



Principles of Effective Auditory Signal Design: Integrating Acoustic Psychology, User Experience, System Development Limitations, and Environmental Context

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ABSTRACT

In interactive situations involving humans and artefacts, systems may employ interface sounds to convey information or imagery to users. Examples include warning tones emitted when users perform inappropriate operations, or non-verbal acoustic feedback. These sounds are designed to enhance user experience by enabling rapid understanding and operation of the system, thereby improving usability and reinforcing brand image. Designing interface sounds requires consideration of auditory psychology, user experience, system constraints, and environmental context. Relying solely on the service provider's perspective risks insufficient user understanding and bias towards personal preferences. Therefore, an evidence-based design approach grounded in research findings is essential. The impression interface sounds convey to users must align appropriately with their intended meaning, taking into account environmental context (e.g., background noise) and user characteristics (e.g., elderly users). This paper focuses on describing a useful framework for defining acoustic design requirements.

1 INTRODUCTION

I have led numerous projects in the fields of auditory psychology and user experience (UX). I have worked as a UI sound researcher and UX consultant on projects where manufacturers lacking in-house acoustic specialists sought to design intentionally incorporated sounds (UI sounds) for electronic product systems. Positioned between manufacturers lacking acoustic expertise and sound designers, I organise what manufacturers require when commissioning external sound designers and establish UI sound design methodologies as the first step towards effective UI sound design. I conduct research and analysis spanning both auditory psychology for understanding users and the field of user experience. This includes providing manufacturer support, conducting subjective acoustic evaluations, performing user research for sound design, defining UI sound design requirements, executing usability tests, and facilitating collaboration between manufacturers and sound designers.

UI Sounds

Auditory signals are sounds emitted by a product to convey information to the user and enable correct operation. This paper uses the term 'UI sound (user interface sound)' to refer specifically to non-verbal sounds designed to convey information, particularly short electronic tones (electronic tones) intentionally incorporated into electronic devices and machinery. Representative examples include smartphone notification tones and application error tones. UI sound also functions as an effective means of providing information to visually impaired users.

The Purpose and Background of UI Sound Design

UI sounds can convey information more rapidly than visual cues and possess the power to instantly capture a user's attention. The purpose of UI sound design is to assist users in quickly understanding and operating systems, thereby contributing to improved user experience (UX) through enhanced usability of products, systems, and services; strengthened safety and reliability; and elevated brand image.

User experience refers to the totality of experiences gained by users when utilising a product, system, or service.

Examples include: 'Being able to swiftly complete registration procedures on an online service' or 'Avoiding accidents caused by carelessness through system warning sounds'.

In today's fiercely competitive market, companies increasingly prioritise user experience (UX) to differentiate themselves from competitors, enhance customer satisfaction and brand loyalty, and achieve sustainable growth. UI sound, an essential element of products, systems, and services, is also required to deliver appropriate user experience.

Challenges in UI Sound Design

Manufacturers without in-house audio specialists often assume that simply outsourcing UI sound design to external sound designers is sufficient when integrating such sounds into their systems. However, manufacturers lacking audio expertise frequently find themselves unable to accurately articulate why the sounds produced by the sound designer do not align with their vision. While the scope of work may vary between individual sound designers, manufacturers sometimes fail to establish clear internal guidelines before commissioning work. Consequently, final deliverables frequently deviate from the original UI sound design objectives. Below are specific challenges encountered in UI sound design:

Challenge 1: Sound

- UI sound must convey information without using spoken language within limited time and pitch ranges, restricting design freedom.
- UI sound may fail to fully communicate intent or messages to users, potentially leading to misunderstandings.
- Excessive UI sound variations can result in similar-sounding cues, making immediate recognition difficult.

Challenge 2: Gaps in User Understanding of UI Sounds

- Users may fail to comprehend why a UI sound was played or the message it conveyed.
- Users may become uncertain about the next action required after a UI sound plays.
- Excessive UI sound variations can make distinguishing individual sounds difficult, leading to confusion.
- Users with conditions such as age-related hearing loss may struggle to perceive specific frequencies, making UI sounds difficult to hear.
- Ambient noise may mask UI sounds, making them harder for users to notice.
- UI sounds may be applied to features users perceive as unnecessary.
- Inappropriate volume or playback timing can cause user discomfort.

