 40 located waypoints to alleviate any possible learning of locations. With each set of locations for a scenario dataset being generated from the same master set of location data, all three scenarios should be, on average, equivalent in difficulty. Flags are assigned a non-repeated randomized number between 1 and 40. Each flag has a specific requirement that must be fulfilled before it can be considered solved. These requirements are randomly assigned and can be categorized as follows:

1. A participant simply found and remained at the location for up to 5 seconds to allow for proper authentication of a found flag.
2. A participant was required to remain at the flag for a preset time limit (e.g., 1 minute, 2 minutes, etc.).
3. Two or three participants were required to have located and remained at the flag for up to 5 seconds, but all participants were required *not* to be there at the same time.
4. The first one or two participants were required to locate and remain at the flag for up to 5 seconds, whereas the last participant was required to remain for a preset time limit (e.g., 1 minute, 2 minutes, etc.). Participants were required *not* to be there at the same time.

The GeoCog software sends an email to the participant at the flag with the required information in order to capture the flag, following one of the four above conditions. To successfully capture a flag, the requirements must be met. The software system will notify participants on successful captures. Examples of emails are seen below:

When needing more users: *GeoCog Server: Waypoint 1 requires more users*

When waypoint completed: *GeoCog Server: Waypoint 1 destroyed!*

In an attempt to control for run order effects of the exercises between teams, 6 unique run orders were used. Each condition appeared twice in first, second, and third place with the run order. Three waypoint location map orders were used in order to counteract any learning of where waypoints were located. Each waypoint location map of 40 waypoints was randomized from a master list of 40 waypoints. This was to ensure equal difficulty across each run. Each team received the same waypoint location map for the first, second, and third exercise. See Appendix C for more information on run orders and waypoint information.

Materials

Participant Packs. For this study each participant received a small pack with assigned equipment. Each pack is associated with an identifying call sign: Alpha, Bravo, and Charlie. Each pack was equipped with a customized HTC™ Incredible™ Android™ smartphone and a two-way radio.

Computers. The main computer is a custom-built tower with a 6-core 3.2 GHz processor, 16GB of RAM, and 3TB of storage running Windows 7 Ultimate. Information is received from an internet connection and sent through the GeoCog software.

A second MacBook Pro laptop was used to record all audio data during the vocal and bi-modal conditions.

GeoCog Software. The GeoCog software utilizes GPS packet information from the smartphones to determine orientation and distance to flags from participant location. (For more information on the GPS system, please refer to Appendix A.) Packet information was received every 6 seconds from each participant. Packet information included GPS location, pack information (Participant A, Participant B, etc.), signal strength, and time stamps. Location information was used to calculate the orientation and distance from flags. Orientation and distance information was then sent back to participants to aid in their ability to locate and "solve" flags. For example, Participant A might receive a message such as:

Participant A

1: NE 200ft

2: NW 300ft

3: W 1000ft

etc…

For participant A, this information indicated their relative location from the respective flags. For instance, flag 1 was located 200 ft north-east of their current location, flag 2 was located 300 ft north-west of their current location, and so on. This information was updated every 15 seconds to participants from the latest information available to the software system. Although specific flag locations were relative to each participant, participants received information regarding the same flags. The system only reported 5 flag positions at a time to the participants.

When a flag was captured the system eliminated reporting on the particular flag and include one new flag. Participants were only able to capture those flags for which locations had been given to them by the system. That is, participants are unable to unintentionally capture a flag they were unaware of (e.g. if participants had information on flags 1-5, they could not have accidentally capture flag 15).

Flag location and GPS information were processed using the Universal Transverse Mercator (UTM) map projection.

Communication and Interaction. Teams were assigned to one of six random condition orders in which they complete one exercise for each of the three conditions, in order to control for order effects. The text condition only allowed participants to communicate via text-based methods only. The voice condition allowed for vocal communication through the two-way radios capable of broadcast conversations with all team members and the experimenter. This condition did not permit team members to communicate via text-based methods. The bi-modal condition did not have any communication restrictions and allowed team members to conduct their communications through either vocal or text-based methods at their discretion. All communications were conducted through a smartphone and/or a two-way radio.

