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Bligård, Lars-Ola, Simonsen, Eva and Berlin, Cecilia
Department of Industrial and Materials Engineering
Chalmers University of Technology
lars-ola.bligard@chalmers.se

Ergonomics and human factors (E/HF) has an important role throughout the whole product development process, but the scope and content of E/HF work differs depending on the phase of the project. The aim of this paper is to describe ergonomics activities in the product development process, with special focus on the purpose of ergonomics activities in different parts of the process. As a base for the description the ACD³-framework is used.

Keywords: Ergonomics, Human Factors, Product Development Process

1. Introduction

During the development process of a product, a variety of design variables are gradually determined to constitute the final design. For products that require input from many different types of expertise, the development process must be led and structured so that this expertise can be involved in a timely manner and with the appropriate level of influence over design decisions. In many design decisions, and consequently in many design activities, ergonomics and human factors (E/HF) professionals have an important role to ensure effective and safe human use. Therefore, the involvement of E/HF expertise has great potential to support the development of useful, usable products, thanks to the discipline's overall goal to improve both human well-being and system performance in parallel.

Design decisions drive the development process and can be made at different levels of detail - from higher system-level issues like the intended use and technical principles, down to low-level specifics like the colour of buttons and size of screws. Depending on the nature of the product development project, some of these design decisions may not be actively made – as examples at both extremes, not all projects will aim to change the product's overall purpose or use, while others will not call into question the assumption that the product can be built of anything other than standard-supplier components. But in all development projects, an awareness of the fact that design decisions should actively be made can be a great benefit to design teams. To prepare for and to make these decisions, the design process involves different types of design activities (such as analysis, synthesis and evaluation) that support the process of making design decisions at all detail levels.

Many methods and tools to support a user perspective exist within the E/HF field – these vary in scope, focus and detail level as the product development nears the realization stage. Within the process, E/HF work results in increased knowledge of the

users' needs, the interaction with the product's interfaces, and enablers and pitfalls that may support or hinder access to the product's intended functionalities. However, it is all too common that E/HF expertise is involved too little or too late, resulting in suggestions for change that come too late to be deemed economically or practically feasible, and thus limited leverage of the expertise. To gain appropriate influence, E/HF professionals must foster a strong collaboration with other roles and professionals involved in the product development process. It must therefore be clarified how E/HF fits into product development work and what benefits it can give to the project as a whole.

To this end, this paper argues that the product development process must be described in a way that clarifies how E/HF work can be integrated with the other parts. This is to avoid the risk of separate parallel design processes with lack of communication (aka "silo thinking"). To support this description, an existing systems-theory based framework for product development, ACD³, is used to provide a language for the different conceptual parts of the main process and how the E/HF expertise at each stage must shift in scope and character across the phases of the product development process. Table 1 provides explanations of the terminology used in this paper.

Table 1. Terms used in this paper to clarify the relation between E/HF activities and the product development process

Term	**Definition**
Design activities	Specific goal-oriented activities carried out by designers/developers for the purpose of identifying, assigning value to and communicating *design variables*.
Design variables	A design variable is a property related to the product that can be specified from the point of view of the designer.
Design decisions	A design decision is made when the possible value of a design variable is constrained. A design decision eliminates other solution variants once the choice is made.
Development work	The gradual formation of a product, technical system or service, with its starting point in a defined problem or a need. Development work is performed in a development process.
E/HF activities	The use of ergonomics and human factors-related knowledge, methods and tools to optimize the use- and user aspects of the product development.
Machine	Term from the ACD[3] framework signifying any human-made artefact, such as a product, tool, production system, workplace, IT system, vehicle, clothes, furniture, etc.
System view	Viewing of the product as a system at a specific level of abstraction, focusing on the relation between objects on that level.
Technical development	The portion of product development that is purely concerned with setting and fulfilment of requirement specifications to optimize technical performance.

