Supporting Situation Awareness in Collaborative Tabletop Systems with Automation

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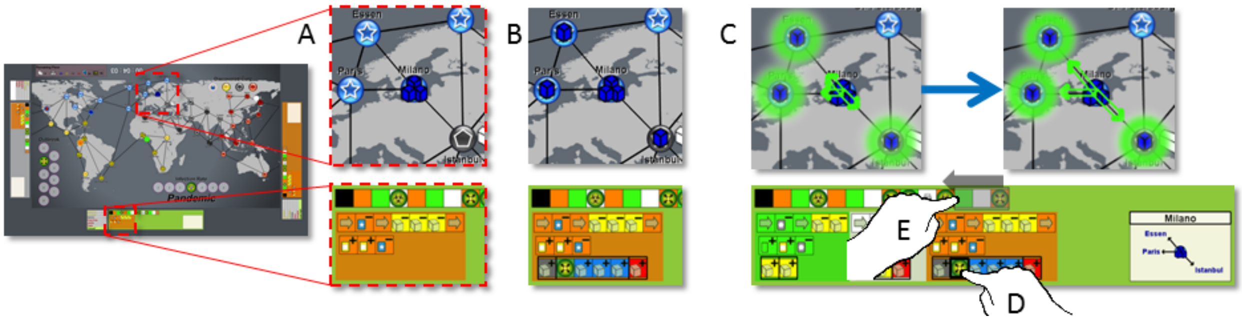

Figure 1: Interactive event timelines. A) Cut-out of the initial state of the data (top) and the timeline (bottom). B) Automated system changes appear (top) and are reflected in the timeline (bottom). C) & D) Touching the timeline invokes a replay of the changes (top, left to right) and details at the right of the specific event. E) A slider can be used to navigate through all past events (bottom).

ABSTRACT
Human operators collaborating to complete complex tasks, such as a team of emergency response operators, need to maintain a high level of situation awareness to appropriately and quickly respond to critical changes. Even though automation can help manage complex tasks and rapidly update information, it may create confusion that negatively impacts operators' situation awareness, and result in sub-optimal decisions. To improve situation awareness in co-located environments on digital tabletop computers, we developed an interactive event timeline that enables exploration of historical system events, using a collaborative digital board game as a case study. We conducted a user study to examine two factors, placement of timelines for multiple users and location of awareness feedback, to understand their impact on situation awareness. The study revealed that interaction with the timeline was correlated with improved situation awareness, and that displaying feedback both on the game board and timeline was the most preferred.

Author Keywords
Digital tabletop; gaming; automation; situation awareness; interaction design; collaboration

ACM Classification Keywords
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INTRODUCTION
There is growing interest in using digital tabletops to support co-located group activities that involve complex, often dynamically changing data. Tabletop interfaces have been proposed for crisis and disaster management [7,29], military simulation [2], and military and commercial maritime operations [6,36]. In these complex domains, decision-makers need to maintain a high level of awareness of changing system data to respond quickly, with appropriate strategies. However, when changes occur in these environments, human operators may become confused by the system state, leaving them "out-of-the-loop" [9] and unable to respond appropriately when necessary. As digital tabletop applications begin to leverage automation to manage complex data inherent to many real-world application domains, keeping users "in-the-loop" will become essential.

To address automatic changes and provide awareness of the current system state, we explored using interactive event timelines (Figure 1) to enable interactive exploration of system event history. We used a popular collaborative tabletop board game, *Pandemic*[1] (Figure 2, left), as a case

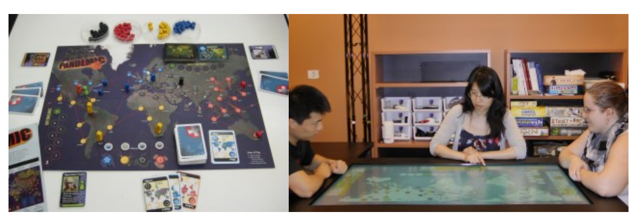

Figure 2: (Left) The physical Pandemic board game; and (Right) The digital Pandemic board game.

[1] Pandemic was published by Z-Man Games, used with permission. We implemented the digital tabletop game.

study to rapidly prototype design concepts, and to enable lab-based studies with a complex task for which "experts" could be easily recruited. Moreover, Pandemic has been shown to elicit the out-of-the-loop automation problem [42].

In this paper, we describe our interactive event timeline design, and a laboratory-based study to investigate design factors we hypothesized would impact the amount of timeline interaction and, consequently, impact participants' situation awareness. These two factors were timeline placement (i.e. one shared timeline per group or replicated timelines per individual) and feedback location (i.e. display feedback next to the timeline, in the shared area, or both locations). The study revealed that at the individual level, more interaction with the timeline correlated with higher situation awareness, and that individual replicated controls led to more interaction than shared controls. At the group level, aggregate situation awareness measures taken were consistently high across groups, despite more interaction by the "driver" when timelines were shared. This consistently high group situation awareness also suggests the success of our interactive timeline design.

