Cuebert: A New Mixing Board Concept for Musical Theatre

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ABSTRACT
We present Cuebert, a mixing board concept for musical theatre. Using a user-centered design process, our goal was to reconceptualize the mixer using modern technology and interaction techniques, questioning over fifty years of interface design in audio technology. Our research resulted in a design that retains the physical controls — faders and knobs — demanded by sound engineers while taking advantage of multitouch display technology to allow for flexible display of dynamic and context-sensitive content.

Keywords
Audio, sound, mixing board, theatre, control surfaces, touch-screen, multitouch, user-centered design

1. INTRODUCTION
A mixing console, also known as a mixing board, sound board or mixing desk, is a device used to "mix, control, and effectively route [audio] signals fed into it." [5] Mixing consoles have existed since the 1930s [6], maintaining a similar physical design and layout throughout the decades. Considering the breadth of capabilities of a traditional analog mixing board, it is a straightforward device in terms of the mapping of signal routing to physical layout. Its simplicity stems from technical limitations of analog technology; the layout of the controls must mirror an audio signal's path through the board, and with relatively few exceptions, every pot, slider, or other control serves only a single purpose, regardless of context.

The advent of digital audio removes these constraints, opening up tremendous feature possibilities, but at the same time allowing designers the freedom to focus on issues like how many channels or effects processors can fit in a given area, which our research suggests is detrimental to usability. Despite the opportunities that digital affords designers, digital consoles continue to use the traditional analog console layout.

This project set out to move the sound board beyond the vestiges of old technology and to identify whether there exists an opportunity for a new metaphor, enabled by digital audio hardware and modern control surfaces, with which to represent audio on a surface. Because of its dynamic, high-pressure environment, we focused primarily on live audio reinforcement in the domain of musical theatre. For example, sound engineers need the ability to respond to rapidly changing live stage performance conditions such as actor improvisation or technical issues.

Our team employed a user-centered iterative design process consisting of ethnographic user research through contextual inquiry, including multiple stages of scenario building. [1] Our outcome was a prototype user interface for the musical theatre console, which we call Cuebert. While the prototype integrates some controls inherited from analog consoles, Cuebert also incorporates new digital interaction affordances, adding a touch-screen control surface to present time-, cue-, and filter-related functions.

2. RESEARCH
2.1 Contextual Inquiry
The Cuebert project used the contextual inquiry process as its primary user research method. In order to gather user data, our team interviewed musical theatre sound engineers, sound designers, and audio technology instructors. Our interviews were qualitative, and conducted in person, in the field, and by telephone [7]. Rather than a discrete line of questioning, our strategy was to engage our subjects in semi-structured conversation about their work. Depending on an interviewee's area of expertise, we asked about a variety of topics, including the processes of setting up, rehearsing, and running a show, the technical needs of a sound designer, the problems sound engineers encounter with mixing consoles, and how new sound engineers learn to use analog and digital mixing consoles. Additionally, the team observed the mixing process on a Cadac J-Type mixing console during a live performance of a touring Broadway show.

Finding a pool of potential participants for contextual inquiry interviews initially proved problematic because our target users work in a niche profession, and are geographically dispersed. However, we successfully recruited interviewees from the theatre-sound Google Group [6], including two sound engineers working on the U.S. national tour of Phantom of the Opera, as well as a sound engineer on Broadway. We also interviewed sound engineering faculty at the University of Michigan, Michigan Technological University, and the University of North Carolina, as well as a designer of show automation software.

Following each contextual inquiry interview session, the team collaboratively interpreted interview notes and other relevant observations to form a corpus of over 600 affinity notes [1]. These findings were then organized by themes that formed an affinity diagram that captured a coherent narrative of the sound engineers' experience with mixing consoles.

2.2 Contextual Inquiry Findings
The contextual inquiry and affinity diagramming processes revealed several key insights about console design for musical

theatre. These findings, described below, informed the design of Cuebert.

2.2.1 Cues

In musical theatre sound, a cue is an individual audio event. Throughout the performance, the sound engineer triggers cues, such as playing sound effects or pre-recorded music, muting and unmuting actors' microphones, or modifying voice effect presets. When working with a console, cues may control particular audio input and output channels, channel groups, roles, actors, effects processors, and presets.

