

Social Implications of Agent-based Planning Support for Human Teams

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Abstract — We present a field trial of how instructions from an intelligent planning agent are dealt with by distributed human teams, in a time-critical task setting created through a mixed-reality game. We conduct interaction analysis to examine video recorded field observations and game log data. The findings highlight the social process by which players interpret and negotiate the agent guidance as well as how these are intertwined with social dynamics of the teams. The insights can be used to develop an understanding of interactional issues around automated team instructions and inform the design of human-centred planning support systems.

Keywords — *team coordination; human-agent interaction; mixed reality game; coalition formation; instructions; planning support*

I. INTRODUCTION

Task planning in teams can be complicated by both spatial and temporal constraints, particularly in time-critical task domains such as disaster response (DR). In a DR setting, responder teams have to coordinate sparse resources and personnel to prioritize geographically distributed tasks, forming and disbanding teams dynamically to carry out DR operations [4]. For example, teams of fire fighters and medics are required to extinguish a fire and to provide first aid, while teams of soldiers and transporters may be needed to clear rubble. These teams, in turn, may need to disband and reform dynamically to perform new tasks and to adapt their planning to uncertainties in real time. Whilst an ‘optimal’ plan of team formation and task allocation may help minimise loss of lives and properties, making optimal plans in real time can be complicated and time-consuming due to large numbers of incidents and responders. To address such coordination challenges, multi-agent research has developed a number of ‘smart’ *coalition formation* algorithms to computationally support planning in time-critical task settings [3,16]. These algorithms typically model humans as computational agents with respective capabilities, for example to dynamically allocate teams of agents to tasks in order to maximise an objective (e.g., number of lives saved), taking into account other aspects of the real world (environment, infrastructures, victims, etc.) [14].

However, most of these ‘smart’ algorithms are based on limited assumptions about human behaviour (e.g., human psychosocial characteristics, movement, and learning ability) [18], and have only been evaluated in computational simulations. In our work, we investigate agent-based planning support in the real world. Specifically, we study the social implications of the ‘division of labour’ between agents and real human teams. In more detail, while coalition formation assumes leaving and joining new teams as an unproblematic process, we study in depth the social, interactional consequences of agent-based instructions that require team formation. For example, Personal preference and social norms may imply that dynamic team formations have a hidden ‘social cost’ that may impact team performance.

We present AtomicOrchid, a mixed-reality game probe of the ways in which human teams respond to agent guidance. The probe is designed to create a socio-technical setting in which distributed teams and a planning agent work collectively to save locally dispersed targets ‘on the ground’. The planning agent runs a coalition formation algorithm to help allocate tasks optimally to the teams. Our analysis reveals social implications of agent support for human teams. In turn, implications for interaction design are discussed that may improve team performance. More specifically, this paper addresses the following research questions on how agent guidance affects the social organisation of team performance:

- How does division of labour play out between humans and agents and how should it be scaffolded by design?
- How do human teams respond to being instructed by an agent, particularly on joining and leaving teams?
- The planning agent makes decisions based on limited assumptions about human behaviour, but what are the ‘hidden costs’ of human behaviour that the agent does not take into account?

Findings from the study highlight the social processes in which members interpret, negotiate, and manage the agent guidance within the social dynamics of teams. We discuss the division of labour between humans and teams; the hidden costs of instructions that suggest team reformation and interrupt on-going tasks. We conclude the paper with a number of emerging interaction design recommendations to

consider when building agent-based support systems for human teams, which emphasise the need for ‘common ground’ between humans and the agent, facilitate accountability between team members, and balance responsibilities between humans and the planning agent appropriately.

II. BACKGROUND

Team coordination can be defined as “the act of managing interdependencies between activities performed to achieve a goal” [11]. Technology support of team coordination in domain specific tasks has been a topic of HCI [20], and computational agents research [15,21]. Human factors researchers have also conducted controlled experiments to identify key aspects of human agent collaboration [2,7,19] and evaluate strategies of agent support for teams [9,10]. Prior research has recognised that interaction design is vital for the performance of socio-technical human-agent systems [12], particularly where an agent directly instructs humans [13]. With inappropriate interaction design, agent-based planning support may function inefficiently, or at worst, hinder the performance of human teams. Yet, real world studies of how human teams handle agent support are rare.