We first present the related work, and discuss challenges in designing for digital tabletop systems with automation. We then present our conceptual design and our design factors, timeline placement and feedback location. Next, we introduce the Pandemic game case study and the design of the interactive timeline. We then present the study method and results. Finally, we discuss the implications of our findings.

RELATED WORK

There has been substantial research done in awareness [23], and our work specifically aims to improve the users' *situation awareness* and *workspace awareness* in a collaborative system with automation. Our work also relates to the specific area of *automation on digital tabletops*. This section provides an overview of and situates our work within the literature in these three areas.

Situation Awareness

Situation awareness describes operators' awareness of the environment, and has been applied to many domains, including air traffic control [38] and nuclear plant operation [3]. Endsley [12] defined situation awareness as the perception of changes in the system state (level 1), the comprehension of changes (level 2), and the prediction of future states (level 3). The second level of situation awareness requires the operators to connect multiple pieces of knowledge (level 1) to infer their meaning and form an understanding of the perceived changes, and the third level describes the ability to predict the future state of the system.

This automation literature has widely identified the phenomenon of *change blindness* as a key cause of deficient situation awareness in automated systems [8]. Change blindness refers to a person's inability to recognize changes in the environment after interruption or deviation in attention [32]. This phenomenon can be mitigated by the use of animation to guide users' attention to changes [4] and to help understand these changes [1]. However, users in collaborative tabletop systems may miss the animation completely due to interruption from a collaborator or the large size of the tabletop display.

The interruption recovery literature has explored the use of persistent, interactive information displays to mitigate change blindness and to rapidly improve situation awareness following an interruption. Interactive visual representations of historical event data have been found to help mitigate change blindness after interruptions, for example, using interactive event logs in tabular format [37] and interactive graphical event timelines [34].

Sasangohar et al. [34] found that interactive event timelines that allowed operators to highlight historical events on the main task display (a map) via event bookmarks displayed on a graphical timeline reduced recovery time and improved decision accuracy after interruptions. They argued that the interactive event timelines provided a "simplified representation of important events [that] facilitated the quick encoding of perceptual information and minimized the visual search" (p. 1155). On a large digital tabletop interface, promoting situation awareness while minimizing visual searches across the entire interface would be ideal. Thus, our work applies this interactive event timeline concept to digital tabletops with automation.

Workspace Awareness

Extensive research has shown the collaborative value and the information richness provided by the objects, people, and environment in co-located collaborative settings [17,19,31]. While situation awareness focuses on a person's knowledge of a system or environment state, the concept of workspace awareness describes a person's knowledge of their collaborators and their actions within a shared (physical or virtual) workspace [31].

In distributed settings, workspace awareness has been supported through techniques such as virtual embodiment (telepointers, virtual arms, avatars) [14,26,40]. Although a significant amount of workspace awareness information can be gained "for free" in a co-located tabletop setting, explicitly indicating others' actions in the shared workspace can also be beneficial, especially during complex tasks. For example, the Cambiera [20] collaborative document analysis system explicitly indicates when a teammate performs similar searches or opens the same documents.

The Cambiera design supports feedthrough, which refers to the information gathered from observing artifacts in the shared workspace [31]. With automation, the feedback for collaborators' actions can happen in an instant, and can prevent users from observing the changes. Our interactive event timelines were also designed to support feedthrough to facilitate workspace awareness.

Automation on Digital Tabletop Systems

There has been substantial tabletop research on interaction techniques for digital object manipulation, menu invocation, information sharing, and tangible interaction (e.g., [22,39,41,43]). In the collaborative tabletop space, significant work has been done on information visualization, coordination and collaboration styles, and the use of control widgets (e.g., [20,21,27]).As more sophisticated tabletop applications are developed for complex domains [2,6,7], situation awareness for automation becomes increasingly important. Yet, little previous work has studied dynamically changing data with historic events. Existing tabletop systems that incorporate dynamic data in a tabletop application provide little to no provision for viewing historical system data and focus on novel interfaces for sharing or collaborating with the current, real-time view of the system state [2,5,25,35].

DESIGNING TABLETOP SYSTEMS WITH AUTOMATION

Automation in traditional manufacturing settings refers to reducing manual workload with machines, or changing physical materials from one state to another [30]. Nowadays, automation is also used to reduce mental workload, and may involve the changing state of virtual objects. For example, a computer can sort an inventory list and present it in different views to support different task goals. Computer applications with automation can reduce mundane work and improve efficiency by delegating work based on the respective strengths of computers and humans. However, as described above, automation can negatively impact situation awareness, often due to change blindness or state changes not even being displayed to the human operator.

As illustrated in Figure 3A and Figure 3B, collaborators at a digital table can be unaware of a change occurring in the system interface due to a variety of distractions inherent to this environment, including other people or changes occurring across the large display. Moreover, even when a change occurs within a person's field of view they may still miss the change due to limited attentional capacity.

