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► **To cite this version:**

Wissal Sahel, Wendy E. Mackay, Antoine Marot. Creating StoryLines: Participatory Design with Power Grid Operators. 7th International Conference on Computer-Human Interaction Research and Applications (CHIRA), Nov 2023, Roma, Italy. hal-04276266

HAL Id: hal-04276266

<https://hal.science/hal-04276266v1>

Submitted on 6 Feb 2024

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Creating StoryLines: Participatory Design with Power Grid Operators

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Abstract. Designing interactive technology to support safety-critical systems poses multiple challenges with respect to security, access to operators and the proprietary nature of the data. We conducted a two-year participatory design project with French power grid operators to both understand their specific needs and to collaborate on the design of a novel collaborative tool called *StoryLines*. Our primary objective was to capture detailed, in-context data about operators' work practices as part of a larger project designed to provide bi-directional assistance between an intelligent agent and human operator. We targeted handovers between shifts to take advantage of the operators' existing practice of articulating the current status of the grid and expected future events. We use information that would otherwise be lost to gather valuable information about the operator's decision rationale and decision-making patterns. This paper describes how we combined a bottom-up participatory design approach with a top-down generative theory approach to design *StoryLines*, an interactive timeline that helps operators collect information from diverse tools, record reminders and share relevant information with the next shift's operator. We conclude with a discussion of the challenges of working with users in safety-critical environments and directions for future research.

Keywords: Collaborative Work · Generative Theories of Interaction · Participatory Design · Power Grid Operation · Safety Critical Systems.

1 Introduction

The *Cockpit and Bidirectional Assistant CAB* project is exploring how to take advantage of the increasing capabilities of artificial intelligence to assist operators of safety-critical systems. Rather than deskilling them or replacing them with new technology, we seek to design tools that enhance each operator's capabilities over time. This requires new forms of co-adaptive [20] interaction where the

This is the author version of the work. The version of record is published in: *Proceedings of CHIRA '23*, H. P. da Silva and P. Ciproso (Eds.), CCIS 1997, pp. 212–230, Springer, 2023. https://doi.org/10.1007/978-3-031-49368-3_13

system learns from the user as the user learns from the system. To be effective, users need to benefit from the system without it disrupting their work.

Achieving this requires a shift from traditional intelligent assistant design that prioritizes creating more efficient algorithms to focusing instead on designing the interaction from the user’s perspective in what we call a human-computer partnership [23]. This in turn requires a detailed understanding of the operator’s real-world work practices, not only how they monitor the system to build situation awareness but also how they capture, interpret and communicate information under both normal and crisis situations.

This paper describes our approach for capturing the day-to-day activities and decisions of control room operators at RTE (Réseau de Transport d’Electricité), the French national power grid. Our immediate goal is to provide better support for their current activities, with a longer term goal of capturing in-context data about how and when they made their decisions to inform an intelligent agent. This is particularly important since the operator’s decisions are judgment calls that balance a variety of trade-offs, only some of which are captured by the system. Instead of assuming an intelligent agent can capture the “ground truth” to define an optimal solution, we need to take advantage of the best characteristics of human common sense and system data management, where the combination of the two is more effective than either alone.

Developing such a system requires understanding operators’ work context and the challenges they face when making decisions, which requires access to them and their work environment. We describe our participatory design [13,22] approach to meeting our first objective: to ensure that the resulting system fits seamlessly into their current and future work practices without increasing their workload. A secondary objective is to collect relevant information that will inform a future intelligent agent that provides recommendations based on detected patterns of behavior. We thus hope to create a virtuous cycle where operators in the course of their daily work feed information to the agent that feeds it back to them in a form that lets them develop a more sophisticated understanding of the system, thus increasing their skills.

We wanted to take advantage of our work on generative theory [4] to design the interaction with the new system. Generative theories of interaction are inspired by established theory in the natural and social sciences but are transformed into concepts and actionable principles that inform design. We describe how we combined bottom-up participatory design methods with a more top-down theoretical approach based on *Instrumental Interaction* [2,5] to develop a novel system we call *StoryLines*.

We began by asking two research questions:

- *RQ1*: How can we gather in-context information from operators without increasing their workload?
- *RQ2*: How can we take advantage of a generative theory to design an interactive tool that supports light-weight data gathering?

The paper begins with a review of related literature on information management for safety critical systems, especially control rooms. We then describe

the results of a preliminary study with control room operators from the French power grid. Next, we describe how generative theories of interaction [4] offer new insights into the design of interactive tools and how we applied the principle of *reification* [5] from the theory of *Instrumental Interaction* [2] to our design. We then describe the series of workshops we conducted with control room operators to design and assess *StoryLines*, a timeline-based tool for capturing information and transmitting it to the next shift operator. We conclude with a discussion of the benefits and limitations of combining theory-driven and participatory design approaches when developing tools for safety critical systems.