2.2.2 Usage Contexts

Sound mixing occurs during various phases of a musical theatre production. During each phase, various demands are placed on the sound engineer, who uses the mixing console in specific ways for that phase. Our research revealed that these phases are: tech, rehearsal, and performance.

The tech phase is the preparatory stage of the production, and consists of sound design, cue programming, and audio signal routing. Specifically, sound engineers work closely with sound designers and other audio technicians to make and modify cues, apply audio effects (e.g., equalization, compression), assign actors to microphones, make changes to audio signal routing in terms of input and output, and organize mixing console channels.

During the rehearsal stage, sound engineers must adapt to unique performance scenarios, such as adjusting for a varying number of musicians in the pit orchestra, muting unused microphones, working with a rehearsal pianist, and controlling cue playback in a stop-and-go fashion. To complicate matters, engineers may be hired for a production to operate a mixing console with which they are unfamiliar, so they must rapidly become comfortable with it during the tech and rehearsal phases.

During the performance phase, sound engineers primarily trigger cues. Engineers must also be able to equalize an actor's voice based on how it sounds during a given performance. The engineer also uses faders frequently to adjust audio levels throughout the show.

2.2.3 Console Size

Based on our research, we found that there are important reasons for limiting a console's size. In musical theatre productions, mixing consoles occupy a fair amount of space that could otherwise be used for additional patron seating. Traditionally, sound engineers have been forced to make a tradeoff between console size and feature set. Digital consoles have changed this equation by allowing for greater feature density.

2.2.4 Ergonomics

Ergonomics plays a key role in console design. For example, the reach of the sound engineer is an important factor to consider when designing a mixing console. We found that a large mixing console is an issue for short engineers because they find it difficult reach certain parts of the console. Furthermore, engineers prefer faders that are parallel to the ground over sloped faders because the latter cause wrist strain.

2.2.4.1 Location of Controls

We found that sound engineers want to have the most frequently accessed controls closest to them to limit the amount back-and-forth reaching across the console surface. Accessing far-away controls is not only time consuming, but may also increase the risk that the wrong control is accidentally adjusted. The most frequently accessed part of the console is called the center section, and includes the group faders, cue playback controls (e.g., Go, Advance, Back), and other controls that affect the overall output of the console.

2.2.5 Customization of Controls

The ability to customize controls is an important console feature for sound engineers. For example, to assign console faders to specific microphones or actors on stage, engineers may program a scene in the show so that the lead actor is the closest fader to them, secondary actors are next to the lead, and other supporting cast work their way down the rest of the console's faders. Engineers also appreciate having a programmable bank of knobs, which gives them the flexibility to configure specific console functions and parameters in the configuration of their choice.

2.2.6 Visual Feedback

Visual feedback of audio status is of utmost importance to sound engineers. They use it to assess the audio signal and diagnose problems that may crop up during a performance. Engineers want to see the status of all channels in one glance at the console, without needing to navigate through menus. The status they wish to see includes fader levels, channel mutes, and group assignments. Channel meters, which display the audio signal level for a given channel, need to be designed with enough resolution to display the noise floor. Engineers also want dedicated displays for the current cue name and channel, actor, or group assignments.

2.2.7 Mapping

During our interviews, our team learned that sound engineers appreciate a one-to-one mapping of the console's physical controls to audio functions; that is, one physical fader dedicated to each channel, and knobs assigned to only one function. On small digital consoles, the engineer interacts with a large number of audio channels through the use of layers: a virtual one-to-many mapping scheme that assigns one physical fader to be shared among many audio inputs. Using layers, an engineer must scroll through multiple "pages" of audio input assignments to find the particular actor whose level they need to adjust. This task is not only time consuming, but tedious and prone to unintended changes to audio controls.

3. SCENARIOS

The Cuebert project used scenarios [1] at three key points during the design process: persona creation, paper prototyping, and hi-fi prototyping. Based on the relevant findings from contextual inquiry, the team synthesized four user personas and integrated them into scenarios describing typical sound engineer interactions with the mixing console. The first set of scenarios described typical work situations, the important features of a mixing console, and engineers' professional values. This exercise helped the team understand how our users accomplish their work. During paper prototyping, the team developed a second, more refined set of scenarios to help narrow the scope of the project. Lastly, the second set of scenarios was combined into a single narrative that demonstrated Cuebert's primary features with the hi-fi prototype[1].