Conceptual Design

To address these issues introduced by the use of automation in a digital tabletop system, we explored the use of interactive event timelines, which provide persistent information about historical system events and fit into a person's field of view, despite the large size of the table. To update their awareness of the current system state, a person can examine and explore the timeline, which provides a high level overview of the system state (Figure 3C). To get more in-depth information, they can invoke further feedback on the shared display and their personal area (Figure 3D). We considered two key design factors in the design of these timelines:

Control Placement. With multiple people at the digital table, there are many choices about who and how the timeline can be controlled. Morris et al. [27] examined individual replicated versus shared centralized controls in a collaborative photo tagging application on digital tabletops. They found that while individual controls were more preferable, shared controls resulted in a higher level of collaboration. The event timeline is a control for invoking feedback, but is also a visualization of historical events. Thus, it was unclear how shared versus individual timelines would impact collaboration and situation awareness. Providing replicated timelines would ensure each person could view and manipulate the timeline. On the other hand, a shared timeline may contribute to improved collective situation awareness.

Feedback Location. When interacting with the timeline, detailed information about the events being explored can be displayed locally (on the timeline) or in the shared space. These alternatives may better facilitate either individual control or group function, respectively [15]. Displaying feedback on the timeline provides a consistent location to look for the information, and it fits into a person's field of view. Feedback in the shared space provides more contextual information to the individual and is also visible to the group. The latter approach may better facilitate feedthrough by using animation in the shared space to help individuals stay aware of group activities [31]. However, the size of the display may still necessitate searching for the feedback, and it may also distract others.

We investigated the impact of interactive event timelines, and of these two design factors, through a case study on improving situation awareness in a cooperative board game.

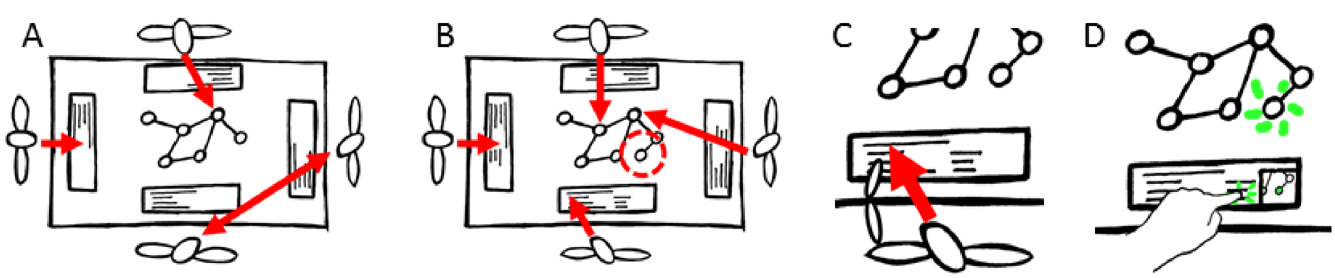

Figure 3: Problem of automation and conceptual design of the interactive event timeline. A) Some users are paying attention to each other and some to the tabletop display. Red arrows represent attention directed to. B) Data in the center changed and users are searching for the change. C) User explores the event timeline and D) interacts with the event timeline to locate changes.

CASE STUDY: TIMELINE DESIGN FOR PANDEMIC

We chose to situate our investigations in the context of the cooperative board game, *Pandemic*, for several reasons. Games allow for a more rapid, human-centred prototyping process, since it is easy to recruit subject matter experts of popular games and we can easily manipulate parameters, such as degree of difficulty. Previous work has shown that digital versions of the Pandemic game can elicit situation awareness deficiencies due to automation [42].Pandemic requires 3 to 4 players to engage in intense discussion on strategies and resource management (Figure 2, left). Players work as a team to save the world from epidemics and outbreaks of diseases. Players win by curing all the diseases, and lose if they run out of time (not having enough cards to draw from) or if the game state is out of control (too many outbreaks or diseases). Every turn, players carry out their strategies to manage the disease spread while making progress on cures. Then, players act as the game board (opponent) and draw cards to spread diseases.

Special events, called epidemics, happen repeatedly at random intervals to make the game more challenging. Outbreaks of diseases may also happen if the game state is out of control. It is important for players to stay aware of these critical events so they can effectively strategize.

Our custom-built digital tabletop version of Pandemic (Figure 2, right) provides automation to reduce manual workload and enforce rules. For example, the game automates opponent (the game board) actions by placing disease cubes based on cards drawn and resolving epidemic events. This involves several steps of drawing cards, shuffling a deck of cards, and placing disease cubes.

Interactive Event Timeline

We designed the interactive event timeline (Figure 4) to improve player awareness of the game's automated actions, and based our design on task analysis for experienced to expert players. It allows players to explore previous game events, including both player and computer actions. The timeline fits into a player's personal workspace and persists on the game board for players to interact with at any time.

The timeline consists of two main components: an *overview* (Figure 4C) and a *detail* view (Figure 4G). The overview provides a high level view of the game progression, and the detail view provides information for all the game actions that occurred during the selected turns.