2 Related Work

Control rooms are highly complex safety-critical environments. Operators must ensure normal operation and resolve breakdowns by managing technologies that help them interpret and manage large amounts of information. Researchers have investigated various aspects of control room management, including identifying advantages and costs of shifting to automated systems; examining how users manage information to maintain situated awareness and designing interactive technology that supports control room operators.

2.1 Adapting to control room modernization

The goal of automating control rooms is usually framed in terms of reducing human error and operator workload. However new systems also risk reducing the operator’s situation awareness and the skills they need to successfully perform automated tasks [37]. They may significantly change the operator’s role [28] and, if poorly designed, may actually increase the operator’s workload. For example, Mackay [20] showed that air traffic controllers’ interactions with physical paper flight strips can be safer than using screens.

Early transitions from analog to digital control systems often affected how operators accessed, perceived, and processed information. For example, Dai et al. [9] showed that interacting with monitors rather than physical control panels in nuclear power plants decreased the operator’s access to information, required additional information management tasks and required operators to rely on the computer system rather than their own memory, thus diminishing their skills over time. In these control rooms, Porthin et al. [37] observed that increasing the number of systems that provide information involves a corresponding increase in the number of interface management tasks. Kluge et al. [18] showed how introducing more advanced technology increased the operator’s physical and cognitive workload by forcing them to collect additional information and build more complex mental models to understand cause-and-effect relationships across system elements.

Salo et al. [43] argue that control room modernization often requires additional training and skill to master multiple systems and resolve inconsistencies. Operators must constantly calibrate their trust in the technology and often lack

a clear overview of the current state of the system. They may have difficulty acquiring and maintaining knowledge of rare events and must continuously adapt to increasing complexity of the technology.

Of course, some of the challenges operators face are due to problems unique to the particular type of control room. For example, radio astronomy control rooms require extensive screen real estate which makes it difficult for operators to access relevant information and increases their cognitive overload [36]. Similarly, maritime surveillance displays are often insufficient for effective situation awareness [32]. By contrast, Han et al.'s study [15] of a steel manufacturing control room highlighted the inefficiency of warnings about irregular situations and the lack of systematic classification and overviews of abnormal work conditions. Walker et al.'s study of oil production platform control rooms [45] described how operators lacked support for diagnosing and resolving non-routine conditions and found that the system's alarms were excessive, not timely, irrelevant or inappropriately prioritized. Operators also suffered from the lack of history logs, which made it difficult for them to identify trends and determine the causes of specific incidents.

Power grid systems often fail to provide operators with an effective overview, which forces them to constantly search for and integrate information from different screens [29]. Prevost et al. [38] show how the excessive number of display pages, missing information about equipment status and maintenance requests prevent operators from effectively synthesizing relevant information. Baranovic et al.'s study of four power grid control centers [1] showed that the SCADA system generates more information than operators can easily handle, especially when multiple faults appear in the grid at the same time. Militello et al. [30] highlight the coordination problems emergency room operators face due to asymmetric knowledge and experience, barriers to maintaining mutual awareness, uneven workload distribution and disruptions in communication.

These studies suggest that control room operators would benefit from better tools for synthesizing an overview of the current state of the system, recording a history of incidents to highlight trends, controlling alarms and reminders for future maintenance activities and supporting collaboration across operators with asymmetric knowledge.

2.2 Operator Strategies for Managing Information

In order to make informed decisions, control room operators develop information management strategies including closely monitoring system components, building a mental model of the current state and developing situation awareness. Vicente et al. [44] describe how operators build and maintain specific situation models using knowledge-driven monitoring strategies [44], while Roth et al. [42] show that operators enhance situation awareness by doubting the accuracy of the system: They check for problems and pursue unlikely findings, seeking additional information to confirm their expectations. Pilots are sometimes confused by inconsistencies between their expectations, the aircraft's behavior and the

auto-flight system [10], which they resolve by turning off the autopilot and fly under manual control.

Hutchins’s classic study of “distributed cognition” on the bridge of a naval ship [16] showed how operators take advantage of physical artifacts and other people to expand their cognitive capabilities, both to remember information and trigger future actions. Similarly, Mumaw et al. [31] showed how nuclear power plant operators offload cognitive demands by creating external reminders and collaborating with other operators. They recommend reducing noise, augmenting signals and documenting baselines or trends to enhance operators’ ability to extract information.

Walker et al. [46] emphasize the importance of communication in the control room, both to facilitate collective sense-making and ensure timely and effective action during a crisis. They describe the phenomenon of “talking to the room” where an operator shares information with the entire room as opposed to conversing with specific individuals. This non-directed talk helps teams interpret and explain ambiguous information and facilitates shared understanding and coordinated action. Similarly, Carvalho et al.’s studies of a nuclear power plant control room [6] found that operators use informal talk to maintain continuous verbal interaction with each other, not only enhancing mutual awareness but also helping operators anticipate and prevent errors.

