Tasks, Trends, Typefaces: A Cross-Domain Comparison of Guidelines for Information Visualization in Control Rooms

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Abstract

The appropriate visualization of a variety of different information is generally of fundamental importance in control rooms. However, looking at different domains (e.g. aviation, power plants, infrastructure), the question arises as to whether there are cross-domain recommendations in view of workplaces that differ with respect to size, resources and workflows. This paper aims to provide a synoptic view of the existing recommendations that were considered in the design of human-centered control rooms in different domains of use. A review of the literature of scientific publications resulted in a list of 14 cross-domain guidelines that are relevant in aviation control, power plant control, and infrastructure control. The guidelines represent a foundation for usable information visualization in safety-critical domains open for expansion and development of domain-specific solutions.

CCS Concepts

• **Human-centered computing** → *Information visualization*; **Visualization theory, concepts and paradigms**; Visualization design and evaluation methods.

Keywords

Control Room, Interface Design, Design Guidelines, Information Visualization

1 Introduction

Control rooms can be defined as "centralized environment[s] designed to monitor, control, and optimize complex processes and systems [where] pervasive displays underscore the necessity for comprehensive and readily accessible visual information to support continuous monitoring and decision-making, ensuring that critical data is always available to operators" [36]. The given and abridged definition seeks to describe industrial control rooms, but it can also be applied to other environments, for example infrastructure control rooms for power plants, power grids, road traffic, or even more confined spaces like airplane flight decks. All of these environments have in common that human operators monitor and manipulate a system. Therefore, they have to make decisions, follow procedures and checklists. Those are activities that must be carried out in the whole spectrum from routine tasks to emergency tasks. Essential for successful work in such a demanding environment are systems that support the operators in performing their tasks. One supportive aspect lies in effective information visualization.

In contemporary control rooms, it is a common picture that at each workplace a set of multiple displays visualizes the necessary data to the operator in a way that is thought to support her or his work in a suitable way. Additionally, large screen displays are a common tool to maintain a common situational picture and ease communication between the workers. Manipulations of system variables are usually done by mouse, keyboard and sometimes stationary touch screens [13, 17, 30].

This work seeks to answer the question: What guidelines for information visualization can be identified that are relevant for contemporary control room display designs across different domains? Here, the aim is to identify rules that are so basic that they are an integral component of effective human-centered design. In order to provide orientation, the listed guidelines will come with explanations and references to best-practices.

The next section focuses briefly on the scientific background of interface and visualization design, their need for progression, and special requirements of control rooms. Then, the scope review methodology is described according to the PRISMA scheme [33]. The results show a list of the 14 identified inter-domain guidelines for the design of control room displays with current technology, which is discussed afterwards. The contribution ends with a summarizing conclusion.

2 Background

With the wider distribution of early commercially successful forms of graphical user interfaces in the 1980s and the following decade, it became clear that computer displays would play a role in future control rooms [1, 41]. This was due to the understanding that this new technology would bring substantial advantages compared to the single-sensor, single-indicator concept, which was the result of previous technological constraints. Consequently, a need for

Mensch und Computer 2025 – Workshopband, Gesellschaft für Informatik e.V., 31. August - 03. September 2025, Chemnitz, Germany

https://doi.org/10.18420/muc2025-mci-ws01-184

the evaluation of graphic displays toward user performance was found [35] and within the discipline of Human-Computer Interaction (HCI) research-based design principles and guidelines emerged that sought to support a user-oriented system design [19, 21]. According to Shneiderman's three-staged taxonomy, guidelines give "Low-level focused advice about good practices and cautions against dangers" [39]. Therefore, these are direct-formulated, easily understood, and applied rules. Higher concepts are principles and on top stand theories. In this article, a focus lies on guidelines for information visualization. Kerren et al. defined this term as the use of computer-supported, interactive, visual representations of abstract data to amplify cognition with the goal of helping people understand and analyze data [23]. This understanding matches with the given control room settings, as computers display measured and processed information on screens to support the operators in performing their tasks.