The overview shows each player's turn in chronological order, colour-coded by the in-game player colour (orange, yellow, and white). Symbols on the overview denote special events (epidemic and outbreak) that happened during the particular turns. Players can drag the viewport (Figure 4F) or tap on a given player turn on the overview to navigate through the game history and reveal details of the turn of interest in the detail view. Dragging the viewport on the overview updates the detail view in real-time (Figure 1E).

The detail view contains the player turns currently selected (Figure 4G). Each turn consists of three rows corresponding

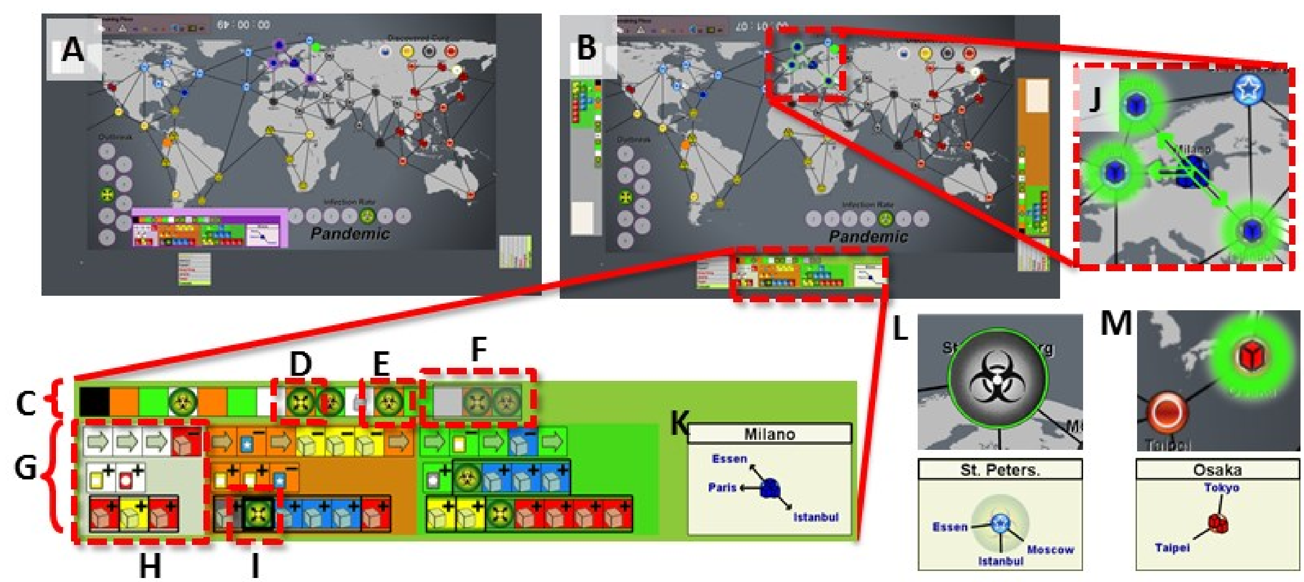

Figure 4: The interactive event timeline design. A) Shared timeline with both feedback locations. B) Individual timeline with both feedback locations. C) Overview showing the players' turns so far with symbols denoting important game events, such as D) outbreak and E) epidemic. F) Viewport for navigating through the game history. G) Detail view showing game events from the selected turns. H) A player's turn in the game, consisting of three rows. A row represents one phase in a player's turn, and an event block represents an action carried out by either the player or the game, black bounding boxes showing related game events (symbols denoting the type of the event e.g., arrow for moving to different cities, bottle for discovering a cure, and +/- for adding or removing game pieces). I) Selected event will have a black bounding box and J) animation in the center and K) information near timeline will be shown. Different events have different feedback, J) and K) for an outbreak event, L) for an epidemic event, and M) for an infection event (plus cube symbol on timeline).

to the three phases in the game (Figure 4H). The first row represents player actions. The second and third rows represent two types of automated actions: cards drawn for players and cities infected. Each block represents one game event (Figure 4I) with a symbol denoting the type of event. Related blocks are grouped by a black bounding box. The colour of each block is derived from the colour coding scheme used in the Pandemic board game. The timeline provides a compact summary for game events. The game event blocks are also interactive. When a game event block is selected, additional information is displayed on the shared game board and/or next to the timeline.

We designed these timelines to study our research question of interest: how do the placement of the timeline control (individual or shared) and the location of the feedback it provides (on the game board or next to the timeline) affect each player's, and the group's, situation awareness?

STUDY

We conducted a laboratory-based study to examine the feedback location and control placement factors. Participants played different implementations of the Pandemic game and answered questions on their knowledge of the board game state to test their situation awareness.

Participants

Participants were recruited from the local community, specifically targeting experienced Pandemic players. Players had to sign up in groups of three. Thirty-six paid participants (23 male, 13 female, ages 22 to 36) were recruited, with all team members having previous experience playing Pandemic prior to the study. The gender ratio likely reflected the population of local Pandemic players.

Design

We used a 2 control placement (between) × 3 feedback location (within) mixed design. The order of the three feedback locations (next-to-timeline, on-board, and both) was counterbalanced, with half using a single shared control and half using replicated individual controls.