Challenge 3: Misconceptions about UI Sound Design from the User's Perspective

Effective user research for UI sounds requires understanding the user's context and reasoning. Therefore, the following are likely misconceptions regarding UI sound design from a 'user perspective':

- Presenting multiple UI sounds to users (the manufacturer's customers) and adopting the highest-rated one constitutes user-centric design.
- Since users are not audio specialists, they cannot precisely specify the optimal sound. Consequently, it is mistakenly believed that user-centric UI sound design is achievable through vague discussions among UX designers, sound designers, and manufacturer developers alone, without conducting user research.

Challenge 4: Problems Faced by Manufacturers Without Dedicated Audio Specialists

Some manufacturers lack dedicated audio specialists, leading to the following challenges:

- Manufacturers wish to enhance system usability, safety, reliability, and brand image through UI sounds.
- However, without in-house audio expertise, they cannot effectively design UI sounds internally.
- Communication with external sound designers becomes difficult, as the ideal sound image cannot be effectively shared.
- There is a lack of understanding regarding the actual users who will utilise the UI sounds.
- Objective criteria for judging UI sound quality are insufficient within the company, leading decision-making to often rely on the subjective opinions of stakeholders or majority vote.
- There is insufficient understanding of the laws and regulations in the countries and regions where the system will be used.
- Personnel changes mean the in-house UI sound personnel change, leading to insufficient grasp of both system functionality and the UI sounds as a whole.
- While there are approximately 50 types of functions requiring UI sounds, there is no intention to create 50 different UI sounds. However, it is unclear which functions can safely share the same UI sound.
- Where safety regulations pose no issues, options such as omitting UI sounds or enabling user on/off selection are conceivable, though these remain undefined.

- As new features requiring UI sounds will be added to systems, the manufacturer wishes to establish a framework enabling internal teams to assess the re usability of existing UI sounds.

Challenge 5: Communication Among Stakeholders

Some sound designers may wish manufacturers to keep their requirements for UI sounds to a minimum. However, manufacturers often hold strong convictions about the UI sounds they develop, particularly when these sounds form part of a long-term service, and may disagree with the sounds created by designers.

2 METHODS

To address the aforementioned challenges, this section outlines a UI sound design methodology to support manufacturers lacking in-house acoustic expertise. By facilitating collaboration with sound designers, it aims to enhance both user experience and manufacturer satisfaction. UI sound encompasses brand identity elements and communicative functions such as feedback and warnings. I primarily use sounds that convey warnings across a couple of levels as examples below.

Establishing Shared Understanding Among Stakeholders

First, an opportunity is created for manufacturers and sound designers to establish a shared understanding regarding the broad types of sounds necessary to achieve objectives. Even if there is common ground that 'UI sound enhances usability and brand image, improving the user experience,' proceeding with sound production without recognising differing directions may lead to avoidable issues. Confirming each party's priorities is particularly beneficial.

A Framework for Systematising UI Sound Design Requirements

When requesting four levels of warning sounds, external sound designers are typically provided with explanations of each level's purpose and the desired acoustic image. However, manufacturers may lack clear definitions regarding the distinction between Alarm Level 1 and Level 2, or the relationship between user perception and alarm levels. Here, we introduce a unique UI sound framework developed for projects operating under such circumstances.

Perspective 1: Environmental Context

Environmental context focuses on the environment in which the system is used. This includes investigating background noise levels in the target system's operating environment, changes in the surrounding environment according to time of day (such as late-night use), and, for globally deployed systems, researching relevant laws and regulations concerning UI sound in the associated overseas countries and regions. Requirements are defined to ensure UI sounds play at an audible volume balanced with surrounding background noise and comply with laws and regulations across different countries and regions.

Examples of situations lacking an environmental context perspective

- Cases where, after UI sound creation, it is discovered that the sounds contravene laws or regulations in the target deployment country or region
- Cases where UI sounds become inaudible due to high noise levels in the actual usage environment
- Cases where UI sounds are played at daytime volume levels during quiet late-night hours, causing noise nuisance

Perspective 2: System Development

From the system development perspective, the focus is on technical aspects and development constraints. Identify industry safety standards and manufacturer regulations relevant to UI sound, and design to ensure compliance with these requirements. Furthermore, within a manufacturer's technical development department, systems are often organised based on the logic of the technical developers. This structure may not align with UI sound design. In such instances, relevant matters should be reorganised as necessary to accommodate UI sound design.