A limitation for mobile phones is that it becomes difficult to communicate vocally with multiple communication recipients at one time. Although there are systems designed for mobile devices to answer this limitation, a two-way radio system was used for all vocal communication to ensure consistent communication across teams. Participants received one smartphone, and one two-way radio as a part of their “pack”. Each phone was stripped of irrelevant programs and tasks to ensure participants were focused on the task, and not communicating with the “outside” world. Remaining programs, not including system required programs, included Google Chat™, Google Voice™, Google Maps™, and Latitude™. Each phone was programmed with three contact numbers: the remaining two participant numbers and the experimenter’s phone number. The phones were programmed to not allow dialing or messaging of any numbers not within the contacts list, which was also locked to prevent further addition. Phones were programmed to allow the dialing of 9-1-1 and University Police for safety and security reasons. All team non-vocal communications utilized Google Chat™.

The GeoCog software sent messages to each participant, individually, through Gmail. There is no interactivity available for participants to respond to emails, only receive. Each account is associated with the participant pack’s call sign (Alpha, Bravo, and Charlie).

Vocal communication was conducted through TriSquare eXRS TSX-300 two-way hands-free radios on private channels. A base listening station was located at the experimenter station for recording all vocal transmissions.

Each smartphone had satellite mapping available. Each participant’s phone utilized the Google™ Latitude™ service to indicate where each participant was on a shared map. Shared map abilities did not include the ability to share any information other than current location, which updated at a rate of every 5 to 30 seconds. The goal was to provide a generalization of teammate locations and placement within the target zone.

Survey. At the completion of each exercise, participants were administered a brief TLX questionnaire. The first six measures were based on the NASA TLX (Hart & Staveland, 1988), and the remaining six measures were from the Team TLX created by Helton, Funke, and Knott (under review). After the three exercises were completed, a demographics questionnaire was administered followed by debriefing.

Chapter 3

RESULTS

Six teams were run in a within-subjects repeated measures design, with each team exposed to each of the three conditions one time. Four of the teams completed the exercises in two days with the first day being initial training, practice, and one full exercise, and day two finishing both of the remaining exercises and completing the demographics and debriefing. Two of the teams completed the exercises in one day. There were no differences in performance between the teams who completed the task in one day and the four teams that completed the task in two days ($F2,8)$=0.72, p =0.51). It is also worth noting that there were nearly no differences in team communication tactics between vocal and bi-modal conditions. That is, four teams treated the bi-modal condition as a second vocal condition without utilizing any text communication whereas two teams utilized the text communication for a total of eight text lines of communication between both teams.

Participant Demographics

Demographics were collected from participants after their final exercise. A total of 16 demographics surveys were collected for analytics. Two participants did not complete the demographics questionnaire. Within participants, 94% had previous experience with using a smartphone (n = 16). A subset of those participants were split 50/50 between Android OS and iPhone users (n = 14). One participant out of 16 responses had previously participated within a geographically distributed team in an experiment similar to this one.

With respect to the nature of the capture-the-flag game, 40% of participants reported prior experience with the game. Ninety-four percent of participants reported playing video games. All participants who had experience with capture-the-flag experienced the game through videos games. Related to teams, 94% of participants had previously had experience working within a team.

Preference and Satisfaction

Addressing the first hypothesis about preference of use within modalities, teams were asked during debriefing their preference regarding the modalities. Not surprisingly, 100% of the teams (n = 6) reported a preference for either voice condition without differentiating between vocal and bi-modal. Only 1 team reporting that there could be an added benefit of the bi-modal condition that was not taken advantage of by them. This reinforces the preference aspect of Hypothesis 1 stating that teams will prefer the vocal conditions above the text-only condition.

Satisfaction was addressed in terms of the satisfaction of the team's performance during each scenario. This was accomplished with the team-task satisfaction question within the Team TLX questionnaire. A repeated measures ANOVA was completed on team-task satisfaction by condition. There were no significant differences between the conditions (*F(2,10)* = 3.46, *p* = 0.07). Therefore, whereas modality preference was confirmed through testing, team task satisfaction differences were not confirmed.

Performance

Performance scores were based on the number of completed waypoints within an exercise. A repeated measures ANOVA was conducted analyzing performance by condition. There were no main effects for condition ($F(2,10) = 1.79$, $p = 0.22$) (Table 1).

Condition	Mean
Text-Only	9
Vocal-Only	11
Bimodal	12

Table 1. Performance by Modality. Table of means.

Communication

Communications were collected through two systems. Text communications were sent through the Google Chat system. The number of messages was then tabulated per participant and then aggregated to the team level per condition. Repetitive chat messages and chat messages correcting spelling were not removed. A similar process was utilized for vocal communications. Vocal communications were collected through an experimenter radio connected to a laptop recording any transmissions. Vocal communications were then analyzed by a MatLab® program, which tabulated unique units of speech, better thought of as individual transmissions. One unique transmission can be considered comparable to one chat message. For the bi-modal conditions, total communications included unique vocal transmissions plus chat messages.