Equipment & Setting

Each group of participants was seated in the lab around a 95 × 148 cm (3840 × 2160 pixel) digital table with an embedded PQ Labs frame to detect touches. Two participants sat at the short edge, and one participant at the long edge, to avoid the situation of one participant seeing the game board upside down (Figure 2, right). The computer was running 64-bit Windows 7 using on Intel® Xeon® CPU E5-1603 @ 2.80 GHz with 4 GB of RAM. Two digital camcorders were placed at different angles to capture the game sessions.

Questionnaires

We measured the players' situation awareness, gaming experience, workload, and general preference in each condition. There were two types of questionnaires. The first was a gameplay questionnaire, which consisted of PENS [33] for player experience, NASA-TLX [16] for workload, and questions on their awareness and teamwork.

The second was a situation awareness (SA) questionnaire. To develop SA questions, we followed the steps outlined in the SAGAT methodology [10,13] by first defining the goal of the game (i.e., win by discovering four cures). Then we identified the sub-goals (e.g., keep diseases under control to allow time for collecting cards) and decisions to be made to achieve them (e.g., determining the top priority cities to treat next turn). Knowledge needed to make these decisions was then defined (e.g., disease distribution and infections coming up). We created an initial set of 22 SA questions.

Three researchers then independently classified the SA questions into three levels of situation awareness (SA1–SA3) as defined by Endsley [11]. The three raters agreed on thirteen questions (inter-rater reliability (Fleiss' Kappa) = .54, $p<.001$), and the remaining questions were discussed to determine their classification and iterated until consensus was reached. Through this process, additional three questions were derived, and we have a total of 25 questions (13 SA1, 7 SA2, and 5 SA3). Because 6 unique questions were required for each SA level (3 sets of 2 questions per SA level), two researchers devised one final SA3 question. Questions were in the form: "name one city/colour/player that…", or "estimate the number of turns away from…". For example, "Name one city that was just infected last turn." (SA1), "Name one set of cities (if any) that may create a chained outbreak." (SA2), and "Which colour is at the top priority for the current game state?" (SA3).

We conducted four pilot studies. The pilot participants confirmed that the questionnaires required intense thinking but that the questions were clear.

Procedure

The study sessions lasted approximately 2.5 to 3 hours. Participants first completed consent forms and background questionnaires. There were three parts to the study: training, Pandemic challenges, and a playthrough of a full game.

Training

After the researcher explained the interface, participants played with no timeline for 10 minutes and completed the gameplay questionnaire. Then, with the same procedure, participants practiced on the same version they would see in the first condition given in the Pandemic challenge phase.

Pandemic Challenges

For each condition, participants started in the middle of a Pandemic game and played for 2 rounds (2 turns for each player). We constructed 3 initial game states (scenarios) from real gameplay with some controlled parameters, such as the number of critical events that happened and the number of cures discovered. The order of the initial game states was randomly chosen.

Players individually completed post-condition questionnaires, which consisted of both the gameplay and the situation awareness (SA) questionnaires. The order of the three SA questionnaires (discussed above) was randomly selected. The same set of initial game states and SA questions were used across all groups. Participants completed a preference questionnaire at the end of this phase.

Full Game

In this final phase, participants played a full game with a configurable version, in which players could freely open up to three timelines that could be moved anywhere on the tabletop. They could minimize and reopen these timelines at any time. Each timeline allowed players to indicate where the feedback generated by that specific timeline was displayed (next-to-timeline, on-board, or both) via toggle widgets at the top of the timeline. All groups had the same game setup. Participants completed the gameplay questionnaire with a free form area for comments after playing.

Finally, the researcher debriefed the participants with the goal and details of the study, and conducted an unstructured interview to receive any additional feedback.

Data Collection & Analysis

During gameplay, we collected various data, including video recordings from two different angles, screen recordings, computer logs, audio recordings, and questionnaires. From the computer logs, we extracted player interactions with timelines. Two types of touch events were captured: *navigation*, when participants explored different turns by dragging the viewport or tapping the overview (Figure 4C), and *invocation of detail*, when participants tapped or brushed game cubes in the detail view (Figure 4G). The situation awareness questionnaire results were scored as optimal (1), sub-optimal (0.5), and incorrect (0) for each question.

Following the experiment, one SA question was reclassified from SA2 to SA3, since participants uniformly interpreted the question differently than intended. Specifically, participants were asked to name the colour that requires the most attention now, which we intended to be the colour with the fewest remaining cubes, (i.e., comprehension of changes, SA2), but participants interpreted this as the colour that would likely be depleted in the upcoming few turns (i.e., forecasting, SA3). Two other questions were also dropped completely due to potential misinterpretation. One question asked players to estimate the number of turns until the next epidemic game event, but none of the participants received the "optimal" score and 32 players (88.9%) were incorrect. This likely occurred due to observed distrust of the automation: comments during the study and on questionnaires indicated a belief that the computer was intentionally making the game more difficult when shuffling and triggering epidemic game events, resulting in an unrealistically pessimistic outlook of the situation. The second dropped question contained an error, which referred to the wrong game phase, and it was unclear how the participants may have interpreted it. The questionnaire in our final analysis nonetheless had an even spread of questions across SA levels (6 in SA1, 5 in SA2, and 5 in SA3).