These studies illustrate the importance of supporting operators’ natural strategies for trying to understand the system. Operators need help resolving conflicts between their intuitions and the system, lightweight methods for extracting information, either from the system or other operators, and low-effort tools for creating reminders and triggering future action.

2.3 Information Management Tools

Researchers have developed various technologies for helping control room operators manage information. Although some systems reduce the overall quantity of information, others use information visualization techniques to highlight relevant information. Other tools focus on facilitating inter-operator collaboration or provide decision support.

Kang & Park [17] argue that improving information visualization is critical for transforming massive quantities of data into useful information. Zhu et al. [47] proposed a data-driven interactive visualization approach for reducing cognitive load and increasing situation awareness for power systems. They proposed powerful data manipulation algorithms to generate visualizations of empirically and mathematically derived data. Pertl et al. [35] also proposed a method that summarizes the current state of a control room so that operators can anticipate and take appropriate preventative measures. However neither of these systems were evaluated with operators. Romero and Diez [41] went further with their *Alarm Trend Catcher* which filters and prioritizes alarms and projects future power grid states, providing operators with additional operational insights. Baranovic et al. [1] proposed an intelligent alarm monitor that not only selected 98% fewer

alarms than the existing *SCADA* system but also correctly analyzed and represented the root cause of the corresponding faults.

Systems that require collaboration among operators usually incorporate large displays to facilitate data sharing, increase situation awareness and encourage inter-operator communication [39]. Conversy et al.’s interactive tabletop for Air Traffic Controllers [8] enabled operators to communicate more effectively, both orally and with deictic gestures. They emphasized the need for “feedthrough” to help controllers maintain awareness their colleagues’ actions. Another study of power grid operators [29] identified problems that arise in rooms where operators must shift between a general overview and specific details related to each alarm. Their prototype supports coordinated views with interactive visual filtering and parallel coordinates and helps operators transition between focus and context views.

Of course control rooms are not static and must change to adapt to changing needs. Marot et al. [28] proposed guidelines for updating power grid control rooms that include redefining the operator’s role to enhance communication and facilitate complex decision making, centralizing information through a common interface and structured decision-making framework and integrating artificial intelligence technology to detect patterns and make informed recommendations.

In summary, the research literature shows that, despite the benefits of introducing automation into control rooms, operators often suffer from increased workload, reduced system awareness and lack of trust in the system. They have developed multiple strategies for improving their ability to make informed decisions and resolve conflicts between their intuitions and the information displayed on the screen. This suggests that future system designs should explicitly support their coping strategies. Finally, future research should take advantage of advances in data visualization research and artificial intelligence to help operators adapt to increasingly complex control rooms.

3 Preliminary Study: Identifying Operators’ needs

The above research literature shows that increased automation in the control room can increase operator workload while reducing system awareness and trust in the system. It suggests that new technologies should provide lightweight ways of extracting information and better synthetic overviews of the different components of the system, with tools for resolving conflicts between their intuitions and what is displayed on the screen. Operators would benefit from interactive incident logs that highlight trends and reminders for future action, both for themselves and others. Finally, they need better support for collaboration and communication with other operators.

We are working with the French national electricity distributor *RTE* (Réseau de Transport d’Électricité), which is responsible for managing the power grid across France and to other European countries. The current system is complex and becoming more so, with recent spikes in demand due to climate change and the war in Ukraine. At the same time, France is transitioning from its former

reliance on nuclear power to other, less predictable forms of “green” energy, such as solar and wind power. By 2022, only 62.7% of electricity came from nuclear power, compared to 70-80% in previous decades.

RTE is a member of the *CAB* (*Cockpit and Bidirectional Assistant*) project whose long-term goal is to take advantage of recent advances in artificial intelligence to provide a bidirectional virtual assistant that augments the real-time capabilities of control room operators. One of the key challenges in creating such an intelligent assistant is to develop the “ground truth” that will serve as the foundation for making effective decisions in a complex, ever-changing environment. However, although the rules and procedures for handling problems are well established, little of the operators’ reasoning about trade-offs and choices is captured. This makes it challenging to design an effective intelligent system that considers the nuances and complexities of different situations.

Initial interviews. Although we were committed to using a participatory design process [21,22] with RTE operators, the project began in the midst of the COVID-19 pandemic, which prevented face-to-face contact with operators or access to their control rooms. Even virtual meetings were initially difficult, given their reaction to previous project interviews that emphasized abstract discussions of the tasks they perform. We later learned that operators who had heard of those interviews viewed them as a waste of time, making them reluctant to talk to us.

After we explained our interview approach, which emphasizes concrete personal experiences over abstractions, we were granted an initial video interview with a junior operator. In order to establish trust, we explained that interviews would not be recorded (although we did take notes) and nothing they said would be reported to their employer.

We first asked the operator to prepare by remembering recent, memorable incidents of breakdowns or problems he had experienced. We then conducted a “story interview” [22,24] that gathers details about their recent experiences, especially breakdowns, workarounds and innovations.⁴ He enjoyed this interview and encouraged a senior operator to participate as well. The two interviews resulted in multiple specific stories about recent breakdowns that formed the basis for future design activities.