Moreover, field studies of CSCW technologies have shown that it is vital to study technology in use to understand potential tensions raised for teamwork. Bowers et al. found that extreme difficulties might be encountered when introducing new technology support for human teams [1]. New technologies might not support, but may disrupt smooth workflow if they are designed in an organisationally unacceptable way [22]. We believe the same is true for the application of agent-based planning support. Before we can build agent-based systems that support human team coordination, field trials are needed to understand the impact of technology support for team coordination. Our approach is to study the social organisation of human teamwork in order to learn lessons for interaction design.

III. METHOD

Computational simulations are likely to be insufficient in elucidating the social and interactional issues around agent-based coordination support [18]. Therefore we adopt a mixed-reality game approach to put people under realistic cognitive and physical stress. Mixed-reality games are recreational experiences that make use of pervasive technologies such as smart phones, wireless technologies and sensors with the aim of blending game events into a real world environment [6]. Arguably, they have become an established vehicle to explore socio-technical issues in complex real world settings [5]. The major advantage of mixed-reality games is the fact that they are situated in the real world, which arguably leads to increased efficacy of the behavioural observations when compared to computational simulations.

To support our field trial, we developed a mixed-reality game probe, AtomicOrchid, in which we embedded a planning agent in order to trial the impact of agent planning on social organisation of human teams. We designed core game mechanics to provoke exploration of the setting of dynamic

team reformation. The game scenario and mechanics are motivated by real world challenges of resource and task allocation for coordinating spatially distributed resources and personnel to carry out DR operations [4]. We analyse video recordings captured through shadowing teams in the field; interaction analysis is an established method to study how interaction is socially and materially organised [8]. In addition, we classify logged messages based on speech act theory [17] to assess participants’ team coordination in the game probe. The study design is detailed further below.

IV. STUDY DESIGN

In this study, we aimed to probe a straightforward interactional arrangement between a planning support agent and human teams (Fig. 1). The interactional arrangement is designed to facilitate the division of labour between humans and agent: a planning agent routinely assigns tasks to distributed responder teams, while human coordinators (the HQ) monitor and support the task execution by responding to arising contingencies. The agent is designed in a way to take into account simple human feedback, i.e., a field responder can either reject or accept their task assignment. The agent will consider the feedback for the next iteration of task assignment.

By examining the socially organised interaction between team members occasioned by this interactional arrangement, we aimed to explore social implications of human-agent interaction. In turn, these inform the design of agent-based systems. In the following, we describe the study in detail.

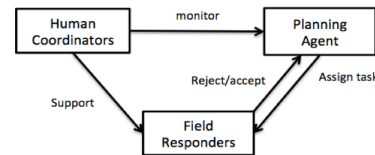


Figure 1. The interactional arrangement.

A. The game scenario and core game mechanic

AtomicOrchid is a location-based mobile game based on a fictitious scenario: a radioactive explosion creates an expanding radioactive cloud. Participants (playing the role of first responders) have to evacuate distributed virtual targets (representing human casualties and resources) before the virtual cloud covers the whole game area. The participants also need to stay “alive” by avoiding the radioactive cloud. The virtual cloud and targets impose spatial and temporal constraint on the coordination of responder teams.

A role-target mapping increases the coordination challenge. First responders are assigned a specific type (medic, transporter, soldier, or fire fighter). There are also four kinds of virtual targets (animal, fuel, uranium, victim). The objective of the field responders is to rescue as many targets as possible by ‘carrying’ them to a drop off zone. To pick up and carry one of the target objects, two responders with specific roles are required in immediate proximity to the object. For example, a soldier and a transporter are required to pick up and carry fuel, and a medic and a soldier are required to pick up an animal. The role-target mapping mechanic creates the demand for

resource coordination – field responders have to engage in ‘agile teaming’ – forming, disbanding, relocating and reforming in teams over the course of the game in order to complete the game objectives.

B. The planning agent

A real-time algorithm was developed to support the coordination problem created by the game mechanic. The coordination problem (described in IV, A) is modelled using a Multi-Agent Markov Decision Process (MMDP) that captures the uncertainties of task execution, extending earlier work [15]. The modelling allows responder actions to be delayed or to fail during the rescue process. The MMDP modelling leads to a large search space, even with a small-sized problem. Hence, we devised an approximate solution to save computation time, which can be executed to support real time planning. The planning algorithm takes into account both time (cloud and human movement speed) and spatial (path planning for responders) constraints. The planning algorithm run by the planning agent produces high task allocations that minimise the travelling distance of first responders, and maximise the number of targets rescued. Before the agent was deployed to support human teams in the game setting, computational simulations were used to benchmark our MMDP algorithm against greedy and myopic methods (see Table 1). The results confirm that our algorithm produces efficient task allocations.

