Usage of Interactive Event Timelines in Collaborative Digital Tabletops Involving Automation

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Abstract   Tabletop computers are increasingly being used for complex, collaborative scenarios, such as emergency response. In such scenarios, maintaining situation awareness of dynamic changes automated by the system is crucial for users to make optimal decisions. If the system does not provide users with appropriate feedback, they can become confused and "out-of-the-loop" about the current system state, leading to suboptimal decisions or actions. To enhance situation awareness of dynamic changes occurring in the collaborative tabletop environment, we designed an interactive event timeline to enable exploration of historical system events. We conducted a user study to understand how various design alternatives of interactive event timelines impacted situation awareness in the context of a cooperative tabletop game. Our initial results showed that, on average, all groups had a high combined level of situation awareness, regardless of the given timeline designs. To better understand what role the timelines played for the groups, we conducted an in-depth video analysis. Participants used the timelines mostly for perceiving new changes by interacting with the detailed information. The analysis also revealed the benefits of the high-level information presented in the timelines for projecting future system states. The information presented in the timelines was considered as the correct historical account and was used to negotiate the knowledge of automated changes. We also report on how other system features, in addition to the timelines, were used for situation awareness maintenance. Finally, we discuss implications for designing interactive event timelines for co-located collaborative systems involving automated events.

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1 Introduction

There is a growing interest in using digital tabletops for co-located group activities that involve complex, often dynamically changing data. Given their ability to provide digital functionality for collaborative work while allowing for face-to-face communication, tabletop interfaces have been proposed for many domains, such as crisis and disaster management [6] and commercial maritime operations [5]. In such domains, decision-makers' awareness of the system state is crucial to the quality of decisions made [11]. However, when the system automates changes in system states but does not provide appropriate feedback via the user interface, human operators are left "out-of-the-loop" [22]; that is, they are unable to keep up with system changes. They may be confused, and are unable to make optimal decisions and interact when needed. As digital tabletop applications become more sophisticated and begin to incorporate more automation to manage the type of complex data inherent to many real-world application domains, keeping users in-the-loop becomes an essential design requirement.

Tabletop applications cannot assume that users will attend to and notice all system changes due to a variety of potential distractors, for example, conversing with collaborators at or near the tabletop, attending to devices being used in conjunction with the tabletop (e.g., a smart phone or tablet), or even being called away temporarily. Consequently, a change occurring on the tabletop (automated, or made by another user) can be easily missed. Existing tabletop applications that incorporate dynamic data provide little to no support of situation awareness maintenance, such as displaying historical system data. Instead, they focus on novel interfaces for sharing or collaborating with the current, real-time view of the system state [1,4].

Interactive event logs and timelines have been previously shown to reduce response time and improve decision accuracy for single-user applications involving automated system changes [21,36]. We were interested in adapting such timelines to a co-located collaborative context on tabletop systems. We investigated two design factors: *control placement* (number of timelines for a group of users and timeline placements) and *feedback location* (where to display interaction feedback of timelines). We sought to understand how these two design factors impacted situation awareness of dynamic changes in collaborative tabletop applications.

We evaluated the design factors in the context of a popular three- to four-player collaborative tabletop board game, Pandemic[2]. This game requires intense strategy discussions, resource management, and advance planning of actions to prevent epidemic outbreaks. Moreover, Wallace et al. [47] found that their digital tabletop version of the Pandemic game elicited the aforementioned out-of-the-loop automation problem, due to the amount and complexity of changes as well as the fact that players were not constantly paying attention to the tabletop interface.

Our study involved two phases. In Phase 1, a controlled experiment tested the two design factors by asking participants to play three short partial games in which

[2] The Pandemic game was published by Z-Man Games, used with permission.

they used three different timeline alternatives. In Phase 2, participants completed a full game from start to finish using a configurable version of the timeline that allowed them to utilize any combination of the *control placement* and *feedback location* at any time.

The results from a detailed analysis of Phase 1, previously published in Chang et al. [3], revealed that more timeline interactions were encouraged with replicated timelines, where each player had a copy in their personal spaces. More timeline interactions correlated with higher levels of individual situation awareness. Despite individual's differences in situation awareness, groups were overall found to have high combined levels of situation awareness in all conditions. In this article, we expand on this prior work by presenting the results of an in-depth video analysis of players' situation awareness maintenance behaviour in Phase 2. The analysis provides a better understanding of how system features, including the timelines, were used to understand dynamic changes driven by the system. The analysis revealed that the timelines were useful as both static and interactive visualizations, and they were mostly used to investigate recent dynamic changes automated by the system. The timelines were used only occasionally to strategize and prioritize tasks while another system feature, the discard pile, was used primarily for this purpose.

We first contextualize our research by presenting the related work on both situation awareness and workspace awareness. Next, we present the conceptual design of our interactive event timelines and discuss previous work that motivated the timeline design alternatives. We then introduce the Pandemic game case study and describe our timeline designs. Next, we present the study method, research questions, and results, focusing on the video analysis results of timeline usage based on Phase 2 of the study. Finally, we discuss the implications of our findings on timeline designs and the limitations of this work, and we conclude with future work.

2 Related Work

There has been substantial research on the concept of awareness and its many forms in the Human Factors and Human-Computer Interaction literature e.g., [32,37]. In this section, we provide an overview of related research, specifically in the areas of situation awareness, team situation awareness, and workspace awareness. In section 3, we discuss related work in digital tabletops to motivate the design factors studied.

2.1 Situation Awareness

Situation awareness (SA) describes a person's awareness of the environment, and has been applied to many domains, including military combat [10], aviation [42], and nuclear plant operation [2]. Endsley [11] defined SA as the perception of changes in the system state (level 1), comprehension of the changes (level 2), and

projection of future system states (level 3). The second level of SA requires people to connect multiple pieces of knowledge (level 1) to infer their meaning and form an understanding of the perceived changes. The third level describes the ability to predict future states of the system based on the person's understanding (level 2).

The phenomenon of *change blindness* [31] is a key cause of deficient SA in automated systems, as observed in the automation literature [7]. Change blindness refers to a person's inability to recognize changes in the environment after interruption or deviation in attention [31]. The interruption recovery literature has explored the use of persistent, interactive information displays to mitigate change blindness and to rapidly improve SA following an interruption to the task in systems with dynamically changing data [36,39,41].

Sasangohar et al. [36] studied interactive event timelines that allowed users to highlight historical events on a main task display (a map) located on a large wall display by interacting with event bookmarks, which were displayed on a graphical timeline located on a secondary handheld display. Their results showed that the timeline allowed people to quickly gain awareness of missed events and helped reduce recovery time while improving decision accuracy after interruptions. They argued that the interactive event timeline provided a "simplified representation of important events [that] facilitated the quick encoding of perceptual information and minimized the visual search" [36:1155]. On a large digital tabletop interface, promoting SA while minimizing visual search across the entire interface is an important design goal. Our work thus applies this interactive event timeline concept to digital tabletops involving automation.

Previous research has largely focused on the design of awareness displays to support individuals' SA [21,36,39]; our research expands on this by applying interactive event timelines to multi-user tabletop environments.

2.2 Team Situation Awareness

As we aim to support team environments where users have a shared goal, examining *individual* SA of the system may not be sufficient to understand the collaborative process of maintaining SA and strategizing as a group.