The correlation between number of messages per exercise and team performance (number of flags captured) was analyzed using a Pearson's Correlation. There were no significant correlations between the two factors ($r=0.23$, $p=0.35$). This directly addresses Hypothesis 2 by rejecting the hypothesis, showing that level of communication is not related to the level of performance.

Communication quantity was then analyzed by modality. A repeated measures ANOVA on the total amount of communications by condition. A significant main effect was found for modality on communication quantity ($F(2,10) = 6.34$, $p = 0.02$). Upon examining this effect, the driving factor was the drastic difference between the text modality resulting in fewer messages than both the vocal-only modality and bi-modal modality (Figure 2).

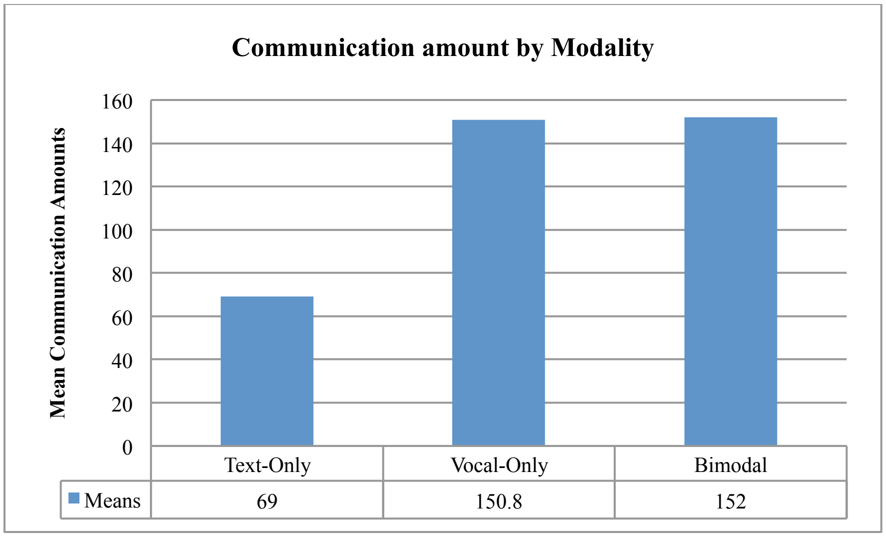

Figure 2. Communication By Modality. Main effect in condition driven by Text-only difference from vocal based conditions (p <0.05)

Because of the similarities between the vocal-only modality and the bi-modal modality the conditions were collapsed and a repeated measures ANOVA was conducted on communication by these collapsed modality conditions. This second model maintained the main effect of condition and communication ($F(1,5)$ = 35.99, p = 0.002). This effect directly supports the third hypothesis that teams within the vocal-only and bi-modal modalities will have increased communications compared to the text-only modality.

A content analysis on communications was initiated in response to the media richness theory. However, it became quickly clear that teams communicated through visual gestures and acknowledgement of these gestures as much as, if not more so than, vocal or text communication. These gestures were possible by the close proximity of team members. Although study protocol restricted team members from being within 50ft of each other, they were still able to effectively see each other. Because this illustrates a missing modality uncontrolled by this study, a media richness assessment could not be accurately conducted.

Workload

Workload measurements were gathered using a Modified NASA-TLX and the Team TLX (See Appendix B). Each participant completed a TLX questionnaire after each exercise. Two separate aggregated scores per team were calculated. The first score designates the first six NASA TLX measures, and the second score designates the remaining ten Team TLX scores. The team scores from both the NASA TLX and Team TLX were not combined due to lack of evidence supporting that analysis technique. These scores were analyzed by modality using a repeated measures ANOVA. The model for the NASA TLX team aggregate score was not significant ($F(2,10) = 3.2$ $p = 0.08$). The model for the Team TLX team aggregate score was not significant ($F(2,10) = 2.15$, $p = 0.17$).

Although aggregated team scores on both the NASA TLX and Team TLX were not significant, a repeated measures ANOVA analysis of condition was conducted for each individual score. Of the six factors in the NASA TLX (Mental, Physical, Temporal, Performance, Effort, and Frustration), there were no significant effects as describe in Table 2.

Factor	F	Sig
Mental	2.58	0.13
Physical	0.27	0.77
Temporal	1.07	0.38
Performance	0.92	0.43
Effort	0.48	0.63
Frustration	0.81	0.47

Table 2. NASA TLX Factors. No factor reached significance.