We were gratified by their positive reaction to story interviews and the focus on their actual, lived experience. The senior operator appreciated our grounded interview approach:⁵ *“I really see the work we can do together from a concrete usage perspective... I am really satisfied since this really makes things concrete for me... I am excited to continue!”* The junior operator agreed: *“This allows us to really make the things we talk about concrete and to clearly show you the problems that we encounter every day, whether they are simple problems or profound problems in the organization we have today. I want to wish you*

⁴ The *Story interview* method was inspired by the *Critical Incident Technique* [11] but adapted to support interaction design.

⁵ Quotations are translated from French.

bravo since, despite the frustration of the fact that we can't be in the same room and interact with even just our hands, you have managed to find tools that are practical enough for us to feel like we are making progress, even if we can't be together physically." Our focus on their perspective about their experiences rather than forcing them to adopt a system-oriented design perspective gave us access to a very scarce resource — the operator's time — and provided a solid foundation for understanding their work practices and generating ideas for improvements.

Control room visit. Despite their highly restricted schedules, within less than three months, the two operators each granted us seven hours of contact time and asked other operators to provide additional input. They also invited us to observe their control room in Nantes (although only through an observation platform due to COVID-19 restrictions).

Workshop 1. The first workshop was conducted in person, in our lab in Paris. The goal was to identify breakdowns faced by operators in the control room. We first sent the operators an explanatory video that explained the five workshop activities with examples of what we expected. We also asked all participants, both operators and researchers, to prepare a one-minute video that illustrated a specific breakdown that they had recently encountered at work. Finally, we asked them to have blank sheets of paper and pens to support paper prototyping. Each participant explained their video and we probed for more details about what actually happened. The goal was to avoid generalized descriptions of what usually happens and instead, capture the nuances of what happened that particular time.

We then conducted an online brainstorming session to collect additional breakdowns, including: retrieval problems due to information scattered across multiple tools, the mismatch between information displays and their mental models, the disruptive effect of interruptions that caused them to forget important information, information overload due to excessive numbers of software tools, paper documents that are hard to manage and often out of sync and system features that waste their time (Figure 1 summarizes these findings.) We concluded with a debriefing to gather feedback and gauge the operators' interest in continuing to collaborate with us.

Workshop 2. The first workshop was extremely well received by the operators who not only recruited an additional operator, but also invited us to visit them at the control room in Nantes for a day-long workshop. This launched the second, participatory design phase of the project, described in section 5. However, in parallel, we also began working on a more theoretically driven design process, described in section 4.

Preliminary design workshop results**Information mismatch**

- Paper and screen-based views out of sync
- Paper and electronic systems are not linked
- No shared view when collaborating with someone
- Display not adapted to current operation, risks confusion
- Lack of real-time visualization overview
- Cannot access views of adjacent sectors

Interruptions

- Phone calls interrupt work flow
- Distracted from a document and forget where I was
- Switching from tool on one screen to another

Risk of forgetting

- Need to update the schema (paper map) after each maneuver
- When busy, easy to forget information for the handover

Wasted time

- Always have to search for options
- Instructions are complex, confusing and not adapted for real-time operation
- System should propose actions relevant to the current alarm

Fig. 1. Preliminary workshop results include issues with information mismatch, interruptions, risk of forgetting and wasted time.

4 Inspirations from Generative Theories of Interaction

The long-term goal of the CAB (Bi-directional Cockpit) project is to design an intelligent assistant that learns from and augments the operator’s skills. However, before we can accomplish this, we first need to collect detailed, in-context data about how operators currently perform complex operations and make difficult judgments. We need to balance two potentially conflicting goals:

1. Capture a large quantity of detailed in-context data from operators, including characteristics of normal and unusual incidents, specific actions the operators performed, which decisions were made and how effective those decisions were.
2. Ensure that the act of collecting this data is not viewed as an additional, cumbersome task that increases the operator’s workload, but rather as a tool that saves them time and makes them more effective.

We thus prioritized our design goals to begin with the user’s perspective so that the resulting system offers them concrete benefits, and only secondarily focusing on capturing the most detailed relevant data possible. Based on our observations and discussions with the operators, we decided to focus on the handover between operators at the end of every shift. We can take advantage of the fact that all operators already prepare information notes for themselves that summarize the current state of the power grid, any upcoming actions or expected critical events, and the results of any research the operator conducted to solve current or projected incidents.

We decided to address the needs identified in the preliminary study (section 3) using the strategy outlined in [4] for applying a *generative theory of interaction* to a real-world design problem. This strategy combines bottom-up analyses of current work practices with top-down concepts and principles derived from theories of human behavior. We were particularly influenced by *instrumental interaction* [2,5], which builds upon theories of affordances [12] and human tool use [34,33,40] from experimental psychology. In particular, we explored the principle of *reification*, which transforms an otherwise ephemeral action into a persistent interactive tool.