Team situation awareness (TSA) is the team members' overlapping knowledge of the situation as well as the full SA required for individuals to successfully coordinate actions and complete the shared goal [35]. Previous work generally agrees that TSA requires high levels of individual SA and communication among team members [8,13,48]. Much of the research in TSA has focused on individual tool design (i.e. to facilitate individual SA) and analysis of communication and coordination behaviours to provide design implications and create advanced measurements [8,13,29,35].

Theoretical models of TSA have also been developed [8,34,35]. However, they tend to focus on high level processes [8,35], such as shared goals, communication, team members' background, and teamwork. This project examined how specific

system features were leveraged by our participants to maintain and communicate SA.

2.3 Workspace Awareness

Extensive research has shown the value and the information richness provided by the objects, people, and environment in co-located collaborative settings [15,18,30]. While SA focuses on a person's knowledge of a system's state, workspace awareness describes a person's knowledge of their collaborators and their actions within a shared (physical or virtual) workspace [30].

In distributed settings, workspace awareness has been supported through techniques such as virtual embodiment (e.g., telepointers [15], virtual arms [45], avatars [25]). Although a significant amount of workspace awareness information can be gained "for free" in a co-located tabletop setting through observation [15], the distance between collaborators and the complexity of some tabletop interfaces can hinder people's ability to observe all activities, especially for interactions happening in collaborators' personal spaces [38]. We aimed to preserve users' workspace awareness while providing them with interactive event timelines to maintain SA. Thus, we tested two factors relevant to the design of timelines for supporting workspace awareness in the context of tabletop systems, and we discuss these factors in section 3.2.

3 Awareness Support for Tabletop Systems Involving Automation

Traditionally, automation has used to reduce manual workload or mechanically change the states of physical materials [28]. Now, automation is also used to reduce mental workload, and may involve changing the state of virtual objects, such as automatically updating data visualizations based on underlying sources. These automated changes can also negatively impact situation awareness, often due to change blindness or state changes not being displayed. As illustrated in Fig. 1A, people at a digital tabletop can be unaware of a change occurring in the system interface due to the large size of the display or other competing demands for their attention, such as conversing with a teammate. Moreover, even when a change occurs within a person's field of view, they may still miss the change due to limited attentional capacity.

3.1 Situation Awareness Support for Tabletop Systems

Substantial tabletop research has investigated interaction techniques for digital object manipulation, menu invocation, information sharing, and tangible interaction [23,43,46,49]. For collaborative tabletop applications, significant work has also been done on information visualization, coordination and collaboration styles, and control widgets [20,26,44]. As more sophisticated tabletop applications are developed to support complex task domains [1,5,6], application tools that allow maintenance of awareness of dynamic changes will become essential. To date, no such tools have been tested in collaborative tabletop environments, and existing tabletop applications involving dynamic data focus on supporting current, real-time views of the system state in collaborative work [1,4]. This work is a first step towards addressing this gap.
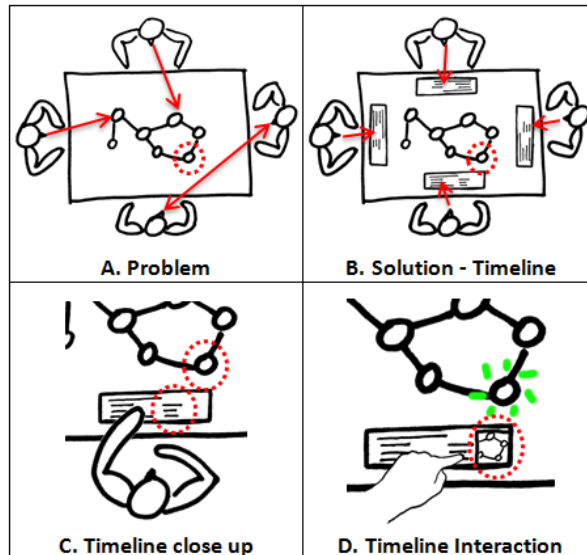
Fig. 1 Conceptual design of the interactive event timeline. A) Problem: users can miss automated changes if their attention is elsewhere (red arrows show attentional focus). B) Solution: timelines provide a way for users to view and explore changes. C) New changes are appended to the timeline, and D) users can interact with the timelines to locate the changes on the shared area (highlighted node) and on the timeline (graph cut-out on the right of the timeline).

3.2 Conceptual Design

To address the issues introduced by the use of automation in digital tabletop systems, we explored using interactive event timelines to provide persistent information of historical system events. Such timelines also provide the information in a visual form that can fit within a person's field of view, despite the large size of the table. To gain awareness of the current system state, a person can examine and explore the timeline, which provides an overview of historical events (Fig. 1B and Fig. 1C). To get more in-depth information, they can invoke further feedback on the shared display or on their personal areas (Fig. 1D). Based on the existing literature, we considered two key factors in designing these timelines: *control placement* and *feedback location*.

3.2.1   Control Placement

The event timeline is a visualization of historical events as well as a control for invoking detailed information of the automated changes. It was unclear how to distribute and place the timelines to best support workspace awareness and situation awareness in a group setting.

Morris et al. [26] compared providing individual replicated system controls around the border of a tabletop system with a single, shared control in the centre for a collaborative photo tagging application. They found that while individual controls were preferred, the groups were more collaborative (i.e., more labels per image) when using the shared controls. This result suggests that a shared timeline may contribute to more collaborative work and improved team situation awareness (e.g., joint investigation for all team members). However, it is unclear how well shared timelines support individual situation awareness since users need to coordinate their use of the timelines.

Ha et al. [16] compared direct touch and mouse pointers for a two-player competitive image search game on digital tabletops, and their results show that the direct touch condition allowed for higher levels of workspace awareness and resulted in quicker response to opponents' moves. Nacenta et al. [27] studied five different interaction techniques for selecting, moving, and rotating images for two collaborative tasks: an image sorting game and a storyboarding activity. They similarly found that the interaction technique requiring explicit input in the shared space (i.e., drag-and-drop) allowed for easier tracking of collaborators' actions and helped avoid conflicting actions. While participants may have higher workspace awareness using the shared control, it was unclear how individual versus shared timelines would impact participants' situation awareness. Providing replicated timelines allows each user to view and manipulate the timeline for the purpose of maintaining situation awareness. As the current research still lacks understanding in how the placement of timelines impacts users' situation awareness, we examined the control placement factor.

3.2.2 Feedback Location

Another design consideration is where to provide the visual feedback related to a user's exploration of historic system events. Information about the event can be displayed locally (on the timeline) or on the shared area of the tabletop. These design alternatives may better facilitate either individual control or group function, respectively [14]. Displaying feedback on the timeline provides a consistent location to look for the information, and it fits into a person's field of view. On the other hand, feedback in the shared area provides more contextual information of the overall situation to the individual. This feedback location also better facilitates feedthrough—the observation of shared artifacts in the workspace to gain awareness of collaborators' actions and work progress [30]—by making collaborators' actions more visible to the whole team. However, the size of the display may still necessitate searching for the feedback in the shared workspace, making situation awareness maintenance more difficult for individuals. Moreover, other users' feedback on the shared area may make searching more difficult and distract users.

Existing work that explored the impact of specific input methods and interaction techniques on workspace awareness [16,27] provides insights that helped us hypothesize how the different feedback locations may impact workspace awareness. However, our timelines were designed for situation awareness maintenance, which is a different goal from the previous work. Thus, the timeline's impacts on situation awareness and the trade-off between providing awareness and reducing distraction need further investigation.