Examples of situations lacking a system development perspective:

- Designed UI sounds may not comply with mandatory specifications, carrying a risk of rejection.
- Relying solely on structures built according to technical developers' logic may prove unsuitable for UI sound design, potentially causing issues or leading to a degraded user experience.

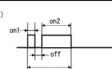
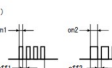
Perspective 3: The Psychology of Sound

From the perspective of the psychology of sound, the focus is on fields such as auditory psychology and music

theory. The relationship between the messages conveyed by UI sounds to users (such as completion or warnings), the auditory signals themselves, and their temporal patterns has been (partially) elucidated. Standards and guidelines exist that define temporal patterns appropriate for specific meanings, such as “completion” or “warning”.

Temporal Patterns

The international standard ISO 24500:2010 ‘Ergonomics – Accessible design – Auditory signals for consumer products’ specifies requirements for the design of auditory signals. In Japan, the corresponding standard is JIS S 0013:2011 ‘Guidelines for Notification Sounds in Household Electrical Appliances’. These specify patterns for ON/OFF sounds (such as invalid reception tones and end tones), the duration of ON/OFF sounds (in seconds), and the number of repetition cycles. UI sounds do not need to be designed in strict adherence to these, but they function as foundational knowledge shared among manufacturers.

	パターン図	基本仕様				イメージ	備考
		音の種類	繰り返し回数	on 時間 (秒)	off 時間 (秒)	基本テンポ (秒)	
w) 受付無効音 及び v) 作動不備音	(1) 	『ビープ』	1回	on1=0.1 on2=0.5	off1=0.1	—	弱い警告音 喚起する ※ 切れの良い (操作直後の 反応)
	(2) 	『ビープビープ』	1回	on1=0.1 on2=0.1	off1=0.05 off2=0.1	—	弱い警告音 喚起する ※ 切れの良い (操作直後の 反応)
	(3) 	『ビープビープビープ』	1回	on1=0.05 on2=0.1 on3=0.1	off1=0.05 off2=0.05 off3=0.1	—	弱い警告音 喚起する ※ 切れの良い (操作直後の 反応)
		推奨サンプル値 [w-a]  推奨サンプル値 [w-e]  推奨サンプル値 [w-f] 					

Source (Association for Electric Home Appliances, 2018)

Figure1: Guidelines for Auditory Signals to Improve Usability in Domestic Appliances

Sound quality, timbre

When we hear a sound, we may describe it as “loud” or “clear”. The three elements of sound refer to the three aspects of sound as an auditory impression: “loudness”, “pitch”, and “timbre”. Among these, timbre is generally defined as possessing a dual nature.

- i. The characteristic that serves as a clue for identifying the source of the sound, the identifying aspect of timbre
- ii. A collective term for the various aspects (multidimensional attributes) of the impression the listener receives from the sound, which carries emotional colouring. The impressionistic aspect of timbre (Sound quality), characterised by its ability to be described using adjectives such as “bright”, “dark”, “clear”, or “muddy”.

Analysis of Sound quality descriptors using statistical methods indicates that terms describing timbre can be represented by coordinates in a roughly 3-4 dimensional space. Consequently, the impressionistic aspect of timbre is considered reducible to 3-4 independent factors. Representative timbre factors include the Evaluation factor, the Potency factor, the Activity factor, or in Japanese, the Aesthetic/Lyrical factor, the Quantitative/Spatial/Impact factor, the Brightness/Metallic factor, and the Softness factor. These factors are known to be stable across generations and eras.

The table below illustrates the relationship between the words on the left (terms describing timbre) and the factor 1 to 3. Larger values indicate a stronger relationship between the paired terms and the factor.

Source (Author, 2025)

Table 1: Image of the factor analysis results

Example of Factor loadings

[illegible]

*Please note that, due to client confidentiality, we cannot disclose the actual project content or detailed information.