The Team TLX factors were individually analyzed using a repeated measure ANOVA on each factor. Half of the Team TLX measures (5 of 10) reached significance as indicated by Table 3.

Factor	F	Sig
Coordination	2.11	0.17
Coordination Demands	5.5	0.02*
Communication Demands	5.76	0.02*
Communication Frequency	3.83	0.06
Communication Complexity	1.8	0.22
Time Management	4.86	0.03*
Team Performance	3.46	0.07
Team Support	13.46	0.001**
Emotionally Draining	1.38	0.29
Emotionally Satisfying	10.42	0.004**

*Table 3. Team TLX Factors. Five factors reached significance. * = $p < 0.05$; **= $p < 0.01$*

Coordination demands measured the self-reported frequency of communications demands in order to work as a team. Coordination demands were driven by the lowered amount of coordination demands within the vocal-only modality, and the higher text-only modality coordination demands (Figure 3).

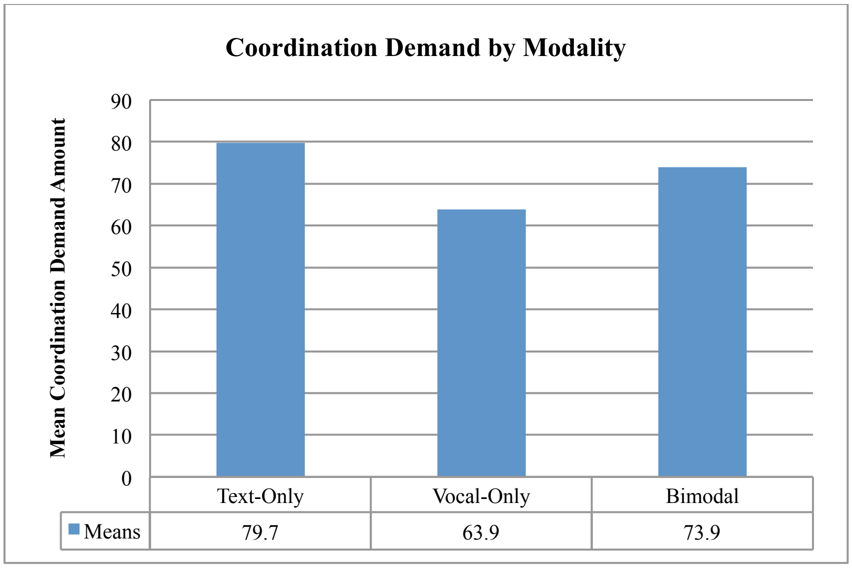

Figure 3. Coordination Demands by Modality. p = 0.02

Communication demands measured the self-reported demands of communication among the team. The main effect was driven by the unexpected difference between both the text-only and bimodal modalities from the vocal-only modalities, as seen in Figure 4.

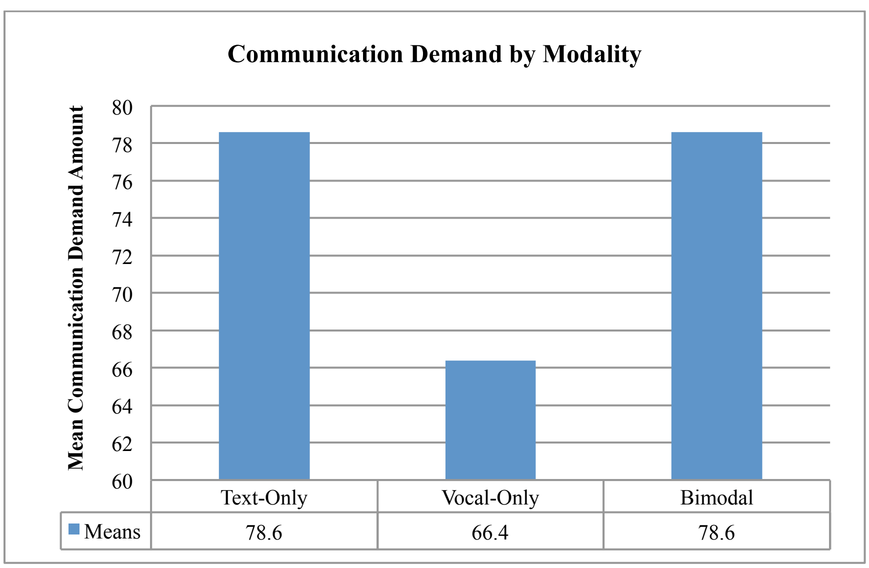

Figure 4. Communication Demand by Modality. p = 0.02

Time management measured the difficulty of managing the time between team work and individual work. Unexpectedly, time management was reported as more difficult during the vocal-only modality compared to the text-only and bimodal modalities. (Figure 5.)