3.3 Research Questions

We sought to understand the utility of different design factors for adapting interactive event timelines to collaborative tabletop applications. Specifically, we are interested in the following research questions:

- For Phase 1, how do *control placement* and *feedback location* affect situation awareness?
- For Phase 2, what are the usage patterns of the configurable timeline in a collaborative tabletop application?
- For Phase 2, how are the different system features, including the timelines, used in a group setting to maintain the three levels of situation awareness?

## 4 Studying Interactive Event Timelines in the Pandemic Game

Our literature review revealed a gap in how interactive event timelines can be adapted to a collaborative tabletop context for situation awareness support. Thus,

we designed an interactive event timeline and chose a cooperative board game as our study context. We describe the study context and timeline design in this section, and we present the study design in the section 5 below.

The cooperative board game, *Pandemic*, was selected 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. We can have more control in manipulating parameters, such as degree of difficulty. Moreover, the digital tabletop version of the Pandemic game by Wallace et al. [47] was shown to elicit situation awareness deficiencies due to automation.

Pandemic is a commercial board game for three–four players, requiring intense collaborative activities, such as forecasting game states, advance planning of actions, and managing resources. Players work together as a team, with distinct roles and abilities, to save the world from epidemic outbreaks. 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). During each turn, a player completes four actions through careful planning and strategizing, such as treat diseases, move, and exchange player cards. Then, they draw player cards, which are collected to trade for the cure (i.e., to win the game). At the end of a player's turn, the team acts as the game board (opponent) and draws infection cards that determine which cities are infected with new diseases (in the original board game, players place wooden cubes (diseases) onto the game map based on the cards drawn). *Outbreaks* and *epidemics* are critical events that increase the difficulty of the game, and players have to stay aware of them to effectively strategize.
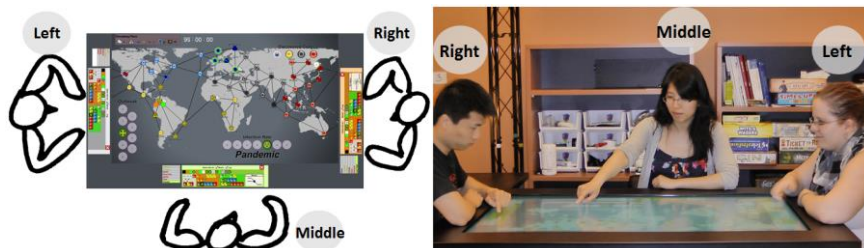
Fig. 2 The *Pandemic* digital game was used as the study context. (Left) a screenshot of the game interface, labeled with participant seating locations, based on the orientation of the game map. (Right) A group was playing the game.

Our digital tabletop adaptation version of Pandemic (Fig. 2) provided automation to help reduce manual workload and to enforce rules. For example, the system automated game board (the opponent) actions by placing disease cubes based on cards drawn, or outbreak and epidemic events. The game provided feedback of the automated changes through the following three system features:

Board. The changes were reflected on the game board, including displaying disease cubes on the map and counters around the map (e.g., cards left, epidemic counters, and cubes left). Moreover, after automated system events, three seconds of system animations appeared on the map to highlight the changes on the relevant

cities (e.g., Fig. 3L). Different animated graphics were used to represent infection, outbreak, and epidemic events.

Infection Discard Pile. The system provided a limited history of previous infected cities in a textual log format, contained in the infection *discard* pile (see Fig. 3M). The pile was periodically emptied into the infection *draw* pile when an epidemic event occurred so it only contained limited history since the last epidemic. Players could open the discard pile via a button on the top left of the interface. It initially opened at the centre of the game map, and can be moved by dragging the pile.

Interactive Event Timeline. The interactive event timelines provided a complete record of events that happened throughout the game (see Fig. 3), and it consisted of automated game events and other players' actions.
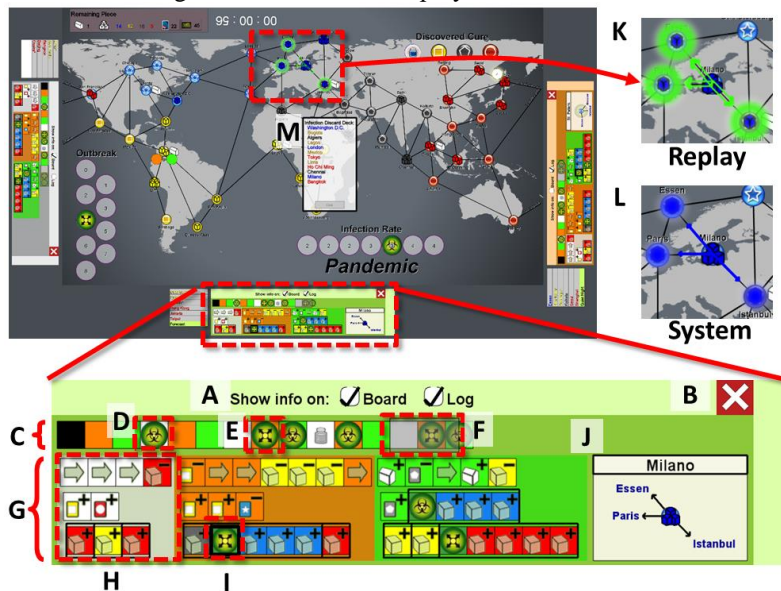
Fig. 3 Design of the interactive event timeline (configurable version). Users could (A) toggle the feedback location on the board and on the timeline as well as (B) close and open it at any time. (C) The overview bar showed all game turns so far with symbols denoting important game events, such as (D) epidemics and (E) outbreaks. (F) A viewport was used for selecting a timeframe to show in (G) the detail view. (H) A player's turn contained three rows, corresponding to the three game phases. Each block represented an action carried out by either the player or the system, and black bounding boxes grouped related game events. (I) Selected event had a thick black bounding box. Location details of the selected event was (J) shown on the timeline as a map cut-out and (K) highlighted through a replay animation on the map (in contrast to the (L) system animation). (M) The infection discard pile is shown at the centre of the map by default. For full details, see Chang et al. [3].

The design was based on a task analysis of experienced to expert players playing the Pandemic game, and it was designed to fit into a player's personal territory on the tabletop, based on prior research on tabletop territoriality [38]. Moreover, it persisted on the game board, allowing players to explore prior game events at any time. The timeline showed history for one game session. When new automated events happened, they were appended to all timelines in the game. Once users started a new turn by executing new actions, the timelines automatically scrolled to show the current game turn.

The timeline consisted of two main components: an *overview* (Fig. 3C) and a *detail* view (Fig. 3G). The *overview* showed an overview of all game turns so far in chronological order, colour-coded by the in-game player colour (orange, green, and white). Critical events were marked with symbols on turns in which they occurred. To navigate through the game history, players could drag the viewport (Fig. 3F) or tap on a given turn to reveal details of the turns of interest in real-time.

The *detail* view (Fig. 3G) contained the currently selected player turns. Each turn consisted of three rows corresponding to the three phases in the game (Fig. 3H): 1) player actions, 2) cards drawn for players by the system, and 3) cities infected by the system. Each block represented one game event with a symbol denoting the type of event and colour derived from the colour coding scheme in the Pandemic board game. Selecting a game event could invoke two types of feedback. First, detailed information was shown next to the timeline (see Fig. 3J), if feedback on the timeline was enabled by toggling Fig. 3A. Second, a replay animation that persisted for three seconds was triggered on the shared game map (see Fig. 3J), if feedback on the board was enabled by toggling Fig. 3A The colour of the replay animation corresponded to the player's in-game colour and the timeline colour. The colour coding was based on the original Pandemic game design.