We analyzed the situation awareness questionnaires using a 2 (control placement) × 3 (feedback location) repeated measures analysis of variance (RM-ANOVA). Since the SA score is computed by the average of each questionnaire, this measure is interval data, which is most appropriately analyzed by a parametric test, such as ANOVA [28]. An intraclass correlation analysis showed that situation awareness scores of the participants in the same group correlate ($ICC_{2,3}$=.66, p=.02), so we have included group as a covariate when the data is analyzed at the individual participant level. A first-order partial correlation controlling for group effects was used to test the relationship between situation awareness scores and interaction count. When relevant, scenario order and SA questionnaire order were included as between-participants covariates to mitigate order effects.

RESULTS

Our analysis revealed that participants used the timeline to understand the automation results and, in general, found the timeline beneficial. In terms of control placement, we found that the amount of player interaction with the timeline positively correlated with situation awareness score. In terms of feedback location, players preferred when feedback was in both places. Groups did well overall and there was no difference in cross-group situation awareness scores (all high). We detail these results for the *purpose of interaction*, *control placement*, *feedback location*, and *group interaction*.

Purpose of Interaction

Players interacted with the timeline to discover the results of automation and to review other players' actions. Figure 5 shows traces of interaction for all participant trials with *individual* controls and feedback in *both* locations. Most interaction occurred at the bottom-left corner, where the latest automation results were displayed (since the timeline auto-scrolls to the new turn). This shows that players frequently used the timeline to understand automated computer actions, as confirmed by the comment, *"I mainly used*

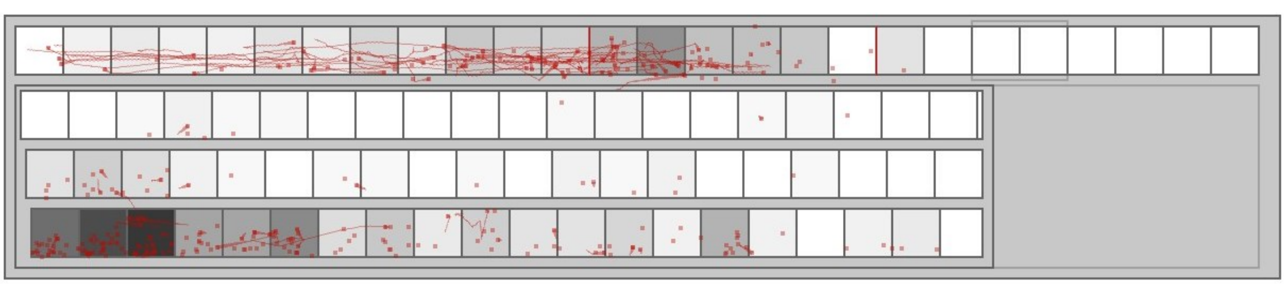

Figure 5: Aggregate traces of player interaction (points=touch down, lines=touch move) for individual control placement and feedback on both. Cells (game event cubes) are shaded by interaction count (darker = higher).

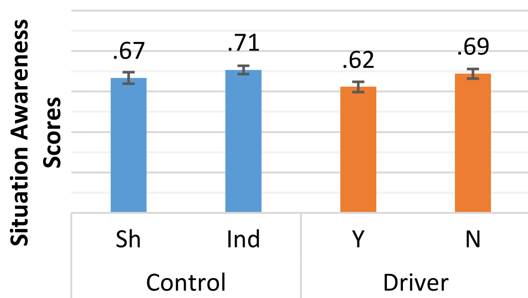

Figure 6: Mean situation awareness scores for shared and individual controls (left) and drivers vs. non-drivers in the shared condition (right).

the game log to identify the individual cities that were infected when I missed the on-board animations" (P35).

Overall, players found the timeline beneficial for reviewing previous turns and strategy formation, as evidenced by the comments, *"It was really fun to move it and show people what I was talking about while feeling like I was in the Matrix." (P25)*, and *"It allowed us to look back at the previous moves to determine the best move." (P26).*

Control Placement

We examined the differences across control placement to see its impact on situation awareness.

Situation Awareness and Interaction Count

The RM-ANOVA on the awareness score revealed a main effect of control placement ($F_{1,28} = 4.7$, $p = .04$, Figure 6, left). On average, players with *shared* controls had lower situation awareness scores than players with *individual* controls. This result suggests that players with individual timelines have better situation awareness. The RM-ANOVA on timeline interaction also revealed a significant main effect of control placement ($F_{1,10} = 6.2$, $p = .03$, Figure 7, left), where participants with *shared* controls used the timeline significantly less, suggesting that individual timelines encouraged greater interaction.