2. The product development process according to Activity Centred Design

ACD³ is a comprehensive framework that structures the development of products based on a systems view and the philosophy that design decisions should (ideally) be made on many abstraction levels; and if they are not made intentionally, they will still be constrained by chance, circumstances and coincidences.

The ACD³ framework (Bligård et al., 2016, Berlin and Bligård, 2016, Bligård, 2015) is intended for use in product development projects to manage decisions and activities that should be addressed among the different professional roles in the process. The

framework visualises a clear structure for where certain design decision types belong, but allows flexibility in the work sequence so as not to inhibit the product development team's innovation and creativity. The three main objectives are:

- Clarify which design variables need to be considered
- Provide a coherent and structured overview of the development work
- Liberate human resources for creative work by clarifying the decision-making

2.1. The ACD³ process

This paper focuses on development process within the ACD³ framework. ACD³ divides the product development process into five distinct phases, within which design activities take place to identify, determine and communicate the design variables. The first phase, *Needfinding*, focuses on formulating the problem, describing the needs and designing the desired effects. The second phase, *Design of use*, concerns how the product is intended to be used to achieve the effects. The third phase, *Overall design*, deals with the product's technical architecture, which enables the intended use. The fourth phase, *Detailed design*, focuses on finalising the design of the product's interface and physical shape. The fifth phase, *Structural design*, deals with the design of the product's internal structure and function. Table 2 shows which principal design decisions that need to be made at which system view during the five phases.

Table 2. The five phases of the ACD³ process

Phase	**System view**	**Principal design decisions**	**Example: vacuum cleaner**
Needfinding	Socio-technical system	The effect that the machine is intended to achieve within the context	A cleaner home
Design of use	Human-machine system	The use of the machine by humans	Manually moving the device when cleaning
Overall design	Machine system	The technical architecture of the machine	An electrical motor that sucks air through a filter
Detailed design	Machine interfaces	The interaction between human/context and machine in details	Design of the physical form and user interface
Structural design	Sub system	The technical elements of the machine	Structural design of the motor, the dust bag etc

Even though the process is described in distinct phases, the work at different detail levels is often carried out iteratively and in parallel. This means that activities in several phases can and should take place in parallel rather than sequentially, and should be iterated both within and between the phases to arrive at well-grounded design decisions that fits into the product as a coherent whole at that particular detail level. When partial design decisions to be made early within the phase are dependent on design decisions made later in the same phase, iterations may be necessary to ensure internal coherence. This kind of iteration within a phase is also a good way to use ACD³ in a project managed with milestones, i.e. when it is more difficult to iterate between the phases. Iteration between the phases may also be needed, since new information emerge later in the process that creates a need to be reconsidered earlier made design decisions (hard to know everything from the beginning).

3. Integrating E/HF activities into the process

Across the previously defined phases of a product development process, E/HF work has a natural role to play in supporting the overall product development work. Work carried out by E/HF professionals typically includes investigation, generating design alternatives and evaluation activities. In general, the emphasis of the E/HF work gradually shifts from investigation, via designing, to testing and validation throughout the development process. However, it is important to note that E/HF activities may be needed to some degree even when they are not emphasised. E/HF activities involve continuous data collection from users and observing the use as a base for guiding design decisions. The data collections in the later phases are also to a lesser extent in content compared to the earlier phases. Furthermore, E/HF activities involve continuously evaluating the appropriateness of design decisions against the use and with users.

The following subsections will first describe each of each phases in the ACD³ process (which prescribe a shift in perspective in each phase to define increasingly detailed requirements) alongside appropriate E/HF activities within each of the phases. The phases are summarized at the end in Table 3, which specifies specific tasks that E/HF professionals should be involved in within each process phase.

3.1. Needfinding

The purpose of the first phase of the ACD³ process is to investigate and determine how the context and surrounding environment place demands on the solution and how the solution in turn will affect the context (i.e. design the effect). Another purpose is to investigate and determine what the user values and requires of the solution, which leads to the formulation of a high-level requirement specification.