Due to technological evolution, it is necessary to steadily evaluate and develop existing principles and guidelines to match the inherent demands of changing human-computer environments. An indicator for this assumption is the constant revision and adoption of Shneiderman's often cited book about strategies for effective HCI [39] which was published in 1987 for the first time and is now available in its sixth edition. With a view on another prominent approach [31], Gonzales-Holland et al. are more frankly when they point out: "There is a significant problem that has emerged with Nielsen's (1994) 10 usability heuristics. Technology has evolved considerably in the last 20 years [...] the factor analysis that Nielson conducted was on usability problems from systems prior to 1994" [14]. While general interface design for commercial computer systems or devices is an advanced field that provides valuable stimuli, this article focuses on control rooms. The constriction is necessary, as in this application field specific requirements and conditions constitute restrictions that separate control room interface design from general interface design effectively. Among other things, there is a strong need for regulatory compliance with a diverse set of standards, and even small changes can lead to licensing and standardization issues [20]. As control rooms are part of industrial or public facilities, financial requirements always play a limiting role and shape decisions.

There is existing work on interface design and information visualization in specific domains (see Table 2). What is missing is a comprehensive overview about recommendations that were considered in display design of contemporary control rooms across different domains.

3 Method

A scoping review appeared to best address the characteristics of the research question. According to Paré et al. this type of review seeks to comprehensively summarize prior knowledge by utilizing content or thematic analyses for data extraction. For this purpose, conceptual and empirical sources with a rather broad scope are selected based on certain eligibility criteria [34]. Although a scope review is not a full systematic review, the PRISMA scheme was used as an orientation to plan, conduct, and report this work [33]. In total, two researchers participated in the whole process. In case of discrepancies, an independent third scholar would have been asked for a decision.

3.1 Search Strategy and Information Sources

Between 3 March and 30 May 2025, the search was conducted in the databases ACM Digital Library, AIS eLibrary, and Digital Library of Gesellschaft für Informatik e.V. (GI). Further, the search engines Google Scholar and scienceOS were used. A filter was set for the publication period between 1985 and 2025. Additionally, reference lists of relevant articles were screened, what created a linking point to a targeted search for single publications in the Nautos Database, the Göttingen State and University Library (SUL) catalog, or the Google search engines. Table 1 provides the keywords, search strings, or prompts that were used for each source.

3.2 Eligibility Criteria

Documents were included if they were published in English or German and addressed guidelines for the design of control room system displays. Additionally, only peer-reviewed articles, books, conference papers, or official standards were considered, and their full text had to be accessible. Sources that focused on systems with multi-modal input, systems utilizing augmented reality or virtual reality technologies, or control systems for unmanned vehicles were excluded.

3.3 Selection Process

Selection was performed in two stages: first, titles and abstracts were screened. Then, full texts of potentially relevant publications were assessed. The titles and abstracts were checked by one reviewer who considered the inclusion criteria mentioned above. In case of insufficient information, the documents were not discarded. In the next step, the same reviewer read the full texts to select the studies to be included. A resource was excluded during the data extraction phase, when the presented guideline did not appear correspondingly in at least one paper of another domain.

3.4 Quality Appraisal

A formal quality appraisal of the sources was not performed due to the heterogeneous types of sources. Data were only considered for this work when the significance of empirical evidence was given or an argument was logic and stringent. The eligibility criteria include a minimum quality threshold.

3.5 Data Extraction

The full texts were manually scanned and organized in a matrix according to the following criteria: 1) domains of use and 2) applied or recommended interface design guidelines. Three domains were identified where the authors stated recommendations for the design of user interfaces or explained principles of their own research project: aviation, power plants, and infrastructure. A fourth general category was used to collect recommendations that were formulated independently from a specific context of use. Thereafter, the matrix was used to compare design recommendations across the domains. When a recommendation appeared in at least two domains, it was formulated as a guideline. In this merging process,

Table 1: Search Strategy and Information Sources

Source	Keywords, Search Strings, or Prompts
ACM Digital Library AIS eLibrary Digital Library of GI	"control room" AND display design, "control room" AND interface design
Google Scholar	control room interface, control room design, crisis management system, digital control system, emergency control system, incident room, hci information visualization, infrastructure management system, interface design, interface design principles, multifunction display, multifunction display design, power plant control interface, process control, traffic control, traffic management
Nautos	DIN EN 894-1, DIN EN 894-2, DIN EN ISO 9241-210, DIN EN ISO 9241-112
Google	AC 25-11B - Electronic Flight Displays pdf
Göttingen SUL catalog	human-computer interaction, Mensch-Maschine-Systeme
scienceOS	"Which principles are there for the design of classical interfaces for control rooms?" "Do control rooms have central displays for the most important critical system information? I mean control rooms in areas like power plants, crisis management, industry, infrastructure, ambulance distribution etc. How do those displays look?" "I am looking for guidelines of display design in control rooms for infrastructure monitoring. Are there some papers concerning this topic?" "Are there Papers about the interface design of mission control or incident control software?" "Was gibt es für Publikationen zu Einsatzleitsystemen von Rettungs- und Sicherheitsorganisationen?"