TABLE I. RESULTS FOR MMDP, MYOPIC AND GREEDY ALGORITHMS

Metrics	MMDP	myopic	greedy
#completed tasks	71%	65%	41%
#responders survived	100%	25%	0%

C. User interfaces

In their mission to rescue all the targets from the disaster space, a centrally located HQ and the planning agent support the responders on the ground. In what follows, we present the player interfaces and the interactions with the planning agent. A demo video can be viewed at <http://bit.ly/1ebNYty>.

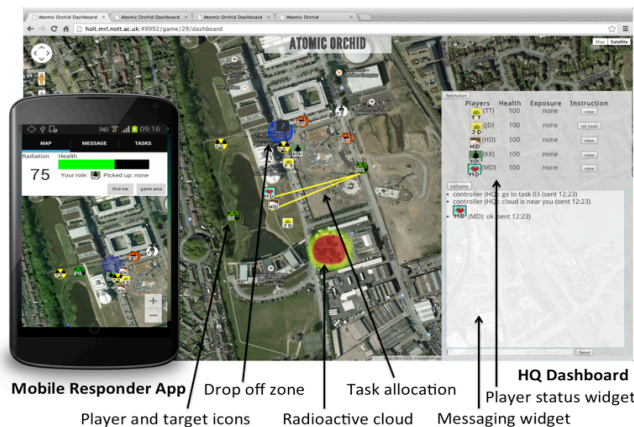


Figure 2. Team coordination interfaces.

First responders are equipped with a ‘mobile responder tool’ (Fig. 2) providing sensing and awareness capabilities in three tabs (Geiger counter, map, messaging and tasks). The

first tab shows a reading of radioactivity, player health level (based on exposure), and a GPS-enabled map of the game area to locate fellow responders, the targets to be rescued and their drop off zones. The second tab provides a broadcast interface to message fellow first responders and the HQ. The third tab shows the team and task allocation dynamically provided by the agent that can be accepted or rejected. Notifications are used to alert both to new messages and task allocations.

HQ controls the ‘HQ dashboard’ that provides an overview of the game area, including responders’ real-time locations (Fig. 2). The dashboard provides a broadcast messaging widget, and a player status widget so that the responders’ exposure and health levels can be monitored. HQ can further monitor the current team and task allocations to individual responders by the planning agent (by using buttons in the player status widget). Crucially, only HQ can ‘see’ the radioactive cloud, graphically depicted as a heatmap. The rationale was to entice frequent communication between field responders and HQ.

D. Integrating the planning agent

The planning agent takes the game status (i.e., positions of players, known status of the cloud, and messages received from players) as input and produces a plan for the current state. The agent is deployed on a separate server. The AtomicOrchid server requests a plan from the agent via a HTTP interface by transmitting the game status in JSON format. Polling (and thus re-planning) is triggered by two kinds of game events:

1) *Completion of task.* On successful rescue of a target, a new plan (i.e., allocation of tasks to each responder) is requested from the agent.

2) *Explicit reject.* On rejection of a task allocation by any of the first responders, a new plan is requested. More importantly, the rejected allocation is used as a constraint within the optimisation run by the planner agent. For example, if two responders (a medic and a soldier) were allocated a task and the soldier rejected it, the planning agent would return a new task allocation with the constraint that this soldier should not be allocated this task.

Once a plan is received from the agent, the AtomicOrchid game engine splits the plan for a given team into individual task allocations and sends these to each responder’s mobile app. The app displays the task allocation in a pop-up and details it in the task tab, including: i) the responder to team up with, ii) the allocated target (using target id), and iii) the approximate direction of the target (e.g., north, east).

E. Procedure

A total of 16 participants were recruited through posters and emails, and reimbursed with £15 for 1.5-2 hours of study. The majority were students of the local university. The procedure consisted of 30 minutes of game play, and about 1 hour in total of pre-game briefing, consent forms, a short training session, and a post-game group discussion.

At the end of the briefing, in which mission objectives and rules were outlined, responder roles were randomly assigned

to all participants (fire fighter, medic, transporter, soldier). The HQ was staffed by a colleague of the researchers in each session in order to mimic an experienced HQ whilst avoiding the same person running the HQ every time.