5   Study

We conducted a laboratory-based study to understand how the two design factors, *feedback location* and *control placement*, impacted users' situation awareness and timeline usage. Participants played the Pandemic game with different design alternatives of the interactive event timeline, and answered questionnaires for us to evaluate their situation awareness and experience.

5.1 Participants

Experienced Pandemic players were recruited from the local community, and they signed up in groups of three. Thirty-six paid participants (twenty-three males, thirteen females, ages twenty-two to thirty-six) were recruited, with all team members having experiences playing Pandemic prior to the study. For this book chapter, the

participants are denoted as $P_{\text{group number, seating position}}$. For example, $P_{1, \text{right}}$ denotes the right player in Group 1 (based on the orientation of the game map).

5.2 Equipment & Setting

Each group of participants was seated in the lab around a 148×95 cm digital table (3840×2160 pixel, 121×67cm for screen size) with an embedded PQ Labs frame to detect touch input. 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 (see Fig. 2). The computer was running 64-bit Windows 7 using an 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.

5.3 Study Design

There were two study phases. Phase 1 (Pandemic Challenges) was conducted using a mixed design, testing two factors:
- Control placement (between-subjects): 2 levels (shared, individual)
- Feedback location (within-subjects): 3 levels (next-to-timeline, on-board, both)

For *control placement*, half of the groups used the shared controls and the other half used the replicated individual controls. The order of the three feedback locations was counterbalanced. The widgets for toggling feedback locations and opening and minimizing the timeline (Fig. 3A and Fig. 3B) were removed in this Phase. The shared timeline was movable. This phase sought to provide empirical data to understand these two factors' impacts on participants' situation awareness.

In Phase 2 (Full Game), participants played a full game with a configurable version of the timeline, in which a group could open up to three timelines that could be moved anywhere on the tabletop. They could minimize and reopen these timelines at any time (Fig. 3B). 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 (Fig. 3A). All groups had the same game setup. Phase 2 provided a more realistic usage data of the timeline to inform further improvements and to understand how it was used to facilitate the situation awareness maintenance.

5.4 Procedure

The study sessions lasted approximately two and a half to three hours. Participants completed consent forms and background questionnaires, and then completed the two study phases: 1) Pandemic challenges and 2) a play through of a full game.

Phase 1 - Pandemic Challenges. After the researcher explained the game interface, participants played with the Pandemic game without using timelines for ten minutes and completed the gameplay questionnaire (study questionnaires are discussed in section 5.5 below). Then, with the same procedure, participants practiced on the same timeline variant they would see in the first Pandemic challenge. For each trial, participants started in the middle of an ongoing Pandemic game and played for two rounds (two turns for each player). We constructed three 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 selected. 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 was randomly selected. Participants were asked to rank their preferences of the timeline alternatives at the end of this phase and to provide free-form feedback.

Phase 2 - Full Game. After the researcher explained the configurable timeline, participants played a full game. Then, they completed the gameplay questionnaire with a free form area for any additional comments. Finally, the researcher debriefed the participants with the goal and details of the study, and conducted an unstructured interview to receive any additional feedback.

5.5 Data Collection

During gameplay, we collected various data, including video recordings from two different angles, screen recordings, computer logs, audio recordings, and questionnaires. The computer logs captured all touch interactions on the timelines, e.g., tap, rotate, open, and close timelines as well as toggle feedback locations.

Two questionnaires were used to evaluate participants' gameplay experience and situation awareness. The gameplay questionnaire consisted of the Player Experience of Need Satisfaction (PENS) survey [33] and the NASA Task Load Index (NASA-TLX) survey [17]. We developed the situation awareness questionnaire by following the steps outlined in the SAGAT methodology [9,12]. Questions were in the form of "name one city/colour/player that…", or "estimate the number of turns away from…". More details on the questionnaire can be found in Chang et al. [3].

5.6 Quantitative Analysis

Each individual's situation awareness questionnaire results (from Phase 1) were scored as correct (1), partially-correct (0.5), and incorrect (0) for each question. We analyzed the situation awareness questionnaires using a 2 (control placement) $\times$ 3 (feedback location) repeated measures analysis of variance (RM-ANOVA). See full details of the quantitative analysis in Chang et al. [3].

5.7 Qualitative Analysis

For Phase 2 (full game), two researchers analyzed eight full game sessions with an open video coding process. One researcher watched the videos and took notes of participants' discussions and activities related to timeline usage and situation awareness maintenance. An initial set of codes was then established, and two researchers coded for players' interactions with the features in the system and their discussion with teammates, e.g., interacting with timeline and discard pile, pointing at the game board, using deictic references for game cities, as well as announcing, narrating and discussing of automated events. The codes were revised until an acceptable inter-rater reliability was reached (79.39%), and then the rest of the videos were coded.

Next, we focused on codes most relevant to participants' situation awareness maintenance, including 1) looked at or touched the timelines, 2) opened and closed the timelines, 3) toggled feedback locations, 4) opened the infection discard pile, 5) discussed automated game events, and 6) corrected each other's knowledge of the automated events. For all instances, we classified the purpose behind the observed actions and discussions as follows:

- Investigation of automation results: the coded instance was conducted for the purpose of finding out the type and location of an automated event that took place as well as connections between automated events.
- Prioritization: the coded instance was conducted for the purpose of gathering information to predict future game states and prioritize player actions.
- Other: the coded instance was for any other purposes, such as played with the timelines, rotated the timelines, and toggled feedback locations at the start of the game for learning. This category also included instances that could not be classified by the researchers (i.e., insufficient information).

The instances were also classified based on whether the participants achieved their goals, such as correct (successfully obtained correct information), incorrect (successfully obtained, but information incorrect), incomplete (failed to obtain information), and unknown (researchers were unable to classify its successfulness).

Next, to understand how players made use of various system features for situation awareness maintenance, we sequenced the codes based on game events investigated by participants. We also examined whether players' investigation of particular game events led to game commands to address them, for example, a player asked about the new infections, another player checked the timeline and found that

Moscow had an infection, and the infection was treated in the same turn. We classified each sequence based on its purpose and whether it led to a success in achieving the goal. Through the video analysis, it became apparent to us that the codes classified under automation results were most closely related to the perception and comprehension levels of situation awareness. The prioritization actions were most relevant to the projection of future game states as participants gather information to determine their urgency.

6   Results

In this section, we first summarize the quantitative results from Phase 1 on the *control placement* and *feedback location* factors (details can be found in our previous publication [3]) to motivate our video analysis. Next, we present our video analysis results on timeline configurations and describe how timelines and other system features were used for the three levels of situation awareness.

6.1 Summary of Phase 1 Findings

The analysis of Phase 1 data revealed that participants who used individual timeline controls had higher situation awareness scores than participants who shared a timeline within the group ($M_{individual}$ = 0.71, M_{shared} = 0.67, $F_{1,28}$ = 4.7, p=.04). Participants using individual timelines also interacted with their timelines more on average in each condition ($M_{individual}$ = 12.5, M_{shared} = 5.6, $F_{1,10}$ = 6.2, p = .03), including navigating and tapping on game events. This finding showed the benefits of the timelines for improved situation awareness, and a partial correlation (control for group) confirmed that there was a positive correlation between interaction with timelines and situation awareness scores (r_{105} = .20, p = .04).