formulations were used that seek to generalize the original domain-specific statement on the inter-domain level without losing the key information. For example, a flight crew alert on a primary flight display and an operator alert in a power plant information system would have been generalized to an operator alert on a display, which is applicable for the level of a guideline. The guidelines were listed up and grouped by content. The extraction was performed by one reviewer and spot-checked by a second. In case of conflicting interpretation, an independent third scholar would have been asked for a decision.

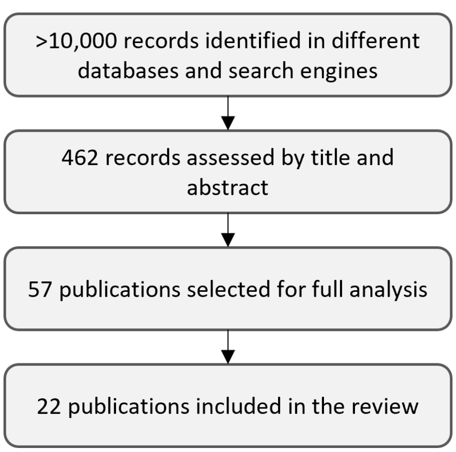

Figure 1: Flowchart of the literature selection process.

4 Results

Figure 1 shows the selection process. A calculation of the total number of identified documents did not yield a meaningful value due to the different source types and redundant entries. A rough estimate indicates a number greater than ten thousand records. 462 records were selected for the evaluation of their titles and abstracts. In total, 57 publications met the eligibility criteria. In the end, 22 publications, published between 1992 and 2023, were found to provide common design guidelines or recommendations for control room displays.

In the following, the reader finds a list of the recommendations found, each followed by an explanation and best practices, as applicable. Table 2 shows the references grouped by their respective domain and Table 3 presents a summary of the guidelines.

1. Not more than six distinct colors should be used to code information. The aim of this guideline is to ensure that meaning of color-coded information is identified quickly through easy discrimination of differences. The less colors an operator has to differentiate, the easier tasks are fulfilled and learned. Additionally, the use of shades of the same color for distinct meaning should be avoided [11]. The exact number of recommended colors differed between the authors, ranged from four [41] to nine [4]. Most of the sources recommended a value of six colors [11, 19, 21, 41].

2. Conventions and standards from work domains and cultural contexts should be recognized and considered for the use of color. This guideline seeks to enable the quick identification of information and also to reduce errors. There are more or less explicit norms regarding the meaning of colors in many life contexts. For example, red is generally associated with danger, while yellow is commonly known for warnings [21]. Nonetheless, there are differences between work domains and cultures which should be identified and taken into account [4, 9, 11, 19]. Thus, technical norms do often emphasize certain defaults for specific contexts like DIN EN 61310-1 or SAE ARP 4032B.

3. Whenever color is used for information coding, at least one additional form of coding should be applied to code the

same information, e.g. size, shape, place, typography, brightness. This ensures that the information will definitely be recognized. The background of this guideline is that approximately nine percent of the human population is to some degree color-deficient [42] and that normal eye aging affects the ability to identify colors [11]. Secondary coding mitigates problems that may arise from these causes by creating redundancy. A good practical application of this principle is the use of military symbols for land operations which are standardized across all NATO members and commonly used to show a situation or plan on maps. The most important information, the affiliation of an element (friendly, hostile, neutral, or unknown), is always coded with color (blue, red, green, yellow) and the element's shape (rectangle, rhombus, square, cloud). This ensures that the core message is always transmitted even under poor lighting condition or when a plan is copied in grayscale [32].