V. FINDINGS

This section presents episodes to reveal how teams accomplish the tasks in the rescue mission, particularly focusing on the social organisation of interaction with and around the agent instructions. In the following fragments, players can be uniquely identified by their initials. Targets are denoted by their unique numeric target id. Task assignments from the agent are represented as two initials and one target id connected by a rightward arrow. For example, the notation **PC, CR -> 22** means player PC and CR are instructed to team up and go for target 22. A standard orthographic notation [8] is complemented by timestamps [0:00], and **system messages** from remote players and HQ.

A. Episode A – task assignment

The following episode depicts a team of two dropping off a target and planning the next step.

[0:00] The team dropped off a target.
 PC: *I think we dropped off now. Ok.*
 [0:07] The team receives a new agent instruction: **PC, CR -> 22**
 PC: *I have a task now (3.0) ((studying screen)), I need to go with CR to 22. Are you CR?*
 CR: *Yes.*
 PC: *Let's go 22*
 CR: *We have done 22.*
 PC: *Oh (1.0), no (2.0) 22 is there ((pointing to direction of 22)), Let's go ((PC leads the way, they start walking to 22))*
 PC: *Right this way.*
 [0:28] The team finishes the task assigned by the agent.

At the beginning of this episode, the team (PC, CR) drops off a target at a drop off zone. Player PC vocalises that they have finished the task (PC: *I think we dropped off now. Ok.*). After about 7 seconds, PC says she received a new task allocation from the agent (PC: *I have a task now*). PC confirms the initials of the other player (CR), and suggests CR to join her to go for target 22. The action is consistent with the agent instruction (PC, CR -> 22), suggesting that PC has read through the instruction and decided to follow it. CR said that they have already finished target 22 (CR: *We have done 22*), which indicates he is confused about the current task allocation. PC resolves the confusion by pointing in the direction of 22 and repeating to go for it. Later, the team successfully drop off target 22 as instructed by the agent.

The episode shows how an agent instruction is brought up and followed by a team in relative straightforward manner. The instruction was delivered immediately after the drop off of a previous target (7 seconds after). PC successfully locates the new target in the instruction and leads the team to pick it up. Although CR is confused at first, PC manages to rectify CR's mistake and they finish the task successfully.

This episode is a typical case of *task assignment* to existing teams, i.e. the agent sent a new task to a team immediately after they finished their previous task. Out of a total of 51

agent instructions, 23 fall into this category. The rate of compliance is high for these cases of *task assignment* to existing teams (21 out of 23; 91%).

B. Episode B – team reformation

Unlike episode A, sometimes the agent instruction implies players need to disband and form new teams after finishing their previous task, in order to enact the computationally optimal plan. 10 out of 51 agent instructions fall into this category. The compliance rate of instructions that require reteaming (50%) is substantially lower than compliance of instructions where players can stay in the same teams (91%). The following episode depicts a typical case in which team reformation fails.

[0:00] After a target drop off, LT and SS joined PC and CR at drop off zone.
 [0:24] HQ sent **message A**: LT, if you think you have the stamina to run to 10 around the north of the lake do so now with a firefighter
 [0:28] Agent instruction received: **NK, LT -> 16**
 LT: *They said ((reads out aloud HQ message A))*
 [0:35] CR ((facing LT)): *Shall we go get 10*
 LT: *Mine is 16*
 [0:38] HQ sent **message B**: **Avoid 17 at all costs (...)** I'd avoid 10, too.
 CR: ((read out HQ message B)) *avoid 10 now.*
 [0:55] New agent instruction received: **NW, LT -> 15**
 LT: *15!*
 [Fig. 3] LT keeps walking and turning back and forth from others. PC and SS discuss next steps, LT does not engage in the discussion with them.
 [1:12] SS ((facing PC)): *Shall we go get 19? ((turning towards LC and CR)) are you going to 10 or something?*
 CR: *Eh::, HQ said no.* [referring to message B]
 [1:24] SS and PC decide to go for target 19, and leave.
 [1:29] NW sent message: **LT where you**
 CR ((facing LC)): *Are you LT?*
 LT: *Yes.*
 CR: *NW is looking for you.*
 LT: *Yah thanks. ((turning away from CR)) Ah::, I will go towards them. ((starts walking))*
 CR: *Okay. Do you want company?*
 LT: ((turning back towards CR)) *Yeah.*
 CR and LT leave drop off zone together to find NW.