Although no main effect was found across feedback locations, feedback both on the game board and on timeline was most preferred as it provided the best of both worlds. For feedback on timeline, it allowed for quick navigation of game events while participants could fixate on the same area. However, participants reported that timelines felt disconnected from the game. Feedback on the board provided contextual information on the map, but participants also reported distraction and confusion associated with board feedback; this problem is further discussed in section 6.4.

Next, we investigated the groups' interactions with the timelines. We calculated a group situation awareness score by taking the best situation awareness score achieved by any one member for each question and then taking the average of these best scores. Overall, groups had high aggregated group situation awareness scores (M = .87, SD = .06). However, there were no main effects for *control placement* ($F_{1,10}$ < 0.1, p = .94) nor for *feedback location* ($F_{2,20}$ = 1.2, p = .33). In the shared

condition, the participant who interacted with the timeline most frequently was defined as the primary user, and the rest were secondary users. However, there was no difference in the individual situation awareness score between the primary and secondary users.

We hypothesized that the information participants gathered from the timelines was shared with the group; thus, the secondary users benefited from the primary users' interactions. Moreover, participants might have gathered situation awareness information through other components in the tabletop interface. Thus, we decided to follow-up with a video analysis of Phase 2 to better understand how various system features was used, including the timelines, to gain situation awareness.
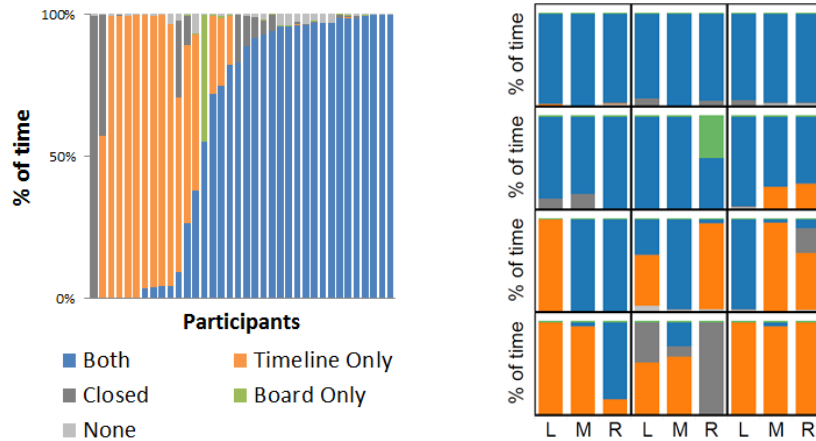
6.2 Timeline Configurations

To understand the usage patterns of the interactive event timelines, we examined the percent of time each feedback mode was kept for individuals and groups in Phase 2. Our data analysis revealed that participants made use of the configurable timelines, and kept it open for most of the time. Next, we investigated how much time each feedback mode was kept. When participants first started the gameplay, the timelines were set to show no feedback and were closed. However, if the game crashed and restarted (happened to two groups), the timelines were opened with both feedback locations enabled by default. The time during game crash was excluded from the analysis. For one group, the participants' timeline configurations before and after the game crash were different, and they did not all reconfigure their timelines. Thus, for this group, the time after the game crash was excluded.

As depicted in Fig. 4 Left, *Both* feedback was the most popular mode ($M = 60.82\%$, $SD = 42.02\%$), followed by *Timeline Only* ($M = 30.05\%$, $SD = 40.32\%$) and *Closed* ($M = 6.38\%$, $SD = 17.93\%$). *Board Only* feedback ($M = 1.37\%$, $SD = 7.31\%$) and *None* (while the timeline was open) ($M = 1.37\%$, $SD = 1.59\%$) were the least kept mode. This distribution was consistent with participants' feedback and our observations, since the *Both* configuration was also rated as most preferred in Phase 1. Some participants reported noticing interference between their own feedback and others' feedback on the board, which was likely why the second-most frequent configuration was *Timeline Only*. While one player used *Board Only* more extensively ($P_{4,right}$: 14.35 minutes), the rest of the participants almost never kept their timelines in this mode ($M = 2.6$ seconds, $SD = 3.69$ seconds). This was likely due to the need to search for the replay animation on the map as well as the interference problem. Although the percent of time in the *None* configuration might be a result of intermediate time between toggling feedback locations, the video analysis presented in section 6.4 below showed some benefits of the timeline as a static visualization.

Participants occasionally switched to different timeline alternatives throughout the game, but it was difficult to determine their intention based on the observable actions as there was no verbal explanation in most cases (only 6/31 cases could be clearly identified as related to understanding automated events).

Fig. 4 Percent of time each timeline configuration was kept by each participant. (Left) Sorted by percent of time a participant kept the *Both* configuration. (Right) Sorted by the average percent of time a group kept the *Both* configuration. Each cell shows a group (12 groups in total) and each bar shows one participant, arranged by their seats (L: Left, M: Middle; R: right).

We further examined participants' usage of timeline configurations as groups, and found that most groups had at least one player keeping the *Both* feedback mode on for most of the gameplay (see Fig. 4 Right). The last three groups (Group 2, 5, and 8 on the last row of Fig. 4 Right) all explicitly discussed the potential interference of displaying feedback on the map, while participants in Group 2 specifically agreed that only one player would be displaying feedback on the map. The configurable timelines allowed the groups to decide on their own strategies of maintaining awareness of each other's interactions with the timelines.

6.3 System Feature Usage for Maintaining Situation Awareness

As the timeline was designed to improve users' situation awareness of dynamic changes, we examined the usage of the timelines in supporting the three levels of situation awareness (i.e., perception, comprehension, and projection) as defined by Endsley [11]. The first level of situation awareness, perception, refers to the knowledge of the changes that happened. In the context of the Pandemic game, the perception level refers to knowing what the dynamic changes were, as well as whether the new changes were casual. The comprehension level refers to participants' understanding of the overall situation and of the changes that they just learned about to know their significance. Finally, the projection level refers to making predictions about future game states.

The three levels of situation awareness are internal cognitive processes. Thus, they are not directly observable without participants' verbal communication, physical interaction with the application interface, and visible body language. For example, participants may be exploring the timeline and thinking about the automated game events' impact on the overall game state. However, without verbal communication, it was impossible to definitely determine whether the interaction facilitated participants' comprehension. For this reason, few observable actions occurred for the comprehension level. Moreover, we incorporated decision making into the third level, projection, although it was originally modeled as a separate process by Endsley [11]. Participants' strategizing and prioritization behaviour represented participants' decisions in response to their projection of future game states. Since our data only recorded participants' visible and audible behaviours, we were constrained to determining how the timelines supported situation awareness based on observable actions.