The focus is on the effects that the user wants to achieve and the problems the user has in reaching them, thus the development work is user-centred. This phase considers the entire socio-technical system that the product will be introduced into, with a particular focus on the users of the solution (where "users" refers both to those who directly use the solution, and those who indirectly benefit from its effects). The main design output from the phase is the formulation of the desired effect that the solution is intended to achieve in its context, while the main requirements from the phase specify the needs that the human-machine system must fulfil.

The main objectives for E/HF professionals in this phase are to identify requirements from the users and the use situation, how the environment affects and places demands on the future product and how the product should affect its environment. The output is then to formulate system effect goals from a user perspective. Furthermore, ergonomics approaches can support the development e.g. by evaluating existing products as a form of benchmarking.

3.2. Design of use

The purpose of the second phase is to investigate and determine which *use* (defined as purposeful human-machine interaction) will meet the defined needs and consequently provide the intended effects, as well as to investigate and determine which overarching (technical) solutions are needed to enable the use.

The focus in this phase is on the use activity, making the work use-centred and the system level view is the human-machine system as a whole (i.e. this phase "zooms in" relative to the previous socio-technical system). The main design output from this phase is the intended use of the machine, while the main requirements from the phase specify requirements stemming from the use that are needed to reach the system goals (and consequently attain the effects).

The main objectives for E/HF professionals in this phase are to specify the tasks that the user performs when using the product and to define requirements based on the intended use (which may include usability and aesthetic aspects).

3.3. Overall design

The purpose of the third phase of the ACD³-process is to investigate and determine the machine's technical structure that can achieve the intended effects; this includes investigating what constitutes a good user interface for the machine and determining the main principle of interaction, aesthetics and form.

The development work in this phase is technology-centric. The main design output from the phase is the technical architecture (i.e. the machine structure divided into parts) that satisfies the intended use elaborated by the previous phase, and the main requirements from the phase specify the demands that the machine must meet in order to enable or afford the intended use.

The main objectives for E/HF professionals in this phase are to participate in and support the design of solution concepts for the physical form and user interface for the product, as well as supporting the formulation of detailed design requirements.

3.4. Detailed design

The purpose of the fourth phase is to investigate how the machine will interact in detail vis-à-vis the user and towards other parts of the socio-technical system, as well as to investigate how the technical subsystems of the machine will work together (i.e. design the machine's interactions with the user and the environment).

Consequently, the focus of the phase is the machine's physical exterior and the development work therefore becomes interaction-centered. The system under consideration is the external structure of the machine, i.e. how the different parts of the machine together constitute the whole. The main design outputs from the phase are the user interface and physical form of the machine and the main requirements from the phase focus on the various parts of the machine in order for them to fulfil the interaction and function as a technical whole.

The main objectives for E/HF professionals here are to support the finalization of the design and to support the design of use manuals and instructions.

3.5. Structural design

The purpose of the fifth phase of the ACD³-process is to investigate and determine how the machine's technical elements (subsystems) should be constructed in detail and investigate and determine how the machine will be manufactured (choose the principle of production to allow for manufacturing preparations).

The focus in this phase is the inside of the machine and the system under scrutiny is the machine's totality of internal subsystems. The main design output from the phase is a complete technical design specification of the machine and base for setup of manufacturing in the form of e.g. drawings, assembly instructions, etc.

The main objectives for E/HF professionals here are to support the development work by testing prototypes appropriately to ensure correct ergonomics and functionality and to assess the performed activities in relation to principles for good ergonomics and human factors.

3.6. Summary of the process and respective tasks and roles

Table 3 below summarizes how E/HF fits in the development work as defined by the ACD³ process, and what outputs can be expected from each phase. Throughout the whole development work, E/HF activities also include data collection from the users and the use as a basis for the design decisions.