For conveying sound impressions clearly

When considering sound impressions in UI sounds, some manufacturer technical developers feel it is difficult for users to articulate the impression or differences between each sound in detail and with precision. However, through evaluation analyses such as those described above, it becomes possible to numerically grasp the impression of each UI sound and visualise the differences in impression. The author has used adjectives in English or Japanese for such surveys. Furthermore, some manufacturer technical developers find it challenging to communicate the impression-related aspects of sound to sound designers. One approach to support this challenge is to analyse the subjective evaluation results using the aforementioned statistical methods, employ the adopted factor names, and use this as material for discussions aimed at improving the sound. For example, if the first factor is aesthetic/lyrical and the second is quantitative/spatial/impact, the manufacturer's intent could be conveyed to the sound designer using expressions such as: 'Sound A should emphasise the aesthetic/lyrical aspect slightly more' or 'Sound B should reduce the quantitative/spatial/impact aspect'.

Examples of situations where the perspective of sound psychology is insufficient include:

- UI sounds fail to convey their intended meaning to users. For example, a warning sound is not recognised as such.
- UI sounds within the same system lack consistency.
- The design rationale for selecting a particular sound becomes unclear.

Perspective 4: Users

The user perspective focuses on understanding the people who utilise the target system. Conduct user research to analyse and clarify users' cognitive behaviours, needs, usage patterns and scenarios, and touch points with UI sounds. Rather than asking users solely about sound, understanding the context of system use and cognitive behaviours aids UI sound design. Users comprise individuals with diverse characteristics (visual/auditory abilities, IT literacy, age, etc.), necessitating consideration of these factors in research.

Generally, a gap in thinking exists between service system users and providers (such as manufacturers). Therefore, providers must incorporate a mindset into design that deeply understands, from the user's perspective, what users wish to know, what troubles them, and what they feel. Creating sounds without user research, then only hearing user opinions during usability testing, often results in only minor changes being possible. This approach may prove inadequate if fundamental changes are required or if the UI sounds fail to achieve their intended purpose. Understanding users before creating sounds is therefore considered useful to reduce rework in the workflow.

Examples of scenarios lacking a user perspective:

- The target audience for the sound or the message it should convey becomes unclear.

- Insufficient criteria to determine whether identical sounds should be used for warning A and warning B, or if distinct sounds are required.
- The benefits each UI sound should provide to users and whether it meets user needs become unclear.
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Establishing the Framework

This framework aims to consolidate internal manufacturer policies by defining UI sound requirements from four perspectives in the initial phase, thereby facilitating smoother communication between manufacturers and sound designers in subsequent stages.

Before defining sound requirements, it is important to organise the classification of sounds more concretely. Taking warning sounds as an example, one should first establish the conditions for each alert level, then determine what sound to assign to each alert level.

The elements necessary for classifying sounds should be clarified through analysis.

1. Share fundamentals of sound psychology
 - Conduct lectures for manufacturers to share the fundamentals of sound psychology.
 - Ensure manufacturers understand the rationale for UI sound requirements from a sound psychology perspective.
2. Clarify environmental context
 - Investigate background noise levels in operational environments and changes in surrounding conditions according to time of day (e.g., late-night usage).
 - Research relevant laws and regulations in countries and regions where the system will be deployed.
3. Conduct user research.
 - Analyse users' cognitive behaviour, usage contexts, and needs. Gather feedback on existing sounds.
4. Reorganise technical constraints and matters structured by technical logic.
 - Identify industry safety standards and manufacturer regulations pertaining to UI sounds.
 - Reorganise matters structured by technical logic to align with UI sound design.
5. Establish concrete definitions for each UI sound and achieve shared understanding within the manufacturer.
6. UI Sounds Requirements Definition
 - Establish sound requirements aligned with each UI sound definition.
 - This includes specifying time patterns and quantifying suitable volume levels and ranges.
7. Logic tree for determining which UI sounds are suitable for new features
 - Some manufacturers anticipate adding new features to their systems in the future, which will likely increase the number of functions requiring UI sounds. However, manufacturers may not plan to commission sound designers each time, and personnel responsible may change roles. Consequently, new personnel may need to determine which UI sounds are suitable for new features without sound designers.
 - As a simple countermeasure, a chart diagram or logic tree is created to support such decision-making. Based on the aforementioned research and analysis, multiple factors determining suitable UI sounds are identified, and questions to verify these factors are prepared.
 - For example, when adding an alarm function, answering all questions about these factors with yes or no will reveal the applicable alarm level for the new function and the suitable UI sounds, unless it falls outside existing alarm levels.
 - Please refer to Figure 3.
8. Workshop 1: Share UI Sound Design Requirements and Discuss with Sound Designers
 - At this stage, the established UI sound requirements are shared with the sound designer.
 - These requirements facilitate discussion, enabling the manufacturer to conduct consultations with the sound designer more smoothly.
 - The concept image is developed following consultation with the sound designer.
9. Create UI Sounds Prototype 1
 - Develop sounds based on the UI sound design requirements.

