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Towards New Ambient Light Systems: a Close Look at Existing Encodings of Ambient Light Systems

Andrii Matviienko[1], Maria Rauschenberger[2], Vanessa Cobus[1], Janko Timmermann[2], Jutta Fortmann[1], Andreas Löcken[1], Heiko Müller[2], Christoph Trappe[2], Wilko Heuten[2], Susanne Boll[1]

[1] University of Oldenburg, Ammerländer Heerstraße 114-118, 26129 Oldenburg, Germany
[2] OFFIS - Institute for Information Technology, Escherweg 2, 26121 Oldenburg, Germany

[1] {firstname.lastname}@uni-oldenburg.de
[2] {firstname.lastname}@offis.de

Abstract. Ambient systems provide information in the periphery of a user's attention. Their aim is to present information as unobtrusively as possible to avoid interrupting primary tasks (e.g. writing or reading). In recent years, *light* has been used to create ambient systems to display information. Examples of ambient light systems range from simple notification systems such as displaying messages or calendar event reminders, to more complex systems such as focusing on conveying information regarding health activity tracking. However, for ambient light systems, there is a broad design space that lacks guidelines on when to make use of light displays and how to design them. In this paper we provide a systematic overview of existing ambient light systems over four identified information classes derived from 72 existing ambient light systems. The most prominent encoding parameters among the surveyed ambient light systems are color, brightness, and their combination. By analyzing existing ambient light systems, we provide a first step towards developing guidelines for designing future ambient light systems.

Keywords: ambient light system, ambient light, peripheral display, light evaluation, design guidelines, ambient displays, light, ambient information, information encoding.

1 Introduction

Designing ambient systems with light is a promising new domain that has gained attention in recent years (Fig. 1). In particular, the integration of luminaires into ambient interactive systems enables a novel way of using light in ubiquitous computing [41]. These systems use different parameters of light such as color, brightness, LED position, and their combination. Several proposed light systems already explore parameters of light for ambient systems, but what is still lacking is a *systematic understanding of the design space* to discover design guidelines.

In this paper, we present a systematic overview of existing ambient light systems from scientific papers, analyze light parameters used to encode information, and discuss how this information was encoded. We excluded commercial products as they do not reveal the design rationals of the chosen light parameters and encodings. We present a systematic overview of 72 ambient light systems from 66 papers, identified before June 20th, 2015. Most of the systems (45/72) were developed during the last 5 years, which can be seen by a sharp increase between 2010 and 2015 (Fig. 1). As a result, we contribute four information classes: *Progress*, *Status*, *Spatial*, and *Notification*. These four information classes help us deriving preliminary design guidelines which need to be verified in the future study. The results of this study will support the future development and implementation of ambient light systems. Furthermore, we discuss and analyze existing light encodings and current trends in the development of ambient light systems.

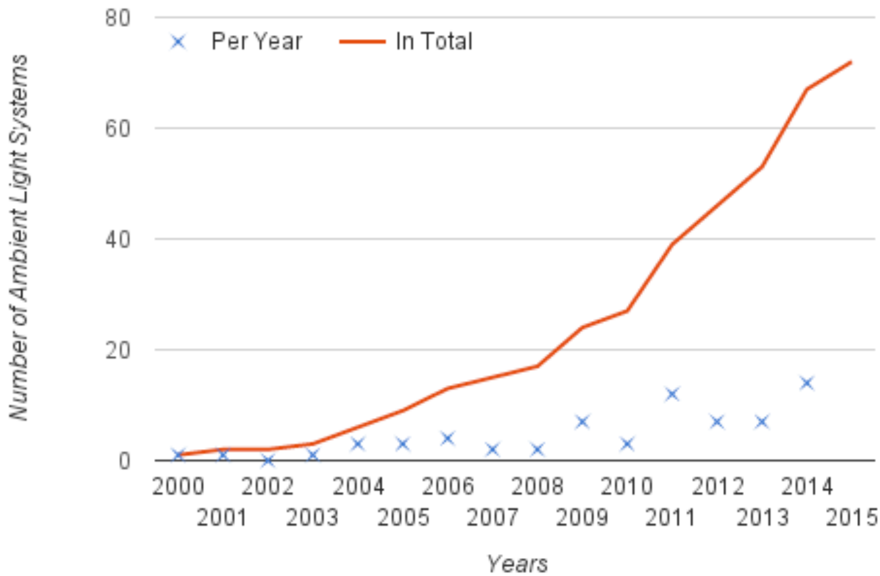

Fig. 1. The number of Ambient Light Systems developed between 2000 and 2015, based on 66 papers reviewed in this article: cumulative (red line) and per year (blue stars).