4. Domain-specific symbols or symbol sets should be used. In case that there are none or the existing symbols are not sufficient, the meaning of the new designed symbols should be understandable without description. Symbol use that is in line with this guideline enables fast and easy identification of system components, system states, system behavior, or controls. That minimizes mental workload and errors. In general, visualized information can be processed much faster than textual information [23]. When symbols are well-known or standardized, it leads to consistency, understanding, and reduces search times as well as learning effort [11, 21, 28]. For a suitable utilization, it is also necessary to scale the symbol's degree of detail on an appropriate level compared to the task that must be supported [21, 23, 28]. Klein et al. described a consistent and intuitive use of symbols in their real-time dispatcher client for public transport management [24].

5. Highlighting effects should be used to attract attention, but should also be used sparingly. Information of high priority needs to be recognized quickly. Further, team communication is easier with highlighted information on large screens. When in a stable state and no highlighting is used, alarms, messages, attribute changes, etc. can be detected easily [2]. Blinking, framing, or bright colors attract the operator's attention effectively and quickly. Attention can be drawn to information of higher priority. So, it is important, that highlighting is reserved for meaningful content. Otherwise, the effect will decrease through habituation [11, 21, 28]. Chen et al. proposed a well-balanced three-level highlighting scheme in a monitoring system for nuclear reactors [5]. In this case, it was used for orientation on the system overview while performing associated procedures. Another application of this guideline is the dimming or graying out of irrelevant information, for example on maps [24].

6. There should be a high contrast between the visualized information and the background. It is essential that displayed information can be discriminated clearly from the screen's background without effort. This ensures that the depictions do not interfere with background elements, which might make it harder to perceive the intended message. To achieve this, the information should stand out from the background. The best way to create this effect is to design a dull, stimulation-free background without pattern fills to avoid visual clutter [2, 11, 41]. The examples in guideline five also represent this recommendation, as both are content-related.

7. Numeric readouts should be presented in a context of scales, value ranges, limits, or pointers. Fast interpretation of values as a nominal-actual comparison must be possible as it is a key sub-task in system monitoring. However, numerical values in themselves are abstract constructs. To interpret a value without context fosters the operator to remember complex system dependencies, several distinct limits or equipment states what causes a high mental workload - also in situations of pressure. It is a massive relief to depict values on scales or bands via pointers and with limits, targets, or value ranges [10, 11]. Graphical indicators that look similar to their analog predecessors seem to support this principle [10, 16, 26, 43]. If the task requires accurate values, numeric readouts might be presented in addition [16]. A common application of this principle is the revolution counter in most automobiles with a clear graduation and a specially marked range for critical high rotation rates. A more advanced visualization is presented by Klein et al. In their public transport management system there is a time schedule for different bus lines. To monitor whether a bus is on time, the nominal and actual times are not presented as absolute strings. Rather, the information is preprocessed and the operator sees a colored bar and the deviation as a numerical printout [24].

8. Trends should be visualized for designated parameters or states. This allows the operator to track developments while monitoring. It also helps identify critical system states and supports wholistic system comprehension. Various researchers argue that the graphic display of trends eases monitoring tasks and promotes the identification of deviations [2, 12]. It can be assumed that trends help personnel learn about system behavior in the sense of causal dependencies or inertia. Such a feature might be beneficial to build and refine the operators' mental model. In their visualization proposal for power system control rooms, Betancur et al. offer a promising layout of a trend plot that encompasses past, current, and projected values of electric parameters [2].

9. Screen space should be spatially coded in the means of determined tiles for distinct function groups. Spatial coding effectively helps the operator to maintain overview by providing expectation conformity and reduces search time. Displays with a basic structure support the user in navigation and search [42]. Functional grouping of elements and assignment to certain consistent areas brings a series of benefits for the user. First, messages, alerts, and hints will always appear in the same areas [11]. Notifications that require immediate attention can be placed in the primary field of view [11, 43]. The information will not obscure or cover each other [11, 21]. Finally, the clear definition of areas enables simultaneous presentation of overview, detail, procedural, and supplementary information when needed for respective tasks [21, 27, 41, 44]. According to the principle of consistency, functions should appear in the same display area when they are part of different views [4, 11]. Ma et al. presented an example of an integrated system display for power plant control rooms. The whole screen follows a well-designed structure with defined spaces for the system overview, procedures, and reminders plus relevant parameters [27]. An early but consequent implementation of this guideline is offered by an Australian interface for a traffic management system. Here, the operator got a screen which is clearly split in areas for geographic map view, incident condition specification and a preprocessed case-specific contact list [44].