For example, the design of *StickyLines* [7] was inspired by studies of designers who spend an inordinate amount of time aligning graphical objects. Users must select the objects to be aligned, navigate via a pull-down menu, and choose the appropriate form of alignment. Any future adjustments of any of these objects breaks the alignment and requires further realignment. By contrast, *StickyLines* “reify” the alignment command into an interactive object that makes the alignment persistent. It acts as a magnetic guideline to which shapes can be attached so that moving the guideline also moves the attached objects. *StickyLines* can align to any shape, such as a circle, and create multiple, interconnected alignments, such as an easily adjustable grid.

When we examined the results of the preliminary study, we saw the opportunity for reifying sequences of incidents and corresponding actions into a persistent, interactive object that we call *StoryLines*. Each operator can collect personally meaningful sequences of events, either automatically or intentionally, to create coherent “stories” that capture relevant information and actions associated with different tools. They can also set reminders or trigger future events. *StoryLines* are designed to replace operators’ hand-written notes but should save time by avoiding duplicate information and providing real-time links back to relevant information on a global timeline that would otherwise require time to search. *StoryLines* should also filter information to give an easy-to-scan overview of current incidents, actions and upcoming events.

The current environment used by operators is an example of what Beaudouin-Lafon [3] calls “walled gardens and information silos”, with no easy mechanisms for transferring information across non-interoperable systems. The design of *StoryLines* is also inspired by systems such as *Passages* [14], which let users create a common representation for transferring information from one tool to another.

The design of the *StoryLines* involved a number of challenging design questions: Do operators want a single *StoryLine* composed of multiple incidents or multiple *StoryLines*? Are *StoryLines* associated with a single operator during a single shift or are they transferred from one shift to another? What is the relationship between individual *StoryLines* and the overall history of events? What is the best way to visualize *StoryLines* and what information should they prioritize? In order to address these and other design questions, we engaged in what turned out to be a two-year participatory design project that involved a series

of remote and in-person workshops and activities with operators and members of the research team.

5 Participatory Design of *StoryLines*

We wanted to combine our theoretical work (see section 4) with a participatory design approach. The traditional “user-centered” approach to designing interactive systems can be oversimplified as first conducting a user study to determine users’ needs, then exploring a new design and finally testing it with target users. By contrast, participatory design [13,21,22] actively involves users throughout the design process. While this has proven to be highly successful in a few safety-critical settings, such as that described by Mackay [20,26] with air traffic controllers, it is relatively rare due to security restrictions, limited physical access to users and their work environments, and the confidential or proprietary nature of the technologies and associated data.

We also cannot risk losing participants’ interest by forcing them to adopt our theoretical stance. Instead, we need to let them express their experiences and needs in their own terms while contributing concrete examples of design ideas inspired by our theories which they can interpret and evaluate as they like.

We followed the participatory design approach outlined in [21,22] and [24], beginning with story interviews that capture detailed examples of recent, memorable incidents, especially breakdowns, workarounds and user innovations. We transformed these into scenarios in which personas who represent actual controllers encounter a series of events that highlight the issues that must be resolved. We brainstormed ideas, first verbally then as short video clips that illustrate the interaction [27] and then collaborated on creating various types of prototypes [25], ranging from paper to Figma to working software. We ran different types of qualitative evaluations to advance the design, and iterated with additional interviews, brainstorming, design sessions and evaluations. Participants found this approach highly engaging, since all the activities were designed to emphasize their perspective, with concrete activities that let them express their needs and ideas, as well as react to our ideas, in an enjoyable, non-threatening format.

These participatory design activities were conducted over a two-year period with delays due to the COVID-19 pandemic, changes in personnel and scheduling challenges, as well as requiring time to digest the results of each workshop and to develop prototypes, which evolved significantly across the different workshops and design sessions.

Participants: We recruited a total of four active participants who contributed to multiple activities over several months and three additional operators who contributed to specific events. One very senior operator participated throughout the entire design process. The junior operator who participated in the first series of activities left RTE after the first year. He was replaced by a junior and a

senior operator who were actively involved in later activities. Three other operators participated in individual workshops and others contributed information or joined discussions at various points in the process.

RTE control room organization: Four researchers visited the RTE control center which began with a “virtual” guided tour from the senior operator. The main control room is designed to support four operators: three who supervise a particular zone (east, west and south) and a senior manager who oversees the others. During busy times, a fifth operator may also be included. Operators are trained on all three zones and spend approximately seven weeks in one zone before shifting to another. The manager supervises all three zones.

The three operator desks were positioned to face a wall-sized display on the back wall with a huge map that displayed the entire energy grid.⁶ The manager’s desk is positioned behind them, with a view of all three desks. Each operator has a large U-shaped desk with an interior approximately three meters wide. We counted about a dozen “stations” for different tools and information sources, including multiple screens, a printer, two telephone stations and areas for other devices. One set of three screens is operated with a single mouse and keyboard, whereas other tools have dedicated keyboards or control panels. Some tools provide overviews and details about the current status of the energy grid, some sound and monitor alarms while others help operators research re-routing solutions to current failures, expected maintenance or other projected problems. The size of the desk area requires them to use rolling chairs to transition from one station to another.