We were also interested in how other system features were used for maintaining situation awareness. The video analysis revealed that the game map and the discard pile were the most relevant features used by participants. The game map refers to the connected cities as well as all information contained within it, e.g., the disease cubes on cities, locations of player pawns, and system animations that highlight particular cities. The discard pile contained a log of limited history of cities infected by automated events, periodically emptied after epidemic events. It could be opened by tapping a button, as described in section 4 above.
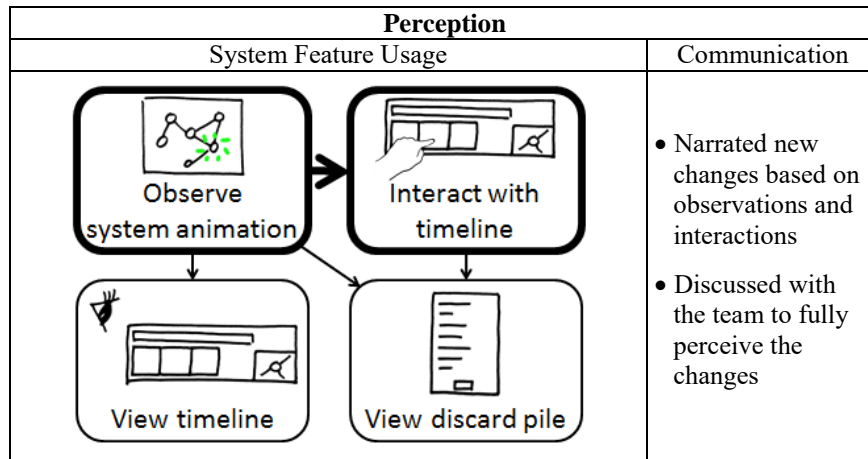
To answer the research question on how each situation awareness level was supported by various system features, we investigated how the timelines, the game map, and the discard pile were used by our participants. In the following sections, we present data pertinent to the system features' usages for each level of situation awareness: perception, comprehension, and projection (as depicted in Fig. 5 to Fig. 7).

6.4 Perception

At the end of each game turn, the system automated the drawing of new player cards (i.e., shared resources) and placing new disease infections on the game map (i.e., changes in the system state). The new changes were reflected on the associated cities and were highlighted on the map by a brief system animation. Moreover, they were appended to the timelines (players had to tap on the new changes to see the associated locations). Participants should aim to find out the types of events that took place, their locations and quantity, and if the events were causal.

The analysis revealed both static and interactive use of the timelines. For simple changes, participants observed both the system animations and the timelines to gain awareness of dynamic changes. However, participants sometimes only caught parts of complex changes or completely missed the changes, and the timelines were then used to investigate the changes. The timelines were considered as the correct his-

torical account, and used to negotiate participants' knowledge especially for complex changes. This section describes strategies for perceiving simple and complex changes, as depicted in Fig. 5.

Perception		
System Feature Usage		Communication
		• Narrated new changes based on observations and interactions • Discussed with the team to fully perceive the changes

Fig. 5 At the perception level, participants typically first observed system animations and then interacted with their timelines to verify or further investigate changes. Changes were often narrated, and participants also discussed changes based on information gathered to negotiate their knowledge.

6.4.1 Observation First Then Investigation

Participants often narrated new changes as the system animations appeared on the game map. Due to the large size of the tabletop display and the fact that players were not constantly attending to the interface during gameplay, players sometimes missed seeing the system animations in time or only noticed that some changes took place without knowing the details (e.g., they noticed an animation occurring in their peripheral view). Complex changes that involved chained events could also be difficult to follow. Thus, participants typically first observe the available feedback then interact with timelines. For example, after the system finished animating on the map, $P_{1,middle}$ noticed it but did not know the exact associated cities from observing the map. He said to the group: "hmm… Something went pop!" He then used his timeline to locate the changes by tapping on the newly automated event and narrated the result to the group: "San Francisco." As he had *Both* feedback on, $P_{1,left}$ then pointed at the replay animation triggered and said: "right here."

The timeline was useful as a static visualization for perceiving new changes, especially because it automatically scrolled to show the current turn and placed the changes in a readily accessible location for users. There were only 9/333 cases of such usage that we coded. The actual usage could be much higher due to the constraints in precisely determining the eye gazes of participants (see Table 1).

Usage categories	Counts
Tap on events in the current turn	272
Navigate to and interact with historical events	22
Learn to use timeline	14
Interact with the timeline for fun	10
View timeline (static usage without interaction)	9
Count critical events on the overview bar of timelines	6
Total	**333**

Table 1 Summary of timeline usage counts. Interacting with current turn game events was most common.

Although the static timeline design did not provide detailed location information of the game events, the colour-coding of game events provided a general sense of regions. The icons indicated the types of events (i.e., infection, outbreak, or epidemic), and the amount of game events provided a hint to the complexity of changes. Moreover, there were a few cases where participants opened and closed their timelines only to view the changes without interacting with any specific game events (evident from their narrations). Participants sometimes narrated the colour of the player cards (shared resources) received by collaborators, showing the value of providing awareness of the changes in shared resources automated by the system. As users tended to first observe without any interactions, making changes apparent is important. While this strategy was effective for simple changes, more complex changes often required interactions with various system features.

6.4.2 Interactions to Resolve Complex Events

For complex disease spread, participants' process of learning the changes was often a joint, iterative effort among the team members. While the game map provided a reference to the current system state and allowed participants to notice changes, the timelines were the main tools for participants to understand how the system automation arrived at the new state, see the observe to interact states in Fig. 5.

Participants interacted with the timelines to verify what they observed on the game map or what they overheard from collaborators. The timeline was also used to investigate new changes. This was the most common type of timeline usage (272/333 cases). It was also common for multiple players to investigate their timelines and announce the results at the same time. We hypothesize that players did so to make sure they, as a group, had the correct knowledge of the automation that took place.

When a group was confused with complex changes reflected on the game map, they used the timelines to investigate and verbalized their perception for negotiation to reach a common ground of the events that happened. In this process, the timeline was considered as the "correct" history and was used to correct each other's "theory" of the changes. For example, while the system animation was still playing, P$_{3,}$

$_{\text{right}}$ noticed that two outbreak events just took place by viewing his timeline, and he announced this to the group. As there were two outbreak events, participants tried to determine if one caused the other. It was a complex event as three types of events happened during the same turn: an epidemic event at Chennai, two independent outbreak events at Bangkok and New York, and an infection event at Moscow. As $P_{3,\text{right}}$ was investigating on his timeline, the rest of the team looked at the game map on which they could see the new disease-spread system animation that was still playing, in addition to the replay animations triggered by $P_{3,\text{right}}$. After $P_{3,\text{right}}$ identified that the first outbreak event occurred at Bangkok, by checking his timeline, $P_{3,\text{left}}$ mistakenly thought that it caused a chained outbreak event in Chennai. $P_{3,\text{middle}}$ then jumped in and tapped on the second game event with an outbreak icon, and this triggered a replay animation on the game map at New York. $P_{3,\text{right}}$ then continued to check game events on the timeline but provided an incorrect reasoning to why the two outbreaks were not chained. As $P_{3,\text{right}}$ had an incorrect reasoning, $P_{3,\text{left}}$ finally started interacting with the game events on his timeline and announced the correct set of events that took place: "It's with Bangkok and then New York. Those are the two outbreaks." This observation showed the importance of the timelines for the correct perception of changes.