2 Ambient Light Systems

To decrease the influence of interruptions and avoid performance breakdowns during multiple task activities, Wickens et al. [72] underlined the importance of using peripheral or ambient systems in task interference. Pousman and Stasko [61] provided an interpretation and requirements for *ambient information systems* that are suitable for the ambient light systems we analyze in this paper. They are:

- “display information that is important but not critical
- shift from the periphery to the focus of attention and back again [...]
- provide subtle changes to reflect updates in information (should not be distracting)” (p. 68)

In addition to the definition mentioned above, Matthews et al. [46] have clarified peripheral display as the one that "shows information that a person is aware of, but not focused on". This definition complements our definition of the ambient light systems, which is:
*An **ambient light system (ALS)** is a system positioned in the periphery of a person's attention that conveys information using light encodings in a non-distracting way most of the time.*
We consider ambient light systems as a subgroup of ambient displays that have a specific focus on a light modality as carrier of information in the periphery. Opposed to display systems, ambient light systems rely on the modulation of basic light parameters to produce a non-iconic yet meaningful representation of information. Moreover, in cases when information is presented in a distracting way we still classify a system as an ambient light systems due to the shifts from the periphery to the focus attention and back [61].

3 Approach

To our knowledge, currently there exists no classification of ALS. However, there are classifications of ambient information systems and peripheral displays that collect common design characteristics. Peripheral displays and ALS in particular are a part of peripheral interaction and we consider the following definition of this term:
Peripheral interaction is an interaction that overcomes frequent context switches, which disrupts form the primary task, by moving tasks to the periphery of attention [26].

Various researchers suggested guidelines and heuristics as an approach for the evaluation of existing ambient systems, but not particularly for ALS. For instance, Matthews et al. [46] described three characteristics that peripheral displays have in common: *abstraction, notification, and transitions*. To incorporate these three key characteristics they also developed a toolkit to support the development of peripheral displays [45].
Pousman and Stasko [61] proposed four dimensions for the classification of ambient information systems: *information capacity, notification level, representational fidelity, and aesthetic emphasis*. Each of the dimensions has five levels of evaluation from low to high.
Tomitsch et al. [69] suggested another classification of ambient information systems with nine significant characteristics that served as design dimensions: *abstraction level, transition, notification level, temporal gradient, representation, modality, source, privacy and dynamic of input*. They extended the number of dimensions provided by Pousman and Stasko to balance the simplicity and descriptive power.
Ames and Dey [3] defined eleven dimensions important to ambient displays based on their experience: *intrusiveness, notification, persistence, temporal context, overview of detail, modality, level of abstraction, interactivity, location, content, aesthetics*. All these suggested dimensions served as a toolkit for both the design and evaluation of ambient information systems.

Mankoff et al. [43] developed a list of heuristics to support evaluation of ambient displays. These heuristics served as low-cost evaluation technique for designers of ambient displays. Brewer [7] provided another set of guidelines for the design process of ambient displays. They are presented as a set of questions that designers have to consider for ambient display design.

Covering a huge space of ambient systems, the existing taxonomies help us to limit and define dimensions for our own classification. All existing classifications have a dimension called notification. In our classification, we have also found *Notification* to be a prominent information class. We define an information class as follows:

Information class *is a classification unit that collects ambient light systems with similar information to encode.*

None of the aforementioned classifications, however, focused specifically on ALS and light as modality. This leaves a gap for designers of ALS to develop the best solutions. As the first step towards design guidelines to assist designers in the future ALS development we decided to define our own classification of ALS.

First, we extracted suitable existing ambient light systems from scientific papers, following the approach of Kitchenham & Brereton [31] and using our definition of ALS. For this, we collected information using web search for the keywords: "ambient light", "peripheral displays", "light", "light evaluation", "ambient displays", "design guidelines", "ambient information" and their combinations. We selected papers from the ACM digital library, IEEE Xplore, SpringerLink, Google Scholar, and conference proceedings, e.g. INTERACT, Mensch und Computer, CHI, NordiCHI, MUM[1], DIS[2], AmI[3], and OzCHI.