Software tools. Energy grid operators are trained on over 50 different software tools that gather information, sound alarms and suggest solutions. These tools have been introduced over several decades with correspondingly different, often incompatible user interfaces. Operators must collect information scattered across their work area and they struggle to form a coherent overview of the power grid. Most information is presented as raw data that rarely matches the operators’ mental models. Worse, some information is cumbersome or difficult to retrieve in real-time and junior operators reported that instructions and guidelines were often difficult to understand.

Paper-based tools. Operators also use multiple paper-based tools. An A0-sized paper map of the energy grid, reprinted monthly, is used to note current breakdowns which they must remember to erase when the problem is solved. Although this paper map provides a concise overview of the grid, it is usually out of date since it is not linked to any online software tools. Other paper-based supports include a large ring binder, exchanged monthly, with hand-annotated printouts of specific “incidents”, an A3-sized log sheet for recording completed maneuvers

⁶ This wall has since been removed as part of a major renovation that will consolidate multiple control rooms.

and “floating sheets” for informally recording notes, reminders and information for the shift handover.

We were particularly interested in the fact that all operators took paper notes that they used to keep track of ongoing activities and manually transfer information from one system to another (which they view as a waste of time). They also create reminders for future actions and list key items to communicate to the next shift’s operator during the handover. We were also struck by the level of oral communication between operators, not only during shift handovers but also across zones and with the manager. Operators were often interrupted by phone calls from clients and other stakeholders. From the perspective of the CAB project, this is extremely valuable information that is lost and unavailable to the system.

Participatory design workshops: After the preliminary study, we conducted a series of participatory design workshops between July 2021 and June 2023. Figure 2 shows this sequence of activities with operators, both in person and online, as well as the evolution of the *StoryLine* prototype from paper mock-ups to working software.

Workshop 2. The success of workshop 1 (see section 3) led to an invitation to visit the RTE control center in Nantes. Workshop 2 was an all-day event with seven participants (three controllers and four researchers). Six were physically present and one controller joined via video from the control room. The controllers gave us a virtual tour of the control room (described above) after which we brainstormed ideas for how to address the breakdowns specified in the scenarios from workshop 1. Next, we paired controllers with researchers to draw a short “interaction snippet” or storyboard to illustrate each idea. Finally, each pair created paper mock-ups and shot short video clips where the controllers demonstrated how they would interact with each idea. The operators especially liked the video brainstorming activity because it gave them a concrete way to communicate both the problem and the solution. The workshop resulted in 10 interaction snippets and five video prototypes, all of which highlighted the need for centralizing information.

Workshop 3. The third workshop was also conducted in person, in Nantes and focused on situating the breakdowns identified earlier in a realistic context. We began with a visit to the observation deck above the actual control room, which allowed us to observe the operators in action. Next, we ran a design session that involved creating realistic personas based on the operators involved in the project and a “current scenario” to illustrate the breakdowns in a realistic context. The operators drew from their experiences to adjust the scenarios, especially with respect to the ways in which small errors, particularly in communication, can cause problems or complicate the situation.

The workshop resulted in scenarios related to two personas: Charles and Julie. Charles is a senior operator with 12 years of experience and Julie is a junior