10. Elements should be grouped by a defined criterion. Again, the guideline seeks to maintain the overview and reduce search times. There is a wide consensus for functional grouping [5, 10, 11, 16, 28]. But there are further sort keys that should be considered. For example, in a group of similar looking indicators, deviating states are discovered easier [10]. Grouping by importance, frequency of use, or sequence of use is also seen as advantageous [28]. In general, gestalt laws provide guidance for grouping of elements [2, 22]. But grouping always comes with a need for discriminability of the single element to avoid confusion [10, 11]. For their microgrid control room, Betancur et al. have developed an energy display. It consists of a topographic model, an area for global values, and separate areas for subsystems. Here, elements are grouped by their affiliation with the respective subsystem in a consistent way [2]. A prominent example of grouping by importance is the "Basic-T" structure of display elements in aircraft cockpits [26].

11. The number of information displayed should match the number of information needed for the task. The system should support the user in staying focused on her or his task. Thus, there should be no distractions through information overload or unnecessary complex visualizations [5, 7, 12, 16]. A rule of thumb is that elements or notifications should be displayed only if they add useful information [11]. To support the guideline, a hierarchical structuring strategy of the abstraction level can be used. Therefore, an abstraction tree would be built. Its root describes the system overview, the leaves represent measuring, control, and regulating points. The deeper the position in the tree, the more details are available [2, 21, 24]. The decision support and alerting system for intensive care units (ICUs) which was presented by Colquhoun et al. was designed according to this principle. It has an overview screen that shows all the ICUs' patients with a limited set of their most important status information. For each patient, there is a detailed screen, that starts again on a global level. Specific information can be accessed through buttons [6].

12. The user should be able to navigate purposefully through the menus. Search time and mental workload must be reduced, navigation errors must be avoided to save capacity for the main task. The user should be confident while navigating through a menu. The navigation should be based on the self-descriptiveness of the menu, not on the operator's memory or the mental model of the menu [4, 11]. A first step is to ensure that one knows the own position in the menu which could be realized via bread crumb navigation if applicable [11, 27]. A consistent structure of menu screens supports a feeling of control [11, 24]. Shortcuts and links to frequently used functions speed up the navigation process [27]. At least, there should be a "return" and a "home" button in a consistent place of all screens [28]. Classic menus are best structured hierarchically, where deeper levels are the most specialized. Additionally, menu items should be functionally grouped and sorted by frequency of use. Catch-all categories like "miscellaneous" should be avoided. All of these recommendations support user-centered optimization [4]. An example for good menu design was described by Klein et al. Here, the user opens a menu by clicking on an object on the overview map. The menus have always the same structure and function symbols are consistent [24].

13. Sans-serif fonts should be used. Reading information should be as easy as possible even in adverse conditions such as poor lighting, vibrations, or presentation of one view on different hardware screens. It takes much longer to process information that is presented in textual form compared to others [23]. Hence, optimization of readability under all possible conditions should be increased. Sanf-serif have proven to be best readable on computer screens [11, 42].

Table 2: Guidelines' References According to Domains

GL	General	Aviation	Power Plants	Infra.
1	[19, 21, 42]	[4, 11]	[41]	-
2	[9, 19, 21, 42]	[4, 11]	[41]	-
3	[9, 42]	[4, 11]	-	-
4	[3, 7, 9, 21, 23, 42]	[11, 28]	-	[16, 24]
5	[19, 21]	[4, 11, 28]	[12]	-
6	[42]	[11]	[2, 41]	-
7	[10]	[11, 26]	[43]	[16]
8	[23]	-	[2, 12, 17]	-
9	[21, 42]	[4, 11, 28]	[27, 43]	[44]
10	[10, 21]	[11, 28]	[2, 5, 41]	[16]
11	[7, 21]	[11]	[2, 5, 12]	[16, 24, 44]
12	-	[4, 11, 28]	[27]	[24]
13	[42]	[11]	[2, 41]	-
14	-	[11]	[41]	-

14. Capitalization rules should be applied. The application of this guideline also ensures easy readability. Texts that are exclusively printed in capital letters are harder to read than those that follow standard capitalization rules of the used language [37].

In most of the cited publications consistency came up frequently across the different guidelines and recommendations. In Nielsen's statistical study, consistency was found to be one of the heuristics with the most explanatory power for usability problems [31]. That supports Shneiderman's perception that this aspect must be allocated on a higher level. Not surprisingly, "strive for consistency" is the first principle in his set of "golden rules of interface design" [39]. That means, consistency is a higher goal for designers that should be held in mind while working on implementation of the single guideline in order to pervade the whole system.