Figure 3. Players from left to right: LT, SS, CR, PC. LT walking around the team, her body orientation suggesting attempts to leave the group.

The episode begins with a recommendation by HQ to LT to go for 10 (message A). The message is topicalised by LT, but it is soon overridden by an agent instruction (NK, LT -> 16). When CR proposes to team up with LT to go for target 10, LT declined (LT: *mine is 16*). HQ then withdraws its previous suggestion to go for 10 in message B. Shortly after; a new instruction (NW, LT-> 15) prompts LT to read out the target number (15), but she fails to raise the other players' attention. While other group members engaged in planning next steps, LT does not engage and keeps looking around. She can be seen turning and walking back and forth (Fig. 3). Perhaps LT is trying to locate the player NW who she had

been instructed to team up with. LT does not take any action until prompted by CR (CR: *are you LT? NW is looking for you*). Then, LT begins to walk to find her teammate. However, when she finally manages to meet up with NW two minutes later, NW has already been assigned another task.

On one hand, LT seems to feel obliged to follow the agent instructions. She turns down other teaming invitations and appears to try to look for NW in her immediate vicinity, indicating difficulty with locating teammates out of sight (despite the real-time location map). On the other hand, her body orientation displays a sense of attachment to the existing group. Her indecisive walking and turning back and forth suggests she struggles to leave. She does not leave the group to follow the instructions until prompted by someone. When CR points out NW's message, LT does not answer the message either. The episode illustrates a combination of interactional 'troubles' as a result of which the reteaming fails: being attached to the local group, struggling to locate teammates out of sight, and failing to reciprocate messages.

Further, we found the distance between instructed players to be a key factor in successful reteaming. That is to say, if instructed players are not within line of sight, the rate of non-compliance with the agent instruction is high. Take episode B as an example, player LT was instructed to team up with a distant player twice. Neither one of the instructions was successfully implemented. Overall, there were 17 agent instructions that implied teaming with distant players; only 1 of them were actually followed by players. Players explicitly rejected 11 of them by pressing the rejection button; the other 5 were not followed without an interface action.

C. Episode C – task interruption

In some other cases, the agent also sent new instructions to teams that had already commenced their task; that is, teams were interrupted by the new instructions. The following two episodes C and D describe how players handled task interruptions caused by the agent.

[00:00] HB, AW at drop-off zone, new instruction received: **AW, HB->44**
 HB: *Alright, who is AW?*
 AW: *Me.*
 HB: *let's go southeast (the direction of target 44).*
 [00:07] AW, HB looking at their screens
 [00:26] HB: *There is no 44.*
 AW: *down there*
 HB: *Ok, yea, yea, yea (0.5), I can't see, Oh, there, yea, let's go*
 [00:35] [Fig. 4] Team begins moving towards 44
 [00:48] HQ sent message: **Target 42 and 44 is not reachable.**
 AW: *((reads out the message))*
 AW and HB stopped walking.
 [00:52] New instructions received: **AW, KD -> 44, HB, AR->31**
 AW: *I got a new instruction.*
 [Fig. 5] AW and HB simultaneously turn and start walking back towards the drop off zone
 HB: *I need to team up with AR*
 AW: *I need to team up with KD! Oh, it is 44 again.*
 [01:01] AW, HB arrived at drop off zone, met AR, KD
 HB: *AR?*
 KD: *AW? We have got (1.0), 44, right?*
 AW: *It said 44 is not reachable, but I got it again, so, let's try.*
 KD: *Alright*
 [01:14] AW, KD begin walking to 44, AR, HB team up as well.



Figure 4. AW (right) leads the way, heading to target 44 as instructed.



Figure 5. After the team received an instruction to disband, AW (right) and HB (left) simultaneously turn back and start walking back to the drop off zone, displaying bodily alignment.

This episode begins with an instruction (*AW, HB -> 44*) from the agent. At that moment, there were 5 players at the drop off zone (AR, KD, LC, HB, AW). Immediately after the instruction, HB starts looking for AW in the local group. Shortly after, AR and HB team up to go for 44 as instructed. However, 13 seconds later the team is interrupted with a HQ message telling them not to go for 44 (*Target 42 and 44 is not reachable*). Four seconds later, a conflicting agent instruction was delivered, implying they disband the team (*AW, KD -> 44, HB, AR->31*) but still pursue the target 44. At first, AW stops walking and topicalises the instruction (*AW: I got a new instruction*), followed by both teammates simultaneously turning towards each other (Fig. 5). The bodily alignment in the action suggests agreement to follow the new instruction. On their way back to drop off zone, HB and AW confirm their intentions (HB: *I need to team up with AR*, AW: *I need to team up with KD!*). In this case, the teammates respond to the interruption by mutually agreeing to abandon the current team and task in favour of following the new assignment.