Our results showed that some participants appreciated the replay animation on the game map and commented that it was beneficial for keeping track of others' exploration on their timelines. However, some also noted that it distracted and confused them. Although the system animation and replay animation looked different (see Fig. 3K and Fig. 3L for an example), participants had difficulties distinguishing these two types of animations quickly. For example, $P_{5,\text{left}}$ mistook the animation triggered by $P_{5,\text{middle}}$ as new outbreaks by the system, and announced "Bogota just outbroke!" He then quickly realized that it was a replay animation triggered by $P_{5,\text{middle}}$, and said "oh no, you are just smashing things. I hate you! I hate the board thing! Turn your board off, please!" $P_{5,\text{middle}}$ then turned off the feedback on the map. This confusion resulted in a negative response to the replay animation feature. Participants continued their discussion and pointed out that the key issue was the lack of awareness of collaborators' actions.

```
P5,left: Inform us when you are going to turn it on; otherwise,
    I go, 'oh no Bogota just outbroke!'
P5,right: It's kinda funny, but I also found it distracting
    when people do it.
P5,left: It's okay as long as you tell people you are doing
    it.
```

Due to the potential interference, some players manually toggled the feedback locations. However, this resulted in mode errors [40] where participants forgot about the current timeline mode and were confused when the replay animation was not triggered on the game map. Such observation showed a need to provide further support for workspace awareness of collaborators' timeline interactions.

The discard pile system feature was used for perceiving new changes as well, although infrequently (8 cases vs. 281 cases for timelines). In 3 of these 8 cases, the discard pile was used in conjunction with the timelines to verify the changes. For

example, after new changes took place during one group's gameplay, $P_{9, middle}$ was confused about why there was an additional disease cube on Moscow. He first navigated through the game history on his timeline to find out when it first happened. $P_{9, left}$ then opened the discard pile to check. Then, $P_{9, middle}$ and $P_{9, left}$ found that the Moscow card was drawn and thus had a new disease in the most recent turn through the timeline and the discard pile, respectively. The discard pile acted as an alternative information source.
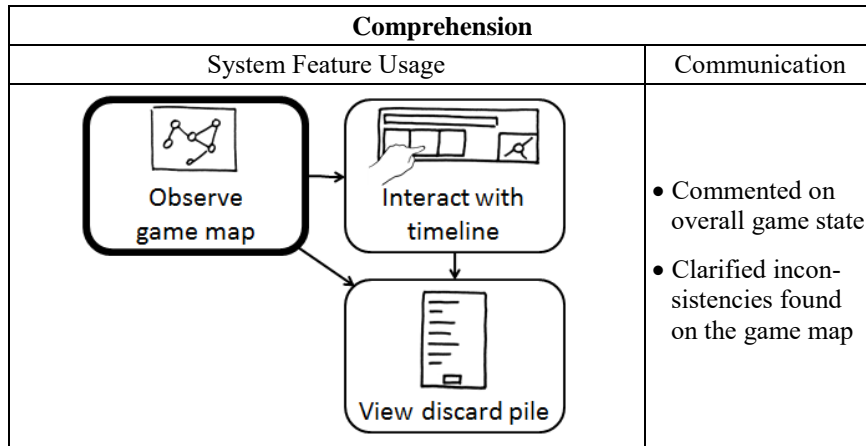
Overall, players reached the correct perception of the automated events most of the time (293/397 cases, 68.26%) even though participants had to correct themselves or each other in 22/293 cases, 7.51%. There were 99/397, 24.94%, cases in which we were unable to determine whether their perception was correct and 5/397 cases, 1.26%, where participants gained incorrect information or could not find the information needed.

The analysis also revealed the flexible work patterns employed by our participants. Participants sometimes ignored the system animations and continued to discuss strategy. Moreover, since advance planning of actions was common and necessary in the game, the current player sometimes focused on executing the actions agreed upon by the entire group beforehand, and relied on team members to observe and report the new changes. This finding showed the importance of providing persistent timelines for individuals to enable such flexible work patterns.

6.5 Comprehension

With the new changes explored, the comprehension level refers to making sense of the new changes and the overall game state. The players should seek to determine how the new changes impacted the overall game state. As participants were all experienced Pandemic game players, they generally understood the meaning of the changes. In some cases, the new changes did not have urgent impact on the game state, while in other cases participants started strategizing about how to address changes right away. We based our analysis on observable behaviours, and our data showed that the game map was used as a reference point for the group to comprehend the overall game state.

The game map was the most frequently used feature in the comprehension level to understand the overall state as well as to spot inconsistency in their understanding of the game state, as depicted in Fig. 6. After new changes took place, participants commented on overall game state based on the game map. For example, in one session, $P_{5, middle}$ commented on the overall spread of the blue colour diseases on the game map: "Oh my goodness, there's a lot of blue going on!".

Comprehension	
System Feature Usage	Communication
	• Commented on overall game state • Clarified inconsistencies found on the game map

Fig. 6 At the comprehension level, the game map was used most frequently to discover inconsistencies between participants' understanding of the game state and the actual game state. The timeline and the discard piles were then used to gather information, which allowed them to collaboratively understand the game state.

The game map was sometimes used in conjunction with the discard pile and the timelines for players to correct their understanding of the system state. For example, $P_{1,right}$ noticed that on the map Bogota had more disease cubes on it than expected, and she asked "have we been noticing that Bogota is a problem?" Then, $P_{1,left}$ opened the discard pile for the entire group to view and $P_{1,middle}$ looked at the discard pile and clarified that "no, it's just out [in the last turn]."
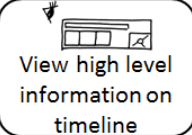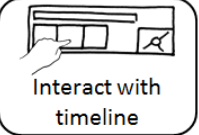
In another example, after new changes took place, $P_{3,right}$ first checked his timeline. Later on, while inspecting the game map, he found that the narrated events were inconsistent with the number of disease cubes on the map. This prompted $P_{3,right}$ to further investigate using his timeline to correct the group's knowledge, and he announced the correction to the group. Overall, the game map provided an overview of the situation for the comprehension of changes and understanding of the system state.

By the end of the comprehension stage, participants had usually reached agreement about the changes that took place and their meanings to the game. Next, they negotiated with each other on the strategies and on which actions to prioritize.

6.6 Projection

The projection level refers to predicting the future game states, and participants strategized, prioritized actions, and managed resources, based on their predictions. Generally, in Pandemic, players need to strategize based on when critical events would happen at which locations. This information can be estimated based on the current and past disease spread as well as when previous critical events took place.

While the timeline and the discard pile were both the key system features used to help remember historical events and forecast future game states, the discard pile was the primary feature used, as depicted in Fig. 7.

Projection		
System Feature Usage		Communication
View discard pile View high level information on timeline Interact with timeline		• Negotiated strategies

Fig. 7 At the projection level, the discard pile was used most frequently to prioritize actions, and participants negotiated their strategies with each other based on the information gathered. The timeline was beneficial for participants to view high level information, but it was used less frequently.

We found that the timeline provided high-level information that was beneficial for forecasting game states. For example, players counted the number of turns since the last epidemic event on the overview bar at the top of the timelines (6/333 cases of timeline interactions). As a fix number of epidemic events was roughly evenly distributed in the game, counting the number of turns since the last epidemic was a good predictor of the next epidemic event. Epidemic events signaled that previous infected cities may be infected again soon to create wider disease spread, so it was important for players to accurately predict when the next epidemic event might occur and adapt their strategies accordingly. Players also navigated through historical events to determine if any cities might be potential problems in the future. Since all other system features only provided limited amounts of historical information (e.g., the discard pile only listed the infected cities since the last epidemic event), players had to rely on the timeline for much older events.