5 Discussion

The aim of this work was to examine, what guidelines for information visualization can be identified that are relevant for contemporary control room display design across different domains. As a result, a set of 14 guidelines could be identified based on a comparison of publications from three different domains. Explanations for their respective relevance were given and in most cases examples for best-practice application were shown.

5.1 Findings

The collection gives guidance for different aspects as the use of colors, fonts, symbols, attention getters, trend visualization, information context, screen segmentation, element grouping, or menu navigation. The list reveals a clear consensus about essential guidelines for the design of today's control room displays that address

Table 3: Summary of Guidelines for Information Visualization in Control Rooms

No.	Guideline
1	Not more than six distinct colors should be used to code information.
2	Conventions and standards from work domains and cultural contexts should be recognized and considered for the use of color.
3	Whenever color is used for information coding, at least one additional form of coding should be applied to code the same information, e.g. size, shape, place, typography, brightness.
4	Domain-specific symbols or symbol sets should be used. In case that there are none or the existing symbols are not sufficient, the meaning of the new designed symbols should be understandable without description.
5	Highlighting effects should be used to attract attention, but should also be used sparingly.
6	There should be a high contrast between the visualized information and the background.
7	Numeric readouts should be presented in a context of scales, value ranges, limits, or pointers.
8	Trends should be visualized for designated parameters or states.
9	Screen space should be spatially coded in the means of determined tiles for distinct function groups.
10	Elements should be grouped by a defined criterion.
11	The number of information displayed should match the number of information needed for the task.
12	The user should be able to navigate purposefully through the menus.
13	Sans-serif fonts should be used.
14	Capitalization rules should be applied.

classical design issues. Due to the fact that each of the 14 guidelines appeared in at least two domains, all guidelines can be understood as accepted for practical use and therefore considered as valuable.

5.2 Interpretation and Previous Research

A closer look at the single guideline reveals their very basic nature that makes them in turn very important. For example, numbers 1 and 11 ensure that the operator is not overwhelmed and can maintain the focus on the task. 2, 4, and 7 allow the user to rely on a standardized basis of knowledge through recognition. Whereas 5, 9, 10, and 12 simply prevent someone from getting lost in the system, which directly supports situational awareness and performance while reducing error sources. The guidelines 6, 13, and 14 support the basic need of any operator to quickly identify, discriminate, and interpret information with the lowest possible mental workload. That means there are good reasons for inter-domain agreement on them, as these guidelines are the foundation for usable displays and efficient operator performance. Without their consideration, subsequent system development will be less effective. In other words: one can predict that these guidelines will help design user-centered displays from their foundation.

These findings are in line with previous research, as control room interfaces should be designed to facilitate efficient information acquisition and processing, enabling operators to make informed decisions quickly, and keep situational awareness. This is crucial in high-stakes environments where timely responses can significantly impact safety and operational efficiency [29, 38]. The results also correspond to general interface design concepts. For instance, the guidelines 2, 4, and 7 can be compared with the heuristic "Speak the user's language" which accounted for 16 % of all usability problems in Nielsen's usability heuristics [31]. Sneiderman points out guidelines that are similar to the numbers 2, 5, 6, 9, and 10 [39]. Eventually, the general category in our review contained domain-independent sources. As nearly every guideline has a source from this category, this supports the assumption that control rooms are a specialized context of use where general recommendations must be applied, too. As control room interfaces are a subset of general interfaces, this is not surprising. The added value of this contribution is that now there is a summary of issues which researchers, developers, and engineers assess as important to report in the distinct inter-domain control room environment which has not been there before. As such, the list presents commonalities. Nonetheless, there must be differences between the domains and these are necessary. Every work context has its own requirements and challenges. Therefore, one can expect specific and different guidelines to address them. In the end, all guidelines, principles and theories stand back behind the overarching goal to support the user in performing her or his tasks.