Second, we applied our exclusion and inclusion criteria. Our inclusion criteria: 1) ambient light displays, prototypes and concepts; 2) Light or/and shadow are used for information encoding. Our exclusion criteria: 1) final products; 2) information encoding without light; 3) software simulation.

Third, we grouped all ALS that went through inclusion/exclusion criteria according to the following categories: name of the prototype, short description, context, number of contexts, light properties, prototype's properties, information encoding, recommendations/guidelines.

Finally, we analyzed the collected information about ALS and explored the encoding similarities among them. Each system has different purposes, light encodings, and contexts of use. Each purpose represented a potential classification dimension, but our goal was to reduce the number of possible dimensions. Therefore, we analyzed the light encodings, which were similar for the systems with similar purpose. As a result of clustering these similarities of light encodings and system purposes we derived four information classes:

1. ***Progress*** *shows a relative indication of goal achievement by monotonously increasing or decreasing values.*
2. ***Status*** *shows the absolute current value with possible change of tendency with no indication of goal reachability.*
3. ***Spatial*** *shows a direction to a point-of-interest.*

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[1] International Conference on Mobile and Ubiquitous Multimedia

[2] ACM conference on Designing Interactive Systems

[3] European Conference on Ambient Intelligence

4. ***Notification*** *shows information that grabs the user's attention.*

This classification supplements the existing ambient systems classifications by forming another application-driven dimension. Analyzing all 72 ALS in any other classification leads to a loss of design and technical details relevant for ALS. Moreover, these information classes cover the whole space of the analyzed ALS, and any further system could be assigned to the existing classes. With this classification we present an overview of the state of the art (see Tables 1 and 2) and build a basis for future design guidelines.

4 An Overview of Existing Ambient Light Systems

In this section we provide an overview of existing ALS to observe trends in the light encodings and define similarities among the existing ALS. To avoid misunderstanding and misinterpretation of the terms used in this paper, we provide a list of definitions in addition to our analysis.

4.1 Information Classes

One ambient light system can belong to more than one information class (23 out of 72 ALS). Almost half of the reviewed ambient light systems (33/72) belong to the information class *Status,* 9 to *Notification,* 4 to *Spatial,* and the remaining 3 to *Progress* (Fig. 2).

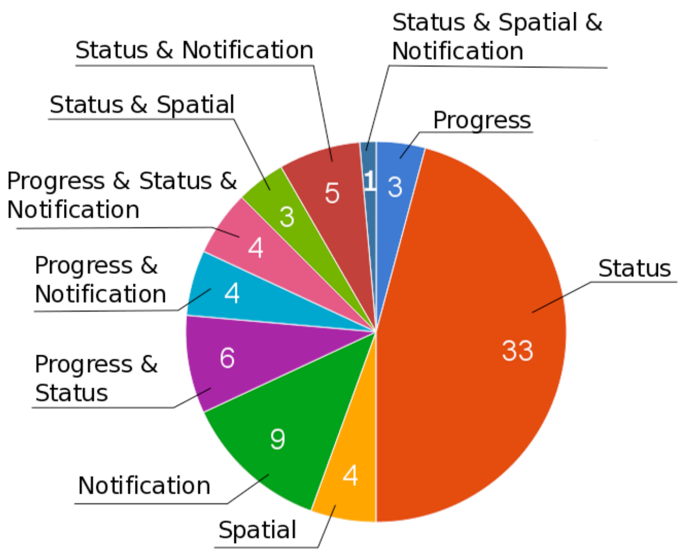

Fig. 2. Overview of the number of ALS in each information class of our classification.

Table 1. Classification of Ambient Light Systems. Basic Light Parameters.