10. Subjective Evaluation

- Conducting sound recognition alignment with manufacturers using actual sounds, and user sound evaluation.
- For global deployment, conduct subjective evaluations with users from multiple countries as required. Analyse trends such as differences in users' cognitive behaviours towards sound or acceptable sound levels across countries and cultures.

11. Analysis using statistical methods

- Analyse subjective evaluation results using statistical methods.
- Identify three to four factors contributing to tonal impression.

12. Workshop 2: Analysis Using Statistical Methods

- Share the analysis results of the user subjective evaluation
- Share opinions on the sounds in each other.
- Explore improvement directions and brainstorm ideas, using factor names derived from the subjective evaluation analysis results.

13. Create UI Sounds Prototype 2

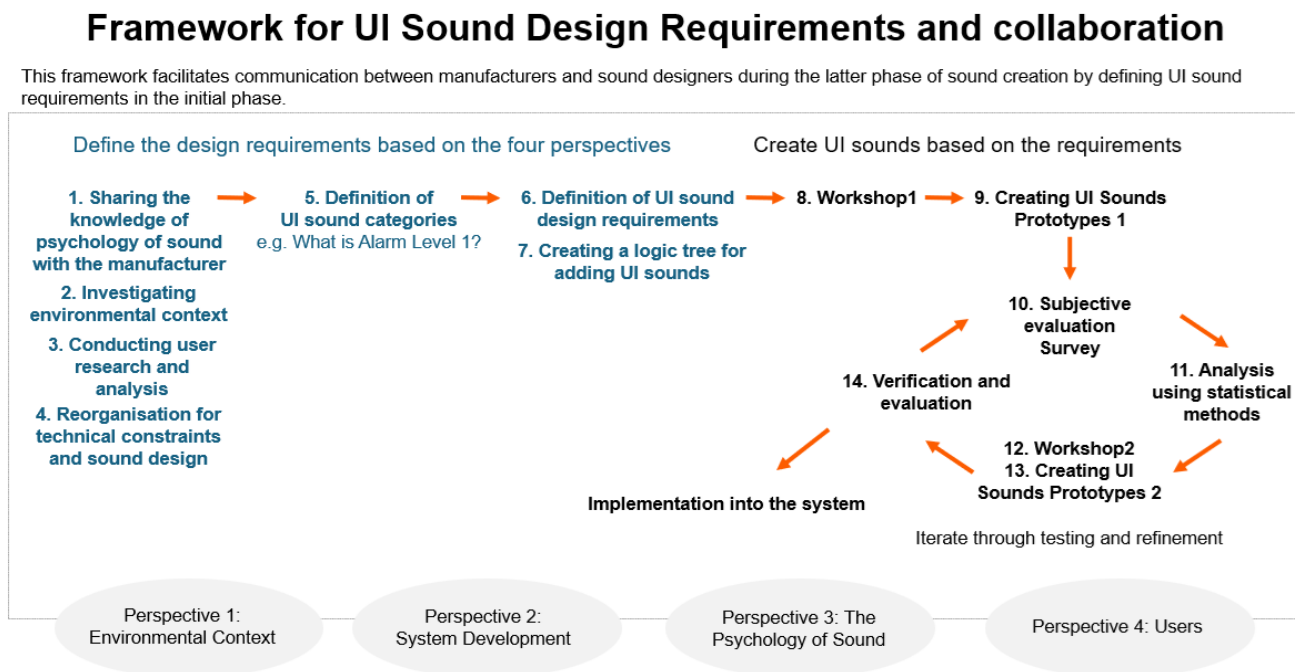
- Develop sounds based on workshop 2.