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[1] Videos available as *Cuebert Scenario*: http://vimeo.com/8165086 and *Introduction to Cuebert:* http://vimeo.com/8121936

4. PROTOTYPING

4.1 Paper Prototype

We began the prototyping process by individually sketching console ideas, eventually converging on a single design. To concretize this design we created a paper prototype (Figure 1). This forced us to consider in detail many user interface design ideas. We created sketches of the underlying information architecture that describes a musical theatre production, and of the layout of all controls used in the performance phase. We also took the size of the console, external audio processing, and one-to-one mapping of physical controls to functionality into consideration. User scenarios helped us frame our ideas in the context of musical theatre.

Figure 1. Example of Cuebert paper prototype

The paper prototype proved to be a useful design tool because of its flexibility and reconfigurability. Paper prototyping allowed us to rapidly simulate adding a touch-screen onto an existing sound board. This afforded us the opportunity to evaluate a full-scale model of our prototype. It also provided a more tactile and authoritative experience of switching between screen-based and physical input devices.

4.2 Hi-Fi Prototype

The goal of the hi-fi prototype was to create a more refined user interface with which to conduct user testing. We started the process with our paper prototype, a salvaged Tascam M-3700 audio recording console, and numerous prototype construction ideas. As we refined our ideas, we found that for our purposes projection would be the most feasible technology to use for simulating a touch-screen on a mixing console. In this approach, the user interface screens developed during paper prototyping were digitized and re-drawn as vector graphics, then front-projected onto the console to simulate the interaction flow (Figure 2).

We began by removing the Tascam's analog electronics situated between the channel faders and the meter bridge. In place of the electronics, we overlaid a thin sheet of wood and installed physical controls such as toggle switches and a knob bank directly into it. To emulate the black touch-screen, we covered the console surface with black paper. We then installed cue control switches on the paper layer.

Our next task was to tweak the graphics and placement of the projector to precisely fit the projected user interface to the physical console surface. We went on to draft a user scenario for live demonstration and user testing, and then designed a set of interface screens to fully demonstrate the interaction flow. Using presentation software and a team-member playing the role of sound engineer, the team was able to simulate the core functionality of the console prototype in a scenario-guided operational sequence.

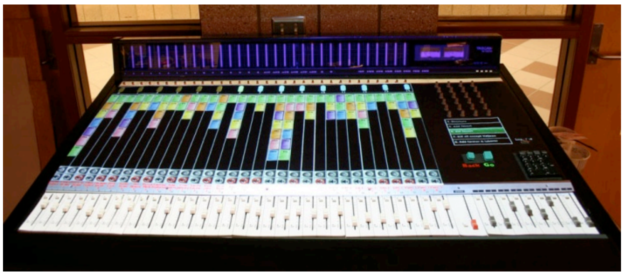

Figure 2. Cuebert Hi-Fi prototype

5. FEATURES

Each of the features developed during the design phase must in some way be supported by the needs of the user as determined by our research.

One of our significant findings is that sound engineers like to be able to see the state of the entire board at once, without having to navigate through menus. To accommodate that, we bring a traditional channel strip to a digital console by reinterpreting it as a series of soft controls for onboard processing that is inline with the signal chain.

This draws on the observation that the layout of an analog mixing console follows the signal path through the console: the actual audio signal passes through a board from the top of a channel strip, through onboard processing and routing, then on to the fader. This is not a metaphor; this layout is dictated by the hardware itself. Despite being limited by its analog nature, this arrangement has several advantages for users, among them the ability to see the state of all effects on all channels, and the confidence that settings will not change unexpectedly.

Contextual inquiry revealed that many current digital consoles break the neat and tidy arrangement of an analog board without introducing sufficient support for a new mental model [4]; learning to operate a digital board often relies on an existing understanding of signal routing in the analog space and memorizing the differences between the domains.

Our solution, rather than fighting the affordances of the analog layout, is, at a high level, a more flexible instantiation of it. We did this by replacing what are traditionally knobs with a large touch-screen panel. This gave us the flexibility of digital while retaining the simple, easy-to-follow layout of analog. All applied onboard effects are shown in a channel's strip, but as a result of being shown onscreen, effects can be added, removed, and even reordered in the signal chain. Each effect is shown as a target large enough to quickly and easily tap with a finger, and whose color corresponds to the effect type (Figure 3).