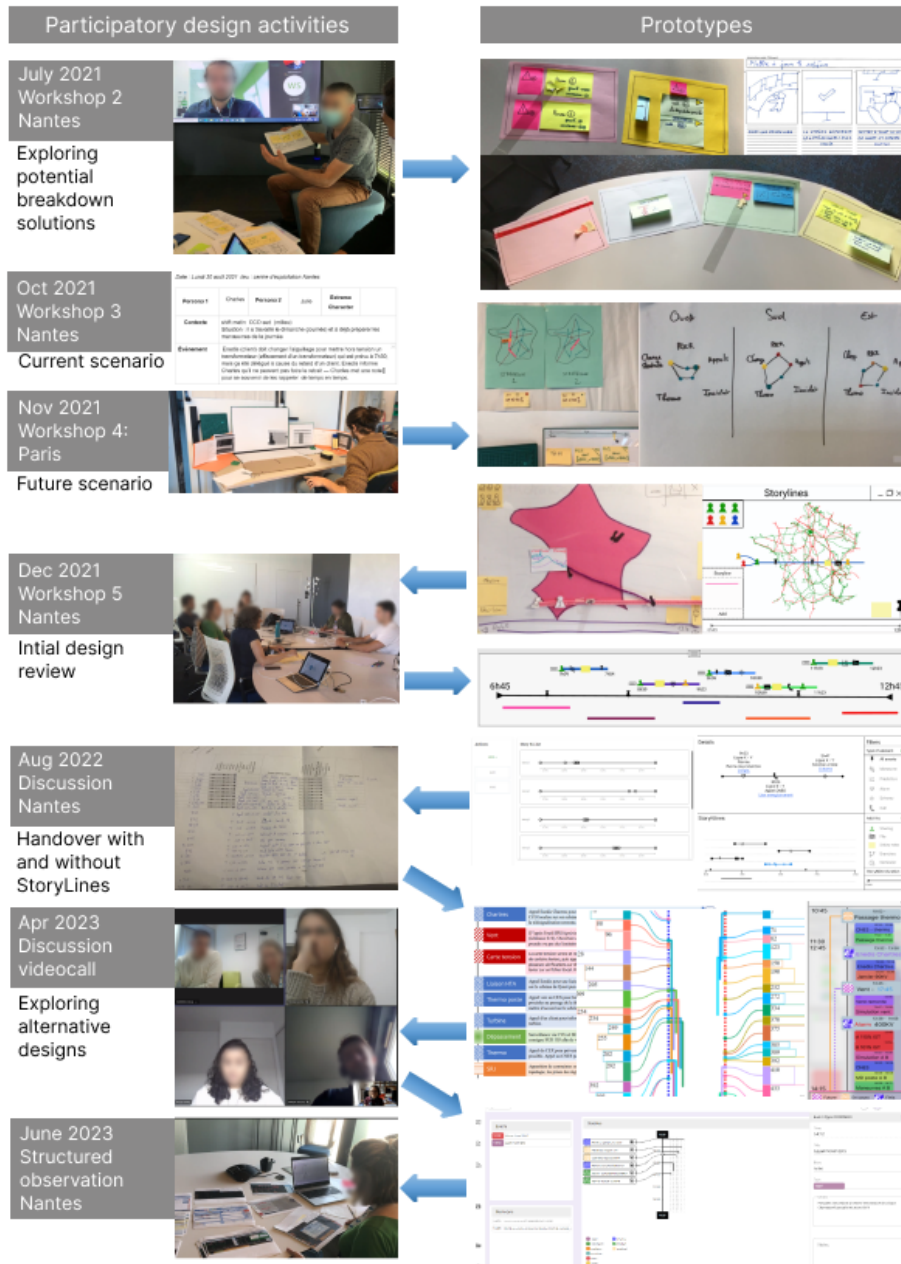


Fig. 2. Participatory design activities alternated between design sessions with operators (left column) and prototypes created by operators and researchers (right column) over a period of approximately two years.

operator who just finished training. The scenario includes three main situations: a busy morning for Charles who just returned from vacation; a rushed and poorly prepared handover to Julie and an afternoon filled with complex problems for Julie.

Workshop 4. The fourth workshop was conducted in our labs with five researchers and two operators. We developed a “future scenario” based on the scenario created in workshop 3 that explored potential solutions. We supplied prototyping materials and simulated their environment with paperboard “screens”. We then created paper mock-ups of the different tools and created video prototypes of various solutions proposed by the operators and researchers. The results included four specific solutions designed to improve communication with the planning team, visualize cognitive load and visualize failures as they evolve over time.

Workshop 5. The fifth workshop was conducted at the RTE control center with three researchers and one operator physically present as well as one remote senior operator. The goal of the workshop was to use a generative walk-through [19] to evaluate the scenarios and ideas from workshop 4. We played the video prototypes and discussed how to improve the proposed solutions, including incorporating new information as a situation evolves, automatic update of other information and tasks, tracking and comparing solutions and taking into account the “last time to decide” (LLTD). This workshop highlighted how much critical information is lost, either because it was transmitted orally or it was never captured in the first place.

Workshop 6. The sixth workshop was also conducted at the RTE control center with four researchers and five operators. Our goal was to present the operators with a working prototype of *StoryLines* and obtain their feedback, suggestions and ideas. We worked with pairs of operators who followed two scenarios, one extremely busy with multiple overlapping events and the other relatively calm. They performed tasks, interacted with *StoryLines*, took notes and prepared for the handover to the other operator, after which they continued with the second scenario. Half of the operators first performed the “busy” scenario, followed by the “calm” one. The other half performed the “calm” scenario first. We conducted two sessions with two operators each and then ran a debriefing session with the operators who participated plus another senior controller.

6 *StoryLines*

We designed *StoryLines* to provide operators with a personal, interactive history and overview of their past, current and upcoming activities. It serves as a shareable repository of relevant information where they can take notes, register reminders and ensure they have access to all the information they need to handle the handover. Figure 3 shows the final working prototype that we tested in workshop 6 with operators at the RTE control center.