A partial correlation analysis on timeline interaction and SA score (control for group) revealed a positive correlation ($r_{105} = .20$, $p = .04$). This result matched our expectation that more interaction with the timeline would lead to higher situation awareness. This result also confirms that the timeline may be beneficial for improving situation awareness.

Feedback Location

The RM-ANOVAs on awareness score and interaction count revealed no significant main effects or interactions involving feedback location. However, we observed differences in participants' usage and reported preferences.

When feedback was located *next-to-timeline*, it allowed close proximity between their fingers and the feedback, which provided quick and easy navigation across multiple game events (commented by six players). This was confirmed by the comments, *"having the information close to where I placed my finger was most convenient," (P22)*, and

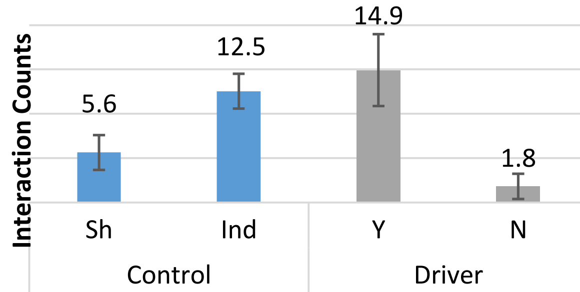

Figure 7: Mean interaction counts for shared and individual controls (left), and drivers vs. non-drivers in the shared condition (right).

"I was able to quickly flip through them [game events] without having to take my eyes off the game log box [with the next-to-timeline feedback]." (P4) Yet, seven participants identified the main drawback being the lack of context and disconnection between the timeline and the game, as evidenced by the comment, *"having information only in the log (timeline) lacks the direct feedback of having information available on the board." (P8).*

When feedback was *on-board*, six players commented that it provided greater awareness of surrounding cities and gave more contexts to a particular game event. However, 58% of the participants ranked it as their least favourite condition, likely because of the large surface (3 players) and the difficulty in visually searching for the feedback (8 players). This trade-off was summarized by the comment, *"the highlights gave geographic context while taking longer to locate." (P3).* Moreover, there was confusion over who triggered the animation (commented by 6 players), as indicated in the comments, *"on the game board makes things clearer, where people are in relation to the site in question, etc, but gets distracting when three different people are querying." (P33)*, and, *"When displaying information on the game board it was occasionally confusing if it was someone triggering log information or a game action taking place." (P8)*. This confusion impacted the players' decisions about where the feedback should appear when playing the configurable version, as illustrated in an excerpt from one group's configurable game play session:

P14 (Middle): [Touched timeline, and Bogota was highlighted]
P15 (Left): Hey Bogota just outbroke! [Realized that it was P14] Oh no, you are just smashing things. I hate you! I hate the board thing! Turn your board off, please!
P14 (Middle): Alright [laughed and turned off the *on-board* feedback].
P15 (Left): Inform us when you are going to turn it on; otherwise, I go, 'oh no Bogota just outbroke!'
P13 (Right): It's kinda funny, but I also found it distracting when people do it.
P15 (Left): It's okay as long as you tell people you are doing it.

Feedback in *both* places was ranked as the favorite setup for 81% of the players. This provided the best of both worlds, with duplicate information, with both quick navigation and geographical context, as confirmed by the comments:

> *"The combination of the two allowed for both immediately accessible feedback as well as more information if needed." (P3)*,

> *"Information displayed on both the board and near the log was the most useful, since I could see information quickly while still seeing what area of the board was being affected." (P32)*, and

> *"Seeing the log [the information] in both the game log and the board makes it easier to see where future potential outbreaks could happen." (P23).*

We also ran an RM-ANOVA on the time spent per turn, calculated as the time between when the system finished automating events and played the animation to the time the next player made the first move, which revealed a significant main effect of feedback ($F_{2,20} = 4.2$, $p = .03$). Post-hoc pairwise comparisons showed that players spent more time between each turn with *on-board* feedback than with feedback in *both* locations (p = .03). It appears that players spent more time searching and understanding the automation result with only on-board feedback.

Group Interaction

Observations during the study revealed that, as a group, situation awareness seemed to be very high, despite individuals having low situation awareness scores. We thus further investigated this phenomenon by analysing a group SA score. We also further investigated differences in SA scores and interaction counts between drivers and non-drivers when groups used a *shared* timeline versus *individuals* (all drivers) when each player had their own timeline.

Combined Situation Awareness

In addition to individual SA scores, we calculated a group SA score based on the maximum score from players in the same group for each question. We ran RM-ANOVA on this data, and found that the main effect of control placement was not significant ($F_{1,10} < 0.1$, $p = .94$) nor was feedback location ($F_{2,20} = 1.2$, $p = .33$). All groups scored high in situation awareness ($M = .87$, $SD = .06$).