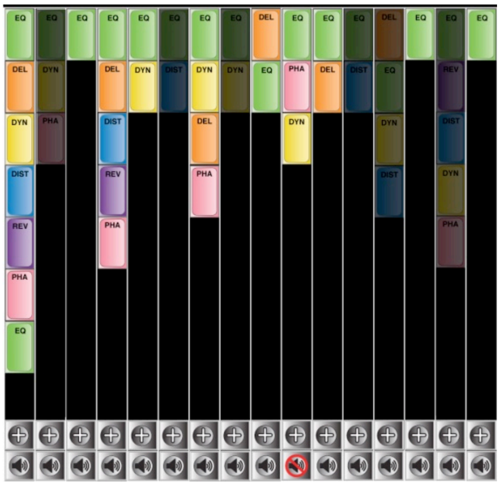

Figure 3. Cuebert touch-screen channel strips

Another important finding from user research is that engineers prefer to work with physical controls such as knobs and faders. To satisfy this requirement, we provide a bank of modal, multifunction knobs with dynamic labeling directly below to eliminate any ambiguity about a knob's current function.

Adjusting an effect can either be done graphically or with the knobs. For example, to modify a channel's equalization, one can choose to directly manipulate [2] the frequency response curve on the multitouch display, or adjust the knobs parametrically (Figure 4).

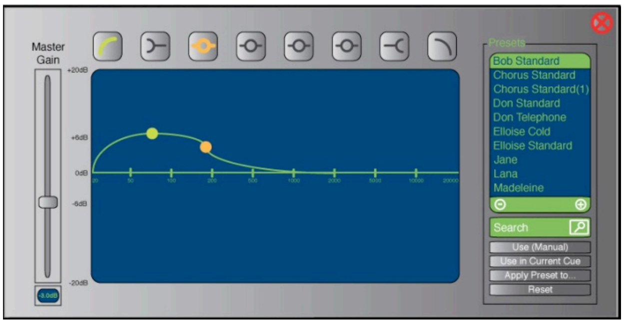

Figure 4. Cuebert multitouch equalizer

To meet the demands of modern musical theatre, we also developed a powerful cueing system. Our interview subjects told us that in their extensive work on Broadway and other touring shows, they have encountered many cueing systems, none of which works entirely satisfactorily. Each has its quirks and flaws, most of which have to do with behavior while modifying a show's existing programming or navigating between cues during rehearsal. Our system is object-oriented, with the objects being channels, actors, the roles actors play, effect and routing presets, and cues themselves that, like a relational database, define the relationships between each of the other objects.

When modifying any programmable parameter, one is presented with three ways to apply the change: use it in the current cue, apply the new preset to multiple cues, or put that parameter into a manual override mode (Figure 4). When in manual override, the affected parameter will retain its newly set state regardless of other programming until the operator explicitly releases it. Applying it to the current cue does simply that: replaces whatever preset was previously programmed in the currently active cue. Choosing to apply the change to specific cues reveals a query-making tool with which to specify what is to be affected when applying the modified preset (Figure 5). A query is constructed by selecting which values of which parameters should be affected.

Figure 5. Cuebert Apply Preset tool

As on most consoles, cues are advanced by pressing a prominent physical Go button in the center section. The current and surrounding cues are displayed in two locations on the board: a cue list in the non–touch-screen center section, and a cue timeline above the channel strips on the touch-screen. This redundant display is done for more than just convenience: we provide a blind mode, which, despite having been available on lighting consoles for years, is an innovative feature on an audio console. When in blind mode, cues and presets can be modified without affecting the board's live output. All physical controls continue to affect the live output, while all touch controls are blind.

Blind mode is used to adjust settings on one cue while actively running another cue; for example, applying an actor's equalization preset to multiple cues during a performance, or to work ahead on programming a show during rehearsal. When the physical live/blind toggle is switched to blind, the cue list in the center section shows the currently active cue because it is not part of the touch-screen. The cue timeline on the touch-screen shows the cue being worked on in blind mode. One can choose the cue to work on by selecting it from the timeline or directly keying it in on the numerical keypad using the Recall Blind button; likewise, one can make a cue live by using the Recall button.

Blind mode is supported by our research subjects' desire for more flexibility while running and programming shows, and by their need to have a more powerful, reliable way to work with cues during rehearsals.