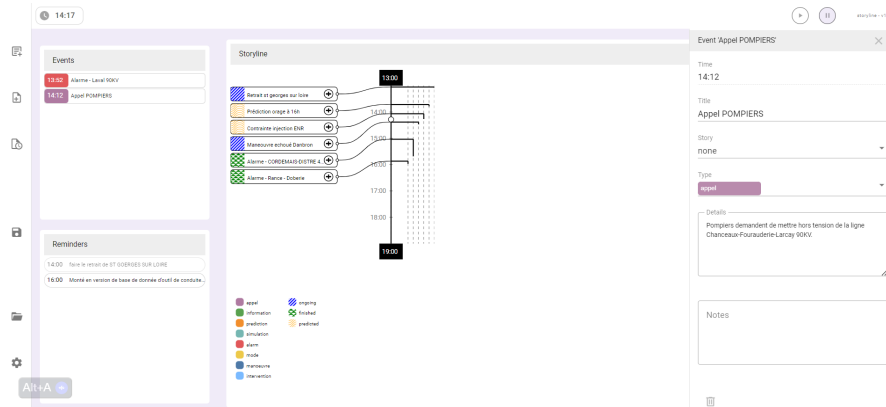


Fig. 3. The working *StoryLines* prototype includes five panels (from left to right): toolbar for adding stories, events and reminders; chronological event list; reminder list; story timeline and the panel for displaying event details.

This prototype includes five panels. The toolbar includes buttons for adding stories, events and reminders. The event panel provides a chronological list of events, including alarms, telephone calls, simulations and actions performed on the grid. The reminder list includes reminders, with the ability to trigger notifications based on time or events. The story timeline includes the series of stories, each with a title, status (completed, ongoing or predicted) and access to events, which can be included with the + button. The Event details panel appears when the operator clicks on an event and lets them inspect its time, type, story, and any associated notes or other annotations.

StoryLines offer a lightweight, central location for the information collected from different tools and is fully configurable by the operator. Operators can link relevant information together into “stories” to describe important events. *StoryLines* preserve the provenance of system-supplied information, which facilitates future retrieval of additional details and captures the context in which various decisions were made. *StoryLines* can facilitate record-keeping by providing templates for common tasks and help operators track their previous decisions for future reference. Finally, *StoryLines* support sharing information between operators, not only during shift handovers but also with managers and other stakeholders during the shift.

Reactions to StoryLines The focus of this prototype was how to provide a concise interactive visualization of the events that make up a story, including the events that occurred and the actions performed. The second-to-last panel of Figure 2 shows an alternative approach, with various strategies for expanding and contracting the level of information displayed. We plan to continue working on the design to further simplify the interface.

The operators found the visualization effective, but shifted their attention to the keyboard-based method of capturing information. They viewed this as

“yet-another-keyboard” and were far more interested in a tablet or paper-based interface that more closely matched their current note-taking methods. They also wanted the ability to use templates for commonly occurring types of events with pre-filled elements and the ability to add additional annotations.

7 Conclusion

We are interested in designing tools for control room operators that enhance their skills instead of deskilling them. This requires shifting the focus from the design of intelligent algorithms to the design of effective interaction with those algorithms in real-world contexts. We conducted a two-year participatory design project with operators from the RTE French power grid, with two key research questions:

- *RQ1*: How can we gather in-context information from operators without increasing their workload?
- *RQ2*: How can we take advantage of a generative theory to design an interactive tool that supports light-weight data gathering?

We examined the research literature and found that increased automation in the control room can increase operator workload while reducing system awareness and trust in the system. Previous work suggests that new technologies should provide lightweight ways of extracting information and better synthetic overviews of the different components of the system, with tools from resolving conflicts between the operators’ intuitions and what is displayed on the screen. Operators would benefit from interactive incident logs that can be augmented to highlight trends and the ability to register reminders of future actions, both for themselves and others. Finally, they need better support for collaboration and communication with other operators.

The results of our studies with operators echo these findings and provide specific examples of challenges faced by users. They also suggest a key opportunity for design, i.e. targeting the operators’ existing use of informal notes to support the handover to the next shift.

We combined participatory design methods with design inspiration from *Instrumental Interaction* to create *StoryLines*, an interactive timeline that helps operators collect information from diverse tools, record reminders and share relevant information with the next shift’s operator. *StoryLines* illustrate a successful application of the principle of “reification” by transforming a series of ephemeral events into a persistent, interactive timeline that serves as a repository for key information during the operator’s shift. We also show the evolution and refinement of the concept through multiple design iterations and discussions with operators.

We are now exploring how to enhance data capture by providing tablet-based interaction, and are working with members of the CAB project to integrate *StoryLines* with the new software system that they are developing. This will enable us to conduct evaluations of *StoryLines* in a realistic setting.

Our work shows that participatory design is an effective way of engaging operators of safety-critical systems in productive design activities, and that combining participatory design with a theoretically based approach can lead to a simple yet effective user-centered design. At a time where artificial intelligence and automation risk deskilling and disenfranchising users, we hope to see this approach applied to other contexts, safety-critical or not, to create socio-technical systems where machines empower rather replace or enslave users.

8 Acknowledgments

This work has been supported by the French government under the "France 2030" program, as part of the SystemX Technological Research Institute within the CAB project.

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