Shared Interaction with the Timeline

When the control placement was *shared*, players interacted with the timeline as a group. Our observations revealed that one player was typically responsible for interacting with the timeline (*driver*), while the entire group was watching, narrating, and understanding the game together. Since drivers are the primary people interacting, they had a higher interaction count than the non-drivers. Figure **7** (right) illustrates interaction counts for drivers in *shared*, non-drivers in *shared*, and players in *individual*. Note that the drivers in *shared* have similar interaction count as the players in *individual* (Figure **7**, left, Ind). The following excerpt illustrates how players narrate together while trying to understand the automation results with a s*hared* timeline:

```
[After seeing an epidemic animation, players
    were discussing strategy]
P18 (Left): Is an epidemic due?
P17 (Middle): [Touched timeline on epidemic
    city] It's there [Epidemic animation
    played on the board @ Miami]
P18 (Left): Yeah
P17 (Middle): Then 3 more black [cubes].
    [Continued to touch the timeline]. Al-
    giers
All players: Karachi and Istanbul.
```

We performed a 3 feedback location × 2 player type RM-ANOVA on SA score, and the main effect of player type was not significant ($F_{1,5} = 2.93$, $p = .15$), nor was the feedback location ($F_{2,10} = .15$, $p = .86$). This extends our earlier correlation between SA and interaction count, suggesting that interactions of drivers still led to higher awareness in non-drivers, and we thus believe that all group members were actively engaged in the process.

With *individual* timelines, participants tended to explore the results simultaneously or work together to understand the game state. The following excerpt illustrates players working together to understand automation results with *individual* timelines:

```
P22 (Right): Did Ho Chi Minh get hit as well?
    [Tapped on the Ho Chi Minh game event on
    P22's timeline] and what was the yellow
    one?
P23 (Middle): [Tapped on the yellow game
    event next to Ho Chi Minh on P23's time-
    line] Lima.
```

Figure 6 (right) illustrates the situation awareness for different categories of players. In terms of situation awareness, the drivers and non-drivers in the *shared* are not significantly different. However, players in *individual* have higher situation awareness than players in *shared*.

DISCUSSION

Our results showed that more interaction with event timelines can improve situation awareness, and suggests that we should design to promote this interaction. Although providing *shared* controls results in a process more similar to the physical game when resolving game events, *individual* controls allowed more and simultaneous interaction and resulted in higher situation awareness. The individual timelines allowed for a higher level of situation awareness without requiring the same amount of manual work needed on the physical board. This result suggests that we do not have to mimic real-world processes, but through interaction with timelines, we can improve situation awareness without requiring the same level of work.

Players' interactions with the timeline can be easily observed by their hand postures. When feedback is provided on the board, the results of interaction facilitated feedthrough. The results showed that the players sometimes were confused about whether an animation was initiated by the computer system or the collaborators, and they had to search for the feedback. While the feedback next to the timeline fits into a player's field of view, participants commented on the disconnection between the timeline and the game board. These results suggest that the timeline should more extensively incorporate the concept of feedthrough by making results clearer for both the individual and the group.

Overall, groups had a high level of situation awareness, in contrast to results from a previous study of a digital version of Pandemic [42] and from our training condition, both of which offered no mechanism for players to explore past events. This finding suggests that the timelines were effective in providing relevant historical game information. For both *shared* and *individual* control placements, players did not always interact with the timeline after each automation animation, and instead relied on other players interacting with the timeline and narrating game events. These results suggest that players can also benefit from other players' interactions with the timeline, providing evidence that players work together to achieve higher performance.

Study Limitations and Generalizability

As with any lab-based study, there are some limitations to the results. While our study has high precision, and we used a commercial board game to achieve higher realism, these decisions come at the cost of some generalizability [24]. Nonetheless, we think our findings are a useful addition to research into awareness in complex collaborative scenarios that involve automation, such as emergency response. Specifically, we chose Pandemic as the experimental task, both because it is representative of a highly popular commercial game genre, cooperative games, and because it emulates some key aspects of non-gaming tasks. Keeping track of and responding to the evolving game state places high cognitive demand on players, and success in the game depends on successful teamwork that utilizes the capabilities of different roles, as well as effective forecasting of future events and planning for future game moves. The game challenges players in their coordination, advanced planning, decision making, and resource management skills. Including only experienced Pandemic players also provided a realistic play scenario, which allows us to collect results that reflect the benefits and future improvements of timelines for expert use, without the need for extensive training.

CONCLUSION & FUTURE WORK

We presented an interactive event timeline that provided visualization of historical game events and allowed interaction to explore this history. We conducted a study to examine two factors, control placement and feedback location, to understand their impact on situation awareness. The results showed that having individual timelines for each player encouraged interaction with the timeline and improved situation awareness. Overall, groups had high situation awareness, which suggest that the timeline was useful.

In the future, we would like to explore ways to enhance the players' workspace awareness, to facilitate collaborative exploration of historical game events, and to support decision planning and making processes. Specifically, we want to improve the link between players' interactions with the timeline to the feedback on the game board so that players can easily understand the results of their interaction and collaborators can distinguish between events triggered by the system versus by other players. Another area for further study is the use of visualization algorithms [18] to simplify the generation of the event timeline for more generalizable use in other board game or non-gaming applications.

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