Information Classes

Parameters used for Information Encoding

	Progress	**Status**	**Spatial**	**Notification**
Color	ActivMON [6], AmbientTimer [51], AmbiPower [50], HealthBar [44], Ambient Progress Bar [55], Illuminated Ring [38], Illumee [18], Faucet Display [32], Shower Display [32], WaterJewel [17]	Ambient Orb [27], Aulura [14], ColourVision [73], Damage [74], egg-shaped USB [49], Energy Consumption Prototype [39], Public Transportation Locator [62], Treasure Hunt [42], HealthBar [44], Chime [11], Ambient Rabbit [48], Forget Me Not [71], Urban Echoes [57], Ambient Social TV [25], PresenceStool [13], Energy Orb [68], Bobo [68], Pop-up Shop [20], Air [53], Emo bracelet [40], Wilting Flower [40], Illuminated curtain [56], AmbiPad [37], mood.cloud [30], Hello Bracelet [1]		Call Detector [62], FireFlies [5], Ambient Notification Display [70], Hello Bracelet [1]
Brightness	Illuminated Ring [38], Bus Display [45], rainBottles [34]	ActivMON [6], AmbiPower [50], DayLight Display [43], Public Transportation Locator [62], Sparkle [52], show-me [30], VisAural [22], Faucet Display [32], Cherry blossom painting [4], Air [53]		ActivMON [6], AmbientTimer [51], AuraOrb [2], Circle (calendar event) [75], Damage [74], Halogen Spots [54], HealthBar [44], "Should I Stay or Should I Go?" [35], Ambient Progress Bar [55], Illuminated Ring [38], Forget Me Not [71], Bus Display [45], Energy Orb [68], GUIDE-Me [21]
LED Position	Aulura [14], WaterJewel [17], show-me [29], Faucet Display [32], Shower Display [32]	Bus Display [45]	AmbiGlasses [59], Rotating Compass [65], Sparkle [52], VisAural [22]	

4.2 Basic Light Parameters

We analyzed the light parameters used to encode information in the ambient light systems in the categories: color, brightness, LED position, and their combination. 20 of the reviewed ambient light systems used only color to encode information, 4 systems used brightness, 24 a combination of color and brightness, 2 LED position, 6

LED position with color, 7 LED position with brightness, and 9 LED position, brightness and color together. We also compared the number of systems along all four information classes for each light encoding parameter (Fig. 3).

Table 2. Classification of Ambient Light Systems. Combination of Basic Light Parameters.

Information Classes

Parameters used for Information Encoding

	Progress	**Status**	**Spatial**	**Notification**
Color& Brightness	Halogen Spots [54], LED Bracelet Prototype [19]	Follow the Lights [27], MoveLamp [16], Nimio [7], Pediluma [33], Power-aware Cord [23], Socially Adaptive Dining Environment [41], Sparkle [52], "Should I Stay or Should I Go?" [35], LED Bracelet Prototype [19], MoodLight [66], Social Radio [63]	Treasure Hunt [42]	Circle (Messaging/ Phone calls) [75], LumiTouch [8], Point [75], Supporting Situation Awareness [15], Treasure Hunt [42]
LED Position & Color	Circle (calendar overview) [75], Circle (fitness tracking) [75]	Circle (temperature) [75], Ambient Rabbit [48], rainBottles [34], IllumiMug [58]	eye-q [9]	Circle (calendar overview) [75]
Brightness & LED Position	Circle (Time) [75]	The Firefly Stairway [47], PowerSocket [28]	Follow the Lights [27], Perception Pillar [12]	Reminder Bracelet [24]
Color & Brightness & LED Position		AmbiCar [36], Circle (Sports) [75], Responsive Lighting [60], "Should I Stay or Should I Go?" [35], Hello.Wall [64]		

4.3 Context of Use

Within the category of usage most of the systems exhibit one context of use. However, 19 systems have 2 contexts and 3 systems have 3 contexts of use. Most of the ambient light systems were designed for home (34) and office (34) purposes, 12 are used in everyday activity, 5 in navigation, 4 in automotive, and the remaining 8 in other environments. A small shift in the everyday activity context is observed between the end of 2011 and June 2015 with an increase by 6% in the systems developed for everyday activity.

4.4 Technical Aspects

As for technical aspects of ambient light systems, we analyzed them in four dimensions: information sensitivity (personal/public), system class, monochrome/multicolor, and single LED/multiple LEDs. Encodings with light in ALS are accessible to the public. Thus, designers of ALS should consider an information sensitivity aspect. Another three technical aspects we have chosen in accordance to two dimensions of classification by Pousman and Stasko: number of colors and LEDs - *information capacity*, system class – *aesthetics emphasis*.