The analysis showed that very few timeline interactions were conducted for the purpose of strategizing (used only 6 times in 88 cases of prioritization). The amount of effort required to navigate through many game turns to locate the target game event likely contributed to the limited use of the timeline for this purpose. More often, participants opened and read the content of the discard pile to prioritize their actions (used 82 times). The discard pile provided a quick way to access recent cities that were affected by disease spreads by providing all information in a single textual log with minimal interaction required (other than to open, and potentially reposition the widget). This information allowed players to decide which cities needed more attention by comparing cities in the pile and the current game state on the map. This showed that the design of such a textual log was more beneficial for the projection level of situation awareness.

The following example illustrates a usage of the discard pile for the purpose of prioritizing actions. $P_{1,middle}$ went through a list of cities that could potentially create outbreaks based on the current game state (i.e., cities that needed more urgent attention). $P_{1,middle}$ first named Moscow and $P_{1,left}$ opened the discard pile for the entire group to see (default location is at the centre of the map). After confirming that it

was not in the pile and thus was potentially high in priority, $P_{1,middle}$ continued to inquire the group about the status of Mumbai and Bangkok. $P_{1,left}$ opened the discard pile again, and $P_{1,right}$ viewed the pile and confirmed that they were in the pile, meaning that players only needed to attend to them when the next epidemic event was near. $P_{1,middle}$ thus concluded that Moscow was the only problematic city: "which is to say, Moscow is the only thing [to be concerned about]." $P_{1,left}$ agreed and reiterated on the urgency of Moscow: "that [Moscow] really needs to be dealt with right now." Players then continued to discuss how to spend actions to move to Moscow, and eventually treated diseases in Moscow in the same turn.

The discard pile was sometimes used as a tool to suggest potential actions to consider. However, this sometimes failed because there was too much information to parse through (i.e., too many cards in the discard pile), or it was simply not helpful due to the game state at the time.

7   Discussion

While the data analysis in Phase 1 revealed no difference across timeline alternatives in group situation awareness, the follow-up analysis showed that there was frequent communication among players to narrate information, discuss changes, and negotiate strategies. This sharing of information facilitated the group situation awareness. The game map, the timelines, and the discard pile acted as information sources for situation awareness maintenance. In this section, we discuss specific timeline designs that were beneficial for participants' situation awareness and lessons learned for potential improvements.

7.1 Perception: Make Changes Readily Available

The timelines were mainly used for perceiving new automated changes, and several aspects of the timelines helped participants to gather this information. The timelines appended new changes and automatically scrolled to the current turn, making the most recent information readily available for exploration. The visual design of the timeline structured the game events based on their types into three rows (i.e., player action vs. system automations) to facilitate locating game events. The colour-coding and icons provided overview information. Moreover, each timeline was placed at individual's personal area to provide quick access to new changes, visually and physically. In contrast, the discard pile was used less frequently for perceiving new changes, and this may be explained by the fact that reaching out to open the discard pile required more physical effort or more coordination to ask the player on the left (the position closest to the discard pile button) to open it. This observation also helps to explain why the shared timelines were used less frequently and resulted in lower situation awareness in Phase 1 of the study. In light of the benefits of timelines,

potential redesign may consider how to further streamline the perception of new changes, such as reducing the interaction required by including more detailed information for the most recent events.

7.2 Projection: Provide Critical Event Overview and Summary View

While the overview of critical events on the timeline helped participants determine the overall strategy, the discard pile was used much more frequently for forecasting events and prioritizing actions. The interactivity of the timeline was beneficial for reducing clutter. However, it required a high level of cognitive and physical effort for the participants to gain an overview of the historical events to project the relative urgency of problems. Moreover, the design that the discard pile appeared at the centre of the game map by default might have better facilitated information sharing and strategizing for a tightly coupled collaboration [44], such as in our context. Future designs of tabletop applications involving dynamic changes should consider providing a different summary view of recent events in the timeline or as a different system feature to support the projection of future system states.

7.3 Timelines for Supporting Group Work

The timeline was designed to support situation awareness for collaborative work. Our analysis revealed that the timeline was often used in conjunction with the game map. While the game map reflected the current system state and helped participants to notice new changes, the timeline was used primarily as the correct historical account to negotiate users' perception of the changes.

We designed the replay animation, invoked by tapping game events, as a way for users to gain more detailed information of new changes and as a way to virtually point on the map for information sharing. While both use cases were found in the data, there were only a few clearly observable instances. Participants mostly physically pointed at the game map to aid their conversations, and we believe that this was due to the turn-based nature of the game and the difficulties in searching for the replay animation due to the current design and large size of tabletop displays.

Moreover, the replay animation sometimes confused the participants and they mistook the replay animations as new system automated events. Since having both replay animation on the map and map cut-out on the timeline was the most popular configuration, future designs should consider more salient workspace awareness cues for the replay animation to facilitate feedthrough [30]. Considering participants' feedback in Phase 1 that the timeline felt disconnected from the game, we may consider a design where the timeline is visually associated with the replay animation to create a redundant encoding of invoker identity and allow for quicker

association. Furthermore, as participants tried to manually toggle the feedback locations, they sometimes forgot about their current setting. A potential solution would be to use a user-maintained mode [40] for the replay animation, where replay animation is only displayed on the game map when users dwell on a game event on the timeline. This design eliminates the need of toggling different modes of feedback locations.

7.4 Support Flexible Work Patterns

Our data analysis revealed several work patterns. Although groups' collaboration styles were mostly tightly coupled, the participants often investigated their timelines concurrently to investigate changes and verify information observed from the game map or overheard from others. Moreover, they sometimes split the workload. One participant carried out strategies previously agreed upon, and the rest of the team investigated new changes. Phase 1 and Phase 2 data analysis revealed the benefits of individual timelines on improved situation awareness. The configurable timelines also allowed participants to investigate changes at their own paces and allowed groups to use different strategies for maintaining workspace awareness.

8   Limitations

The Pandemic game provided a platform for rapid prototyping, and it was effective in eliciting complex planning and decision making behaviours. Moreover, its turn-based mechanics simulated the long down time and short spurs of urgent discussions that are similar to other contexts, such as emergency response and military training. However, when applying the interactive event timeline to other domains, it would need to be adapted to represent real-time data, which may impact its effectiveness. Nevertheless, the Pandemic game provided a context for quick iterations and resulted in design lessons for other co-located collaborative tools.

9   Conclusion and Future Work

This project contributed in further understanding timeline usage for situation awareness maintenance in the context of collaborative tabletop applications. Our video analysis showed the benefits of the interactive event timeline design for users to maintain situation awareness, especially for investigating complex, automated system events. It was used as both static and interactive visualization, and was primarily used for the perception level of situation awareness. While the summary of critical events on the timelines was useful for the projection level of situation

awareness, the results showed a need to provide summarized historical information optimized for strategizing.

In the future, we would like to investigate the following timeline redesign: streamlining the perception of new changes, providing a summary view to facilitate strategizing, and enhancing the replay animation to better facilitate observation of collaborators' actions. Furthermore, we would like to deploy the system in the field, e.g., a home or a game shop. Such environments have more interruptions and will help us understand the necessity of providing different types of information on the timelines. We would also like to apply our findings to other domains that require real-time awareness displays, such as emergency response, to understand how to adapt timelines for real-time data. Finally, timelines can also be applied to other co-located contexts, where a person in a monitoring role needs to keep track of the activities happening in the workspace to provide timely assistance, such as in classrooms [24] and in workshops [19].

Acknowledgments

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