6. FEEDBACK

In order to obtain feedback on our design, we created two video demonstrations and shared them with the highly active theatre-sound Google Group. We also showed it to several members of the University of Michigan audio community. We received positive feedback from these audio professionals, along with some very constructive criticism and suggestions.

Some examples of the type of positive feedback received from those who watched our videos include: "I tip my hat, based on the video you've covered just about every one of my personal wants and gripes, almost as if you were reading my mind!" and "Great concept. We're in the middle of a yearly production now and using a well known, small-frame digital console for our wireless microphones. The concepts you describe are very real to me right now. Make it so." We were pleasantly surprised to only have only one of over fifty comments give pushback against the boldest aspect of our design: replacing a large portion of the console with a touch display.

We did get a number of suggestions that we would like to incorporate into future revisions of the Cuebert. One of the more surprising findings was that there is actually a demand for layers, especially among sound engineers who are used to working with them. Engineers also said that they would like to be able to integrate Cuebert with other show control systems and be able to play back prerecorded audio. Other feedback included concern about the ease of distinguishing live and blind modes, and that the ergonomics of the cue timeline positioned at the top of the channel strips may be poor as a result of the fairly long reach required to reach it.

We also showed Cuebert to a group of audio industry veterans and students at our university. They responded positively about the possibilities multitouch opened up for rearranging channels and programming signal routing. They also gave us the suggestion that group labels and their corresponding group faders be color-coded.

7. DISCUSSION & FUTURE WORK

A number of open concerns must be addressed in order to create a more refined console prototype for musical theatre.

7.1 Cue Management

In the course of designing the console, our team developed an information architecture for organizing the primary components of a musical theatre production from the perspective of the sound engineer. This information architecture resembled a relational database with tables populated with channel, actor, role, group, cue, effect, and preset assignments. Our team needs to further investigate how such an organizational system could be leveraged to improve operator–console interaction during the tech and performance phases.

7.2 Group Faders

Our current prototype does not focus on group fader interaction. In practice, group faders are commonly used to control the level of a number of individual channels at once. Our team needs to further investigate group fader use and design the process of assigning channels, actors, and roles to groups.

7.3 Output Section

Because our design concentrated on the input section and console's operation while in performance mode, we did not work on the console's output section, such as the output matrix that feeds a theatre's amplification and speaker system.

7.4 Interfacing to external audio processors

The Cuebert console assumes all audio processing, such as equalization and dynamics, are built in. In reality, cascaded audio processing would most likely cause time delays in the playback of the processed audio signal. Our team needs to investigate how Cuebert could potentially interact with low-latency audio processors operating as auxiliary sends. Related to this would be devising a send/return interaction mechanism for each channel.

7.5 Automation

Today's consoles provide motorized faders that perform pre-programmed adjustments to an audio channel. It would be worth looking at how motorized faders and other automated controls could be displayed and overridden on Cuebert.

7.6 Programming

Cuebert focuses on interaction that occurs during the performance phase of a musical theatre production. As a future design task, our team needs to consider the tech phase, during which the console is used in unique tasks such as programming cues, assigning physical channels to microphone inputs, and working with a sound designer.

7.7 Interactive prototyping

To build a more refined prototype with more fluid interaction — rather than a scripted scenario — our team would need to implement a more robust simulation system. This system could potentially comprise a rear-projected table-top touch-screen capable of multi-touch gestures as input to a host application running on a standalone computer.

These open issues, and others, will require several more rounds of iterative design, including user research and prototyping.

8. CONCLUSION

Our work suggests that the live theatre audio world is ready for a change in user interface design. The design of digital audio consoles relies heavily on an imbalanced combination of the retention of analog design conventions and the adoption of digital designs that fail to fully support a coherent mental model. This characteristic of many digital consoles is not considered optimal by their users in live theatre audio. Our research resulted in a design that retains the physical affordances — faders and knobs — demanded by sound engineers for operational clarity under rapidly-shifting, dynamic conditions, while taking advantage of multitouch display technology to allow for flexible communication of dynamic and context-sensitive content. Reconceptualizing the functionality once mapped to the channel strip allowed us to apply this more flexible paradigm without introducing undue complications for performance-time operation. The resulting interface was well received by the live theatre sound mixing community, as represented by members of the theatre-sound Google Group and select staff and faculty from our university.

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