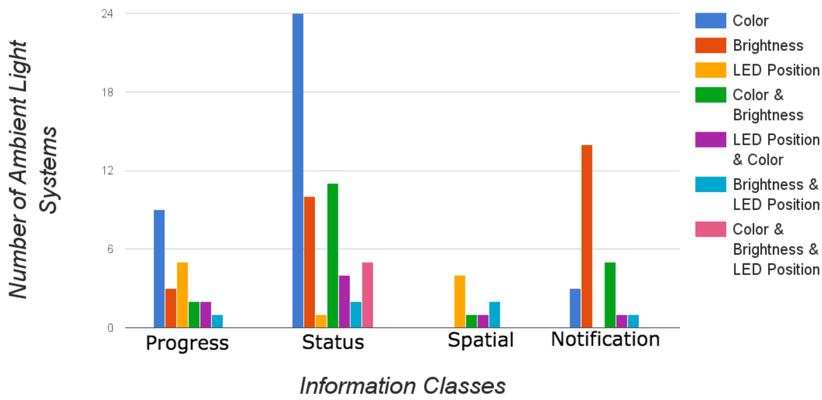

Fig. 3. Overview of the number of ALS for each information class and basic light parameter.

Information Sensitivity
Personal Information – type of information displayed on the system with light encoding that only one person can correctly interpret.
Public Information - type of information displayed on the system with light encoding that not only one person can correctly interpret, but also observers in public.
Regarding the information sensitivity, 49 of the reviewed systems are built for the encoding of personal information.
System Class
Wearable – term that refers to systems that can be worn on or around the human body: wrist, watches, glasses, jewelry, shoes, t-shirt, etc.
Portable – category that collects systems easy to transport in hands or bags.
Stationary – class of systems that are embedded into the environment and hard to transport manually.

Class *Stationary* collects 30 of the ambient light systems, class *Portable* - 27, and the remaining are wearable (Fig. 4). Additionally, we observed correlations between context of use and system class (Fig. 5). All of the wearable systems are designed for everyday activity context, and majority of portable and stationary systems are used in home and office environments. Most of ALS (58) use multiple colors, and 65 use multiple LEDs to encode information.

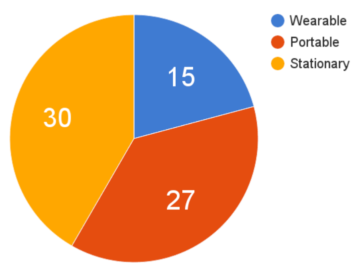

Fig. 4. System Class

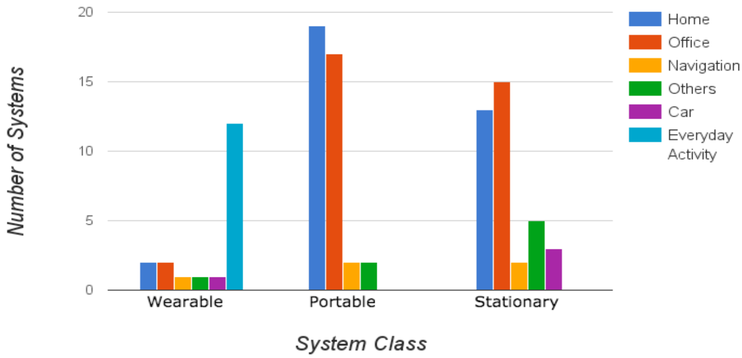

Fig. 5. Correlations between context of use and system class

5 Discussion

In this subsection we are going to discuss the categories mentioned above and derive the tentative design guidelines.

Information class *Progress* collects prototypes that encode monotonously increasing or decreasing goal achievement. Encoding of time is one example of monotonously increasing progress. For example, AmbientTimer [51] uses a linear fade from green to red to encode time change. However, Halogen Spots [54] uses LED position to indicate how much time has passed: the more LEDs are on, the more time has passed. Another example of progress is energy (AmbiPower [50]) and water (WaterJewel [17], Faucet and Shower Displays [32]) consumption during a period of time. AmbiPower uses a linear fade from green to red, where green means low energy consumption and red – high. Similarly to Halogen Spots water consumption shows the progress via sequential progression of activating LEDs: the more LEDs are on, the more water was consumed.