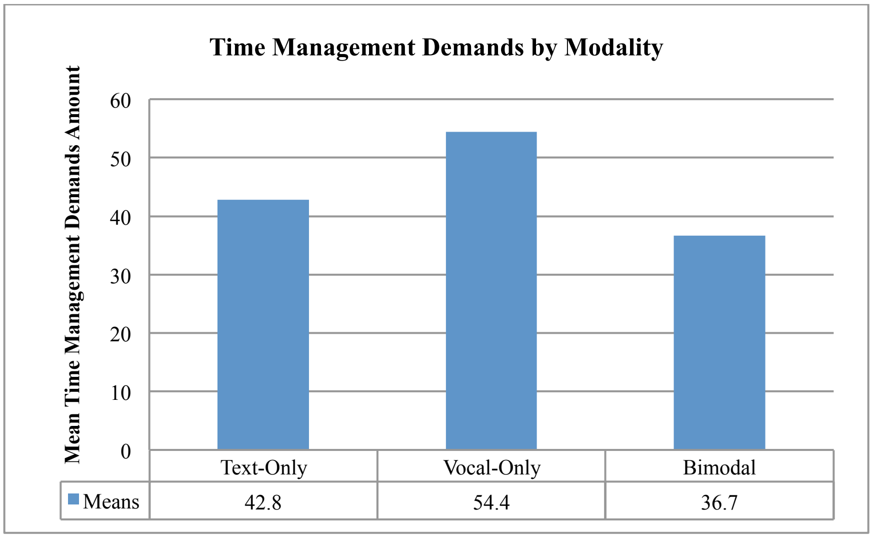

Figure 5. Time Management Demands by Modality. p = 0.03

Team support measured the self-reported difficulty of providing and receiving support from or to the team. Again unexpectedly, the vocal-only modality reported higher difficulty compared to both text-only and bimodal modalities (Figure 6).

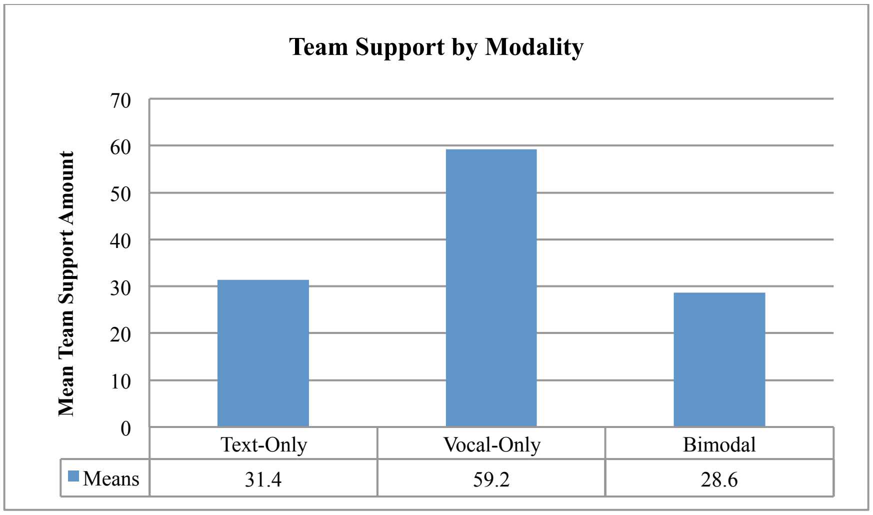

Figure 6. Team Support by Modality. p = 0.001

The last factor of significance was within emotional satisfaction to work as a team. Teams reported less satisfaction for working as a team within the vocal-only modality, and the highest satisfaction for working as a team within the text-only modality (Figure 7).