It should be noted that the interruption was received only 17 seconds after the team commenced the task, probably contributing to a low perceived cost of abandoning the current task. Further, all players involved in the subsequent reteaming were not far away from each other. AW and HB had not walked too far from the drop off zone; so everyone was still within line of sight, further facilitating successful reformation.

D. Episode D – disagreement on task interruption

[Following on from Episode C]
 AW, KD on their way to target 44.
 [01:39] New instruction received again, **AW, HB -> 44, AR, KD ->31**
 AW: *new instruction, HB and 44 again, haha.*
 AW turns back towards drop off zone immediately.
 KD: *AR and 31 ((Reading his new instruction)) ehh, have they gone? Because we can just decline and carry on.*
 AW: *Ok, I rejected it.*
 AW turns back towards KD, who also rejects the new instruction. They resume their walk to 44.
 [01:54] New instruction delivered to AW (**AW, YF ->46**)
 AW: *new instruction 46, yeah! ((team stop walking))*
 KD: *Do they know we are already on the task?*
 [02:00] New instruction delivered to AW (**AW, LC ->37**)
 AW: *yea, but I think, Oh, no, got new instruction again, (team up with) LC.*
 [02:13] AW starts walking to LC, who is at drop off zone within line of sight, leaving behind KD.
 KD: *((reads out HQ message)) AW and KD you won't reach 44. Alright, Let's go to 46.*

[Continued on next page]

AW ((turning back towards KD)): I don't know, I got a new task with LC.
KD: Ahh, I do not have a task.
AW turns and walks towards LC again. KD follows.

In this fragment, we can observe disagreement and negotiation of team reformation. Following episode C, player AW disbands his team with HB and teams up with KD. However, 20 seconds after the reformation, AW is instructed to abandon the on-going task again. AW laughs, but turns back to find player HB again. Before AW sets off, KD disagrees with the new instruction and proposes to reject it (*Ehh, have they gone? Because we can just decline and carry on*). AW accepts KD's suggestion and turns back to KD.

After the rejection, AW receives 2 consecutive reteaming instructions from the agent, finally teaming them up with LC, while KD does not receive another instruction. KD's question (*Do they know we are already on the task?*) suggests that he might think the agent is unaware of their situation, and that he disagrees with disbanding the existing team. In spite of KD's disagreement, AW declares his intention to follow the new instruction (*got new instruction again, [team up with] LC*) and he turns to find LC. However, KD ignores this (KD: *Alright, Let's go to 46*), indicating he does not agree with AW's intention to disband the team. AW interjects (*I don't know, I got a new task with LC*), and continues to walk towards LC, denying KD. As KD realizes he is without assignment (*Ah, I do not have a task*), he follows AW to find LC.

In this episode, teammates agree to reject the first task assignments. We found task interruption could be a major reason to reject new instructions. 10 out of 11 rejected instructions are associated with task interruption. In an extreme case (not pictured), one team reached an agreement to ignore any agent instructions after the agent tried to interrupt the team's on-going task.

In the end, the player that received the new instruction disagrees with his teammate's suggestion to ignore the instruction and decides to leave the current team. The team is disbanded in disagreement, in contrast to episode C where both teammates agree to leave the team after both received new instructions at the same time. Here, the teammates spend a fair amount of time arguing whether to follow or ignore instructions, hinting at the hidden social cost of 'coalition formation' algorithms when applied to human teams.

Overall, the majority of new instructions that interrupted on-going tasks required team reformation. When tasks were interrupted, the rate of compliance (22%) is substantially lower than when teams were required to reform after a task was completed (50%). Task interruptions were also much more likely to lead to rejection of the new assignment. 10 out of 11 assignments that interrupted tasks were rejected.

E. The headquarters

HQ sent a total of 147 messages in the two sessions. We identified 50 assertives and 68 directives in two sessions through speech act analysis. The majority of assertives were focused on providing situational awareness and safe routing

the responders to avoid exposing them to radiation. E.g. "NK and JL approach drop off 6 by navigating via 10 and 09." Or "Radiation cloud is at the east of the National College".