Unlike *Progress,* information class *Status* collects prototypes that encode the current changes of information. Among them there are prototypes that encode real-time energy consumption (Bobo [68], Energy Orb [68], Energy Consumption Prototype [39]) and physical activity (HealthBar [44], MoveLamp [16]).

To display the current energy usage Bobo uses the following light pattern: white – below average, blue – average, red – above average usage. Energy Orb and Energy Consumption Prototype, on the other hand, use a linear fade from red to green to display the current energy consumption, where green means low and red - high consumption level. Regarding physical activity, HealthBar and MoveLamp indicate the time span a worker remained seated at the workplace. The light pattern has a linear color fade from green to red. Green means no movement required for a worker, red – worker has to walk.

The information class *Spatial* uses only the LED position and a combination of LED position with brightness to encode *direction (*The Firefly Stairway [47], VisAural [22]*)*. Mappings between a direction in the real world and LED position on both prototypes provide a clear and understandable assistance: when LED on the left hand side is on, it means go left, on the right hand side – go right. It makes encodings with color or brightness only insufficient. 30% of the reviewed ALS that use monochrome light belong the information class *Spatial*.

Information class *Notification* collects prototypes that grab the user's attention to stress the importance of events. Brightness or a combination of brightness with color is used the most frequently to encode such information (Reminder Bracelet [24], Energy Orb [68], Forget Me Not [71]). Color usually indicates identity or type of notification and brightness - the level of notification importance. Different levels of notification importance are encoded through blinking patterns: the higher the frequency, the higher the importance.

Visual dynamics in everyday activity are meant to grab our attention. Our peripheral vision provides us with clues about changes e.g. a person is passing by, or light changes its brightness [67]. Therefore, we assume that different levels of brightness are used to grab human attention and notify about a new event or message. As shown in Fig. 3, brightness is the most frequently used light parameter used in *Notification* information class. Moreover, most of the monochrome and single LED ALS belong to information class *Notification*. As far as the main notification parameter is brightness, color is used to indicate the nature or type of notification.

One ALS usually does not encode one type of information. This leads to the classification of one ALS into multiple information classes simultaneously. There are 26 systems among the reviewed ALS that belong to multiple information classes. Due to this fact, the majority of ALS increases its complexity using a number of LEDs and multiple colors in order to encode more information within one system. This leaves the question open as to whether ALS with high level of complexity of light encoding influence the cognitive load of participants.

Among the reviewed ALS there are 49 that belong to the personal information encoding category. We explain this outcome by better suitability of ALS for personal information encoding than for public. A reason for that could be a lack of generalized, standardized and widely accepted light patterns that can be interpreted unambiguously.

Regarding the correlations between the context of use and the system class, we observed that the majority of the reviewed ambient light systems were used in the contexts of home and office. This can be explained by a need of unobtrusive time tracking during the office work or stationary household activity. Wearable ALS are mostly used for physical activity purposes, and are at the low exploration level in the other contexts. It leads to another research direction of designing wearable ALS for home and office contexts.

Our four information classes and analysis of the technical aspects and light encodings of the existing ALS presented above allow us to define the following preliminary design guidelines:

GL1: The sequential progression of activating LEDs is the most suitable encoding for monotonously increasing or decreasing information. (*Progress*)

GL2: Linear fade from red to green and back is the most suitable light pattern for the encoding of the real-time activity. (*Status*)

GL3: LED position is the most important parameter for direction encoding. (*Spatial*)

GL4: Blinking light is the most suitable pattern for notification encoding. (*Notification*)

In order to verify these tentative guidelines we plan to conduct a lab study, where users map information scenarios to light patterns in the first part and light patterns to information in the second part as a verification step. Basing on the results of this study, we aim to investigate presented tentative guidelines and derive new ones for future development of ALS.

6 Conclusion & Future Work

In this paper, we reviewed and analyzed 72 ambient light systems from 66 papers with a focus on the basic light parameters and their encodings. We presented a systematic overview of existing light systems and defined a complementary classification of ambient light systems, which consists of four information classes: *Progress*, *Status*, *Spatial*, and *Notification*. These four information classes in the combination with additional analyzes of the existing ALS helped us to derive preliminary design guidelines for ALS development. In future work, we will conduct user studies, where we will investigate these preliminary guidelines and derive new guidelines that will support the future ALS development.

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