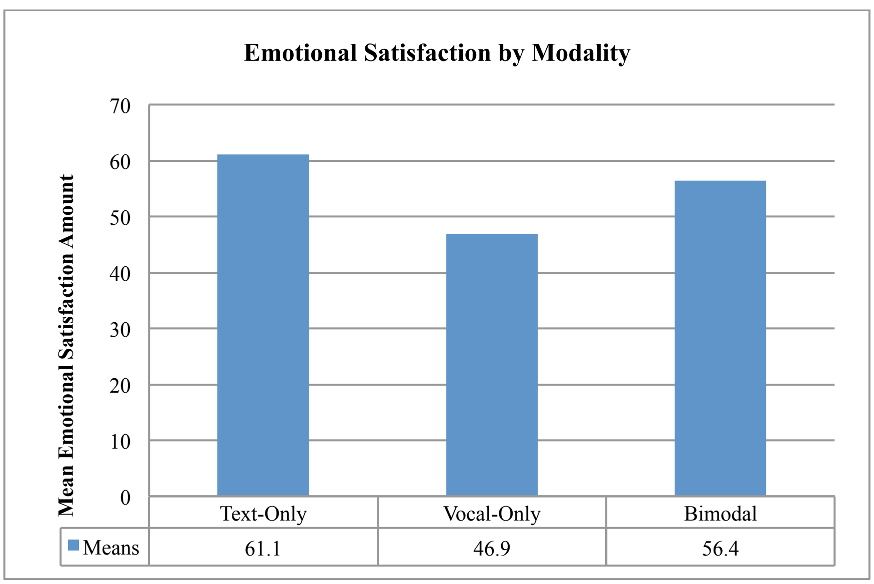

Figure 7. Emotional Satisfaction by Modality. p=0.004

Aggregated team scores failed to show significant differences between modalities in both the NASA TLX and the Team TLX factors. Although specific factors showed significance, there is not enough evidence to support the 5th hypothesis.

Chapter 4

DISCUSSION

With advances in technologies, the increasing demand of complex distributed coordination, and the ever-growing mobile nature of society, research on geographically distributed mobile teams is increasingly important. This study addressed basic questions of communication modality and its impact on performance, workload, and communication of distributed mobile teams

This study attempted to address four research questions.

1. Will communication modality impact distributed mobile team performance?
2. How will modality changes influence amount of communication?
3. Will operator modality preference or task satisfaction differ across modalities?
4. Will modalities have an effect on workload?

To address the first question, we should recall that this study found no differences between modalities. Therefore the result for the first question is inconclusive at best.

When the communication levels were analyzed by modality, a significant effect emerged. Between the vocal-only and bi-modal modalities, there were virtually no differences. In fact, the means were so close together that the modalities are almost identical within communications (vocal-only mean: 150.8; bi-modal mean: 152). The true difference driving the effect lay between either of the vocal-based modalities and the text-only modality, which had a mean of 69 messages within the modality. Given the similarities within communication for both vocal-only and bi-modal modalities, the conditions were collapsed and compared against the text-only modality. This model was able to show the difference between vocal-based modalities and text-only modalities as significant (p=0.002). This finding supported the hypothesis that modalities would have differentiating effects on communication and answers our second question. What is not supported with these findings are any improvements teams encountered by the addition of text communications to vocal communications within the bi-modal modality.

To illustrate some of the findings, during debriefing one team highlighted the theoretical difference between text-only and vocal-based modalities as an explanation for their performance within the text-only exercise. The comments explained that within the text-only modality, they did not require any repetition of information, whereas the vocal-based modalities often required repetition. This was, however, promptly followed by the reaffirmation that the vocal-based modalities were still preferred for ease.

Building a practical application, the selection of a modality may depend on the desired amount of communication. Because this study found no performance differences, but only communication differences – a modality may be selected based on the amount of communication and interaction desired. For instance, for an emergency response team – text-based message may be a better choice in which participants may not be interrupted by a communication in the middle of an important task. This may also reduce the amount of communications such teams would send or be required to send without impacting performance. This may highlight an important difference between vocal-based modalities in tasks such as emergency response.

Although systems may be beneficial, if the user is not satisfied while using the system, then just how useful is the system for that user? The third question addresses the first hypothesis regarding the satisfaction and preference of modalities by the teams within this experiment. When teams were asked at the end of the experiment which modality they preferred, teams unanimously agreed that the vocal-based modalities were much preferred to the text-only modality. This shows strong support for the first hypothesis with regards to preference. However, when addressing satisfaction, there was no consensus within the data. This finding gives mixed support for Hypothesis 1 and our second question here leaving this hypothesis as inconclusive. Teams may prefer a specific modality, but satisfaction with the modality is not affected by preference. However, it may be beneficial to the team in a given task to utilize the preferred modality. For instance, taxi drivers probably would not prefer (and it should never be suggested!) to utilize a text-based communication system. It would be nearly impossible to keep up such a communication system in that environment.

One of the more puzzling sets of findings within this study came from the analyses of the workload measures data to address our final question. When scores were independently aggregated for both the NASA TLX data and the Team TLX data, neither scores showed any effect of modality. When NASA TLX scores were independently analyzed by modality, no factor showed significance.