16 out of 68 directives were directly related to task allocations and teaming, which is substantially less than the number of agent instructions (51). Among the 16 directives, HQ sent 11 direct instructions to the field players (e.g. "SS and LT retrieve 09"), while the remaining 5 are related to forward planning, (e.g., "DP and SS, as soon as you can head to 20 before the radiation cloud gets there first"). 6 of the HQ instructions are consistent with agent instruction, while 5 other HQ instructions override the agent instructions. It is worth mentioning that field players implemented only 5 out of 16 HQ instructions. In the interview, HQ reported that they felt they supported the agent rather than take control.

VI. DISCUSSION

In the previous sections, we described how the agent guidance is interleaved with the social interaction, in which teammates organise the task planning and execution. We found that while the agent supported division of labour, the agent guidance had various social implications. We now reflect on (A) how division of labour is achieved; (B) the social implications and hidden cost incurred by team reformation and task interruption; and (C) the limited feedback mechanism.

A. Division of labour between the agent and the human teams

Overall, players followed 30 out of 51 agent instructions, out of which 21 tasks were completed according to the instruction (success rate of 70%). Only 2 targets were evacuated without agent instruction, which indicates that, to a large extent, the agent successfully supported routine task planning activities. Episode A demonstrates a typical case of division of labour: the agent handles planning of teaming and task assignment, freeing the team to focus on navigational issues (identifying the target on the interactive map and finding directions). The following of agent instructions speaks of players' trust in the agent's decisions. In the 30 cases where instructions were followed, we can observe similar patterns of labour division.

The distribution of HQ messages may also indicate a division of labour between HQ and the agent. Only a small proportion (16 out of 147) is directly related to task assignment, indicating routine task allocations were delegated to the agent. A relatively large proportion (118 out of 147) of messages are used to provide situational awareness and safety routing the responders to avoid radiation exposure. However, the fact that only 5 (out of 16) HQ instructions are implemented suggests that HQ was unable to effectively override the agent when they wanted to. This fact highlights that the planning agent plays a strong role in the 'control loop', compared to the human coordinators in the HQ. The planning agent can directly instruct field responders without consent of the HQ, and the HQ does not have an effective way of overriding the agent's decision. This has implications for interaction design that are discussed in the next section.

B. Hidden costs of team reformation and task interruption

While team compliance rate with agent instructions was high when no reteaming was required (91%), we found that the rate of compliance with agent instructions is much lower when team reformation is involved (50%), and even lower when in addition an on-going task is interrupted (22%) (see Table 2). Our interaction analysis shows the ways in which team reformation and task interruption are associated with ‘hidden costs’ in the social organisation of team performance.

TABLE II. COMPLIANCE WITH AGENT INSTRUCTIONS BY CONTEXT

Context	#instructions	followed	compliance
Existing team (see V.A)	23	21	91%
Team reformation (V.B)	10	5	50%
Task interruption (V.C,D)	18	4	22%
Total	51	30	59%

Firstly, we found that team disbanding can be difficult. Players have to make their actions accountable to gracefully disengage from an existing team to avoid breaching social norms (e.g., politeness). Members have displayed a sense of attachment to a local group (section V.B), which delayed the task substantially until the team reformation failed. Despite interrupting an on-going task, new instructions for both teammates can facilitate smooth, mutually agreed disbanding (V.C), while instructions for only one member have coincided with interactional ‘trouble’, disagreement and delays (V.D).

Secondly, the impact of attachment between co-located teammates was further amplified by distance between proposed teammates. While they frequently accounted for actions with co-located players, they did not make their actions equally accountable to remote team members. For example in episode D, the agent interrupted the local team’s task and instructed them to team up with distant players. The co-located team decided to reject the instruction without contacting the potential teammates they rejected. The system lacked support of accountability between remote members.

A further observation is that players were unwilling to give up on-going tasks after a certain time. In episode D, the teammates first agree to ignore new instructions. This preference to stick with on-going tasks may also explain the high rejection rate for instructions involving task interruptions.

The social organisation of coordination reveals implications for the simplistic model of interaction held by the agent. The agent’s ‘coalition formation’ re-plans and reshuffles teams, in order to optimise group performance by minimising the travel distance to the targets. However, our study has revealed the ways in which social norms and the accountability of social conduct ‘get in the way’. This raises questions of the effectiveness of approaches that treat ‘coalition formation’ of humans as unproblematic. The agent does not consider the social cost of team reformation and task interruption. Our field study has shown that the social process to disengage from groups and on-going tasks can be costly. The tension between the social process and the model held by the agent echoes the notion of “workflow from within and

without” [1]. The authors point out that models imposed by technology (from without) may come into tension with the actual workflow achieved through methods internal to the work (from within).