14. Refine using the human-centred design process

- Verify whether improvements were achieved in the subjective evaluation of UI sound prototypes through usability testing, etc.
- Identify issues and formulate improvement proposals.
- Repeating the process of going back and forth until completion.

3 RESULTS

The image below shows the output generated by the aforementioned methodology. The framework defined manufacturer-specific, unified UI sound requirements.

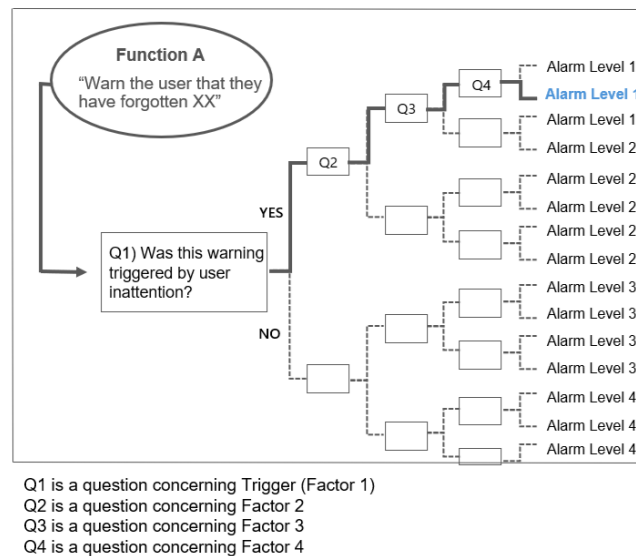


Source (Author, 2025)

Figure 2: Framework for Organising UI Sound Design Requirements

Definition of Alert Levels

This chart summarises the correspondence between UI sounds and functionalities. The figure below illustrates an example for the newly added functionality 'Function A'. This alerts the user when they forget to perform an operation. By answering the chart's questions with "Yes" or "No", it becomes clear that this Function A corresponds to Level 1 within the classification of Alert Levels 1 to 4.



Source (Author, 2025)
Figure 3: Definition of alert levels

*Please note that, due to client confidentiality, we cannot disclose the actual project content or detailed information.

4 CONCLUSIONS

Defining design requirements using the UI sound framework yielded the following outcomes:

- Defining design requirements deepened manufacturer employees' knowledge and understanding of the sounds their company requires.
- Incorporating this understanding of required sounds enabled manufacturers to communicate more specific sound specifications to sound designers, leading to the evolution of UI sound.
- Criteria for defining quality sound moved away from reliance on stakeholders' personal preferences, majority votes among manufacturer staff, or user polls. Instead, sounds could be evaluated based on whether they met the design requirements.
- User research and subjective evaluations deepened both the manufacturer's and sound designers' understanding of users' contexts and impressions of sounds.
- The constructed logic tree enabled new UI sound personnel within manufacturers lacking in-house acoustic specialists to consider which sounds to adopt when adding UI sounds.
- Manufacturers can now design UI sounds to be added to systems using consistent logic.

There are various approaches to sound design, but this paper emphasises the importance of preparation and defining requirements in manufactures before the sound creation phase. This affects the ability of manufacturers to solve certain problems. Manufacturers develop an in-house understanding of UI sound, establishing fundamental policies and design requirements to support the sound creation phase. This is achieved by collaborating with researchers who specialise in sound and UI. These UI sound design requirements form the basis for conveying intended meaning to users while allowing sound designers a certain degree of creative freedom.

In the subsequent sound creation phase, manufacturers commission sound designers to create UI sounds. The design requirements created in the previous phase are specific and serve as useful communication tools for

sound designers and manufacturers alike. If the final sound differs from the requirements, the manufacturer can highlight this. Furthermore, subtle differences in timbre can be discussed using the three or four factors identified through sound quality evaluation.

Separate requirements should be created with the sound designer for more strategic elements, such as building the manufacturer's image through sound.

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