The decision to utilize the Team TLX generated by Funke and colleagues was in an effort to study the team aspects of workload. Although this scale was used, it was decided to not combine it with the NASA TLX during any analysis. This was due to the lack of validation for the Team TLX scale that exists for the NASA TLX. However, it is with use and repetitive use that a scale may become validated, and with this hope it was utilized here. Among the ten factors of the Team TLX, five factors were significant. These five were coordination demands, communication demands, time management, team support, and emotional satisfaction. These findings were mostly driven by the difference between the vocal-only modality and the combination of the text-only and bimodal modalities. These findings show that the vocal-only modality required less communication and coordination demands, but required more time management and team support while being less emotionally satisfying compared to the other two modalities. This result becomes astonishing when considering that within performance there were no observed modality differences, and within communication there were virtually no differences between the vocal-only and bimodal modality. Analytically the vocal-based modalities should have been identical in all outcomes based on performance and communication – the two main measures within this study. But this result must be taken with a grain of salt, this study cannot currently account for the workload modalities differences seen within the results. Therefore our fourth question is left unanswered as it is inconclusive.

A result missing from this study was that of any indication of media richness. Originally unaccounted for, teams often communicated with visual gestures, maintained visual contact, and communicated supportive information regarding visually provided information. Because of this, the visual modality is unaccounted for, was unmonitored, and no during or post-scenario attempt at collecting this information was undertaken. Therefore an assessment of media richness with existing data would effectively ignore a very important modality. Therefore, the analysis was halted after this missing modality became readily apparent.

This study has highlighted some very intriguing findings. Notwithstanding, these findings are somewhat limited due to a rather important caveat. During task development, *a priori* power analysis indicated that to gain adequate power, only six teams would be needed if run in each condition with moderate correlation between the individual runs. Although the best efforts were undertaken to gather as much data as possible, *post hoc* power analyses illustrated that though power was never incredibly low it was borderline low. In order to account for this, replication or continuation of this study is advisable.

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APPENDIX A

GPS LOCATION INFORMATION

The Global Positioning System (GPS) is a constellation of 24 satellites launched in 1993 broadcasting location information to qualified GPS receivers in order to present the user with a global position within approximately three meters (Defense, 2008). In the case for a mobile distributed team, the location information of team members may become particularly important. Stemming from the early systems utilizing GPS that merely provided a user's location, a multitude of services have developed around this technology. Li and Chen (2010) catalogued a variety of social networking services that were based on the location information provided by the GPS. These location-based online social networks would allow users to interact based on location or plan potential physical interactions based on proximity. One such noted service is that of Google Latitude in which individuals see themselves and their approved "friends" displayed on a map and updated in predetermined increments. This level of information may become important for planning spatial tasks and coordinating logistics of distributed teams.

As with any space-based technology, the limitation to this system is that for an accurate signal users must have a clear view of the sky and remain outside for accurate readings. However, in field operations conducted outside, this presents little-to-no potential complications. A more recent development, mobile devices containing GPS receivers are able to broadcast their location through a hybrid method: either through cellular signals, wireless Internet, or Bluetooth (although limited by range). For this study, I have selected to use two GPSlocators: a high fidelity receiver independent of the mobile device and the mobile devices' own GPS receiver.

APPENDIX B

NASA TLX AND TEAM TLX

Task-Load Index

Please make an "X" in the spaces between the lines on the scales in order to answer the questions. Please do not place an "X" on the lines themselves.

1. How mentally demanding was the task?

Very Low | Very high

2. How physically demanding was the task?

Very Low | Very high

3. How hurried or rushed was the pace of the task?

Very Low | Very high

4. How successful were you in accomplishing what you were asked to do?

Very Low | Very high

5. How hard did you have to work to accomplish your level of performance?

Very Low | Very high

6. How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low | Very high

7. How much coordination activity was required (e.g. correction, adjustment, etc.)? Were the coordination demands to work as a team low or high, infrequent or frequent?

Very Low | Very high

Infrequent | Frequent

TEAM TLX

8. How much communication activity was required (e.g. discussing, negotiating, sending and receiving messages, etc.)? Were the communication demands low or high, infrequent or frequent, simple or complex?

Very Low Very high

Infrequent Frequent

Simple Complex

9. How difficult was it to share and manage time between task-work (work done individually) and teamwork (work done as a team)? Was it easy or hard to manage individual tasks and those tasks requiring work with other team members?

Easy Hard

10. How successful do you think the team was in working as a team? How satisfied were you with the team-related aspects of performance?

Unsatisfied Satisfied

11. How difficult was it to provide and receive support (providing guidance, helping team members, providing instructions, etc.) from team members? Was it easy or hard to support/guide and receive support/guidance from other team members?