C. Feedback to the agent

To recap, a feedback mechanism is included in the interaction design to give responders some control over the task assignment. On receiving an instruction, players can either accept or reject instructions. On rejection of a task allocation, a new plan is requested. The rejected allocation is, in turn, used as a constraint within the optimisation run by the planner agent, which means the rejected target will not be assigned to the rejecting player for a while (1 minute).

Our observations show there may be a significant cost associated with “rejection”. Overall, 6 out of 25 re-plans were triggered by rejections. In turn, tasks were re-assigned to all players. Frequent new instructions may cause extra coordination overhead (time spent on interpreting new instructions, more team reformation and task interruptions, and over-constrain the planning). Players did not seem to be aware of the implications that their rejections had on others.

We also found that players’ expectations of the rejection were not always aligned with its actual effect. Instructions involving reformation and interruption are more likely to be rejected. Player’s statements indicate they perceive the rejection as a way to reverse to previous states (see episode D). Other statements indicate rejections were expected to pair them with a new teammate instead of a new target. The mismatch between expected and actual effect highlights the lack of intelligibility in the current interaction design. We aimed at simplicity (by providing only accept/reject options), which might be important for interaction in time-critical task settings, but it comes at the cost of intelligibility. Therefore, we argue that intelligibility and simplicity need to be carefully balanced according to details of the setting.

VII. IMPLICATIONS FOR INTERACTION DESIGN

Our observations reveal the tension between agent planning support and the social organisation of teamwork. The tension does not simply mean the model held by the agent is “incorrect”; it highlights potential trade-offs we need to consider in system design [1]. Providing a detailed design solution is beyond the scope of this paper. Instead, we propose three design implications to scaffold the division of labour when building agent-based planning support for human teams.

1) *Achieve ‘common ground’*: two main issues arose that challenged this ‘basis for collaboration’ [2,19]. Firstly, a notion of the ‘social cost’ associated with instructing teams should be taken into account when designing planning agents. For example, disbanding teams can be difficult and time-consuming as it is governed by rules of social conduct and etiquette, particularly where the new teammates are out of sight or only one of the teammates received a new instruction. Secondly, a mismatch between the expected and actual function of rejections further shows intelligibility needs to be

improved. Therefore, we suggest the design of agent support that a) takes social factors into consideration (e.g., ensuring team disbanding is facilitated by reteaming both teammates at the same time; avoiding task interruptions etc.), and that b) agent functionality is appropriately surfaced to help achieve common ground (e.g., by providing explanations of agent action at the interface level).

2) *Facilitate accountability*: while the rules of social conduct ensured accountability of action among co-located teammates, we found the impact of rejections on remote players was not properly appreciated; nor did the interaction design support making these rejections accountable. Therefore, we believe the interaction design shall reveal the hidden cost of certain actions (e.g., rejections) to facilitate making local decisions accountable to remote team members, ensuring consequences of local decisions for the welfare of all teams are understood.

3) *Balance responsibilities between humans and agent*: The social implications and other situational contingencies are likely difficult to be modelled computationally. Alternative approaches argue for mixed-initiative control and flexible autonomy between humans and agents [2]. The ways in which the HQ used messages to provide situational information that complemented the agent instructions show that humans are readily able to deal with arising situational contingencies. The

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division of labour between humans and the agent appeared most effective in that the agent took on routine and repetitive jobs (task assignment), which freed the responders to focus on the situated rescue mission. In our interactional arrangement, the role of the human HQ was relatively weak. For example, the HQ struggled to overwrite the agent's instructions through the messaging channel. In the future, we seek to allow the HQ to play a stronger role in the control loop to enable more direct mediation and amendment of agent instructions (e.g., by directly modifying the task assignments, or by adding information relating to the assignments, such as safe routing).

VIII. CONCLUSIONS

In this paper, we examined how the guidance from a planning agent is handled socially in a team setting. To support our field trial we developed a mixed-reality game, which is used to create a time critical task setting. Our observations indicate how HQ and field responders coordinate agent instructions, revealing significant costs associated with instructions that require members to reform new teams, and that interrupt on-going tasks. Based on the findings, we presented three design implications to consider when creating agent-based planning support systems for human teams.

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