Last, all the guidelines refer to a distinct workplace setting that is characterized mainly by multiple desktop screens, office computers, mouses and keyboards as input controls, embedded in the wider environment of multiple such workstations and large screens in a control room. Thus, the classic setup is addressed by classic design guidelines. With every technological update of a control room, one must examine which of the guidelines might be applicable in the future system. Especially in the light of the increasing relevance of virtual (VR), augmented (AR), or mixed reality and the forced embedding of artificial intelligence (AI), additional facets will appear and need to be considered. Derby and Chaparro point out that classical usability heuristics can be used to a certain extend for the design of AR applications, but that there are aspects which are not covered [8]. Another study came to the result that Nielsen's heuristics can be adapted for AR design, but that there are additional aspects to consider. For example, intuitive gestures for control were found to be ambiguous, what led to confusion [25]. Such findings indicate that a foundation of guidelines will remain, but that new features also require tailoring usability to them. That might be an adaptation of conventional guidelines, but can also mean the development of new ones. However, detailed inspection of design guidelines for VR / AR systems lies beyond the scope of this paper.

The good news is that AI tools seem to be very helpful for user interface development and evaluation [15]. Therefore, they might help understanding user preferences and support the design process with optimization through real-time feedback, pattern recognition, and automated tasks. Whereas designers could focus on providing context, creativity, and empathy [40]. The chances from collaboration of designers and AI are that human-centered designs become more matched as AI tools have more power to integrate large data sets with evidence than human teams could. Further, there is a chance for more personalized designs. The guidelines of this work might serve as a part of the data analyzed in the future to guide fundamental design.

5.3 Limitations

There are several limitations to this work. Only publications in English or German were considered, what shrinks the pool of possible sources. Further, the examination was conducted on the base of available scientific publications. As there are security and commercial interests, publications about the design of productive systems are scarce. The number of guidelines that could be found for this article is small, as no profound analysis of live systems was conducted. Finally, the inclusion of the aviation domain can be questioned as a cockpit is a different environment with respect to used computer systems, screens or controls. However, for this examination, it was found appropriate, because aviation is one of the best researched contexts and comes with a series of strong restrictions. The commonalities with control rooms that were stated in the introduction allow a cautious transfer to normal control rooms.

Further, the list has limited power for practical work, as it is far from complete. As mentioned above, guidelines are on the lowest level and provide clear advice. As every detail can be addressed, the number of guidelines must be much higher than 14. For example, the U.S. Department of Health and Human Services' Research-Based Web Design and Usability Guidelines encompass 388 guidelines [18]. This gap can be explained by the narrow scope of this work, the search for consensus which is an exclusive act, and the fact that the reviewed literature consisted merely of practical work reports that did not point out all underlying details. So, the 14 guidelines do not stand alone and need to be set in the context of other HCI concepts for application.

Finally, each of the presented guidelines gives a clear goal, but in real life some goals are conflicting. For every designer or developer, there are the tasks of identifying, analyzing, and prioritizing the project requirements, as well as finding measures to address them in an appropriate way. That might result in insufficient but allegeable consideration of single guidelines. Usability evaluations will decide whether this leads to problems in the specific case.

5.4 Future Work

Instead of system development, the list is better used to understand what is relevant in contemporary control room display design as a starting point for further research. In order to validate these results and to get a more comprehensive picture, qualitative evaluations of live systems could be a linking point. Another promising way to utilize or assess the findings would be to perform a case study by applying the guidelines to a deviating system. Then, a usability evaluation could provide an estimate of effect.

With an extended set of guidelines, it would be interesting to look at which guidelines will stay relevant or need adaption when future technologies are introduced to control rooms. There are complex practical questions like: What kind of design and structure will menus have in smart glasses?, How can optimal distances and angles of view between virtual objects and the operator be maintained to ensure readability and visibility in virtual reality environments?, What are the limitations regarding usability for an operator's customization of the own virtual space?

Independent from new technologies, there might be a basic set of rules that will stay relevant due to human physical nature in terms of abilities and restrictions. So, one further goal for research might be the identification and separation of technology-independent guidelines.

6 Conclusion

The aim of this paper was to provide a synoptic view about existing recommendations that were considered in display design of contemporary control rooms across different domains of use. A set of 14 guidelines was found that are relevant in aviation, power plant control, or infrastructure control. These common recommendations have a very basic character as they form a foundation for usability. Thus, they show some substantial agreements on what constitutes good design for control room displays. The presented list is not exhaustive. Rather, it gives an idea of the contemporary state and marks a starting point for further research as newer technologies will find their way to control rooms in the future.

Acknowledgments

This research was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation), SPP 2199 - Project number 521584557 (PervaSafe Computing).

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