Easy Hard

12. How emotionally draining and irritating versus emotionally rewarding and satisfying was it to work as a team?

Draining Rewarding

Irritating Satisfying

APPENDIX C

SCENARIO RUN ORDERS AND WAYPOINT LOCATIONS

There were six different orders for condition presentation. Within this, each condition appeared twice in the first, second, or third presentation order. This is explained below in the table.

Team	First Apperance	Second Appearance	Third Apperance
1	Text-Only	Voice-Only	Bimodal
2	Voice-Only	Bimodal	Text-Only
3	Bimodal	Text-Only	Voice-Only
4	Text-Only	Bimodal	Voice-Only
5	Voice-only	Text-Only	Bimodal
6	Bimodal	Voice-only	Text-Only

Only the first 20 locations are listed, no team saw more than 20. Behavior will be listed as the following:

Instant: A participant simply found and remained at the location and received a message indicating that they have captured the waypoint.

Delay: A participant is required to stay at a flag for X amount of time for capturing the waypoint.

Team: Requires two or more team members to have been at the waypoint, but not at the same time.

Team Delay: Requires two or more team members to have been at the waypoint, but not at the same time. The last required participant must remain at the waypoint for X amount of time for capturing the waypoint.

Practice Scenario.

Waypoint	Number of Participants	Behavior	Time Delay Amount	Northings	Eastings
1	2	Team Instant		4407835	751601
2	2	Team Delay	60	4407808	751540
3	3	Team Instant		4407828	751511
4	1	Delay	60	4407847	751655
5	1	Delay	30	4407712	751521

Scenario 1.

Waypoint	Number of Participants	Behavior	Time Delay Amount	Northings	Eastings
1	3	Team Instant		4407606	751484
2	2	Team Instant		4407652	751330
3	2	Team Delay	90	4407799	751280
4	1	Delay	90	4407699	751299
5	1	Delay	90	4407855	751614
6	3	Team Instant		4407483	751545
7	3	Team Delay	45	4407628	751313
8	1	Delay	90	4407407	751541
9	1	Instant		4407639	751267
10	2	Team Delay	45	4407697	751342
11	3	Team Delay	90	4407678	751475
12	3	Team Instant		4407780	751431
13	1	Delay	45	4407759	751286
14	3	Team Instant		4407558	751267
15	1	Instant		4407752	751233
16	1	Instant		4407576	751445
17	2	Team Delay	90	4407571	751633
18	1	Delay	90	4407706	751265
19	1	Instant		4407564	751405
20	2	Team Instant		4407827	751304

Scenario 2.

Waypoint	Number of Participants	Behavior	Time Delay Amount	Northings	Easting s
1	3	Team Instant		4407780	751431
2	1	Delay	45	4407442	751495
3	2	Team Delay	45	4407825	751463
4	3	Team Delay	90	4407573	751226
5	3	Team Delay	90	4407517	751239
6	2	Team Delay	45	4407697	751342
7	3	Team Instant		4407615	751567
8	1	Delay	90	4407855	751614
9	2	Team Instant		4407827	751304
10	1	Delay	45	4407664	751379
11	1	Delay	90	4407720	751367
12	1	Instant		4407639	751267
13	1	Instant		4407564	751267
14	3	Team Delay	45	4407597	751331
15	3	Team Delay	45	4407914	751417
16	2	Team Delay	90	4407697	751452
17	2	Team Instant		4407652	751330
18	1	Instant		4407752	751233
19	2	Team Instant		4407371	751579
20	3	Team Instant		4407483	751545

Scenario 3.

Waypoint	Number of Participants	Behavior	Time Delay Amount	Northings	Eastings
1	1	Delay	45	4407442	751495
2	1	Instant		4407752	751233
3	2	Team Instant		4407652	751330
4	2	Team Instant		4407371	751579
5	3	Team Instant		4407606	751484
6	1	Instant		4407564	751405
7	3	Team Delay	90	4407573	751226
8	1	Instant		4407639	751267
9	1	Delay	45	4407759	751286
10	2	Team Delay	90	4407571	751633
11	3	Team Instant		4407558	751267
12	2	Team Delay	90	4407799	751280
13	2	Team Delay	45	4407697	751342
14	1	Delay	90	4407699	751299
15	1	Delay	90	4407706	751265
16	1	Delay	45	4407676	751230
17	1	Delay	90	4407407	751541
18	3	Team Instant		4407483	751545
19	1	Delay	90	4407720	751367
20	2	Team Delay	45	4407520	751583