Table 3. Specific tasks for E/HF professionals to take part in and/or lead during the ACD³-process

Phase	**Tasks for E/HF professionals**	**Focus and outputs**
Need-finding	- investigate and describe main problems that justify the product's existence - investigate the delimitations of the development work - investigate and describe stakeholders - investigate existing machines - investigate existing use and users - describe intended use and users - set system goals (effect goals) - investigate and identify needs from use and users	*The users of the solution* - Description of the intended effects of the machine - Specification of needs that the machine must meet
Design of use	- perform in-depth analysis of system goals - design the intended use of the machine - explore ideas for interaction, aesthetics and forms - investigate and specify use and user requirements - develop guidelines for usability and aesthetics - evaluate the design use with users	*The use* - Design of the use - Overarching technical principle
Overall design	- analyze what is needed to enable the intended use clarify central design variables for the machine - generate suggestions for the interaction overall - specify system requirements for the machine as a whole - develop design guidelines for detailed design - evaluate overall design with users	*The technical architecture* - Description of the machine in parts - Specification of requirements that must be met to afford the intended use

Detailed design	- design the human-machine interaction, i.e.
	  - design the physical form and the user interfaces
	  - design the manuals and technical documentation
	  - design the training (for use)
	- evaluate detailed design with users
		The interaction
		- Description of the user interfaces and physical form
		- Specification of requirements on interacting machine parts

Structural design	- test of the structural design - verification of the structural design - final risk analysis of the structural design - validation of the structural design - evaluation of the completed E/HF-work	*The machine's subsystems* - Complete technical design specification - Specification of manufacturing requirements

4. Discussion

The purpose and scope of E/HF activities vary throughout the development process. At the beginning the focus is on understanding the user and the use, in the middle on supporting the design of the solutions, and in the end on testing and evaluating solutions from an E/HF perspective. This paper has used a framework (the ACD[3]) to clarify how and when E/HF work can be integrated throughout the product development process, by matching the outcomes of E/HF-activities to decision-support needs in the development work. Identifying and clarifying the purpose of E/HF activities is meant to raise the awareness of how E/HF work supports the planning and the implementation of the development work as a whole; both in terms of helping to clarify the possible space of design solutions, and in order to ensure explicit definition of how the design possibilities are gradually constrained towards a final solution. But to enable a development project to get the greatest leverage from E/HF expertise, additional aspects need to be considered, as discussed in the following sections.

4.1. Competence and staffing

Since the E/HF knowledge and competencies needed in the beginning of a process are not the same as those required at the end, it is important to map out types of E/HF activities that should be performed in the phases. This mapping should then be compared to the available E/HF-competence that exists within the organisation. If there is a mismatch and more competence is needed, it can be solved in three ways: 1) by educating existing or hire new staff, 2) hiring consultants, or 3) adjusting the E/HF-work to fit the competence of the organisation. If ignored or done inaccurately, the result of the mismatch may be a less useful product, or that resources may be used sub-optimally. Also, it is not enough to identify the need for E/HF-work and which persons in the organisation should perform these activities. In order to be able to perform the E/HF-work successfully, knowledge of suitable methods and theory from the ergonomics / human factors discipline is crucial. The description of the E/HF activities in development work proposed in this paper is not aimed to remove the need for E/HF-competence; on the contrary, it is meant to clarify and emphasize the need for such competence.

4.2. The guiding nature of E/HF activities

The guiding nature of E/HF activities is often the hardest to communicate to project management, since it can be hard to quantify the benefits of letting E/HF have a prominent, proactive role in development projects. Product development is often initiated by the emergence of a new technical solution, a possible new market or the emergence of a new problem/need. However, regardless of initiation, E/HF activities play a central role to ensure successful *use* of the machine and consequently enable the intended effects. These activities include the work of clarifying and describing the overall purpose of the machine, which frames the entire development work and provides significant input to the other disciplines in the development process. For this reason, E/HF activities should be performed early in each phase of the development process so that input can be leveraged. It is also important that other disciplines participate to an appropriate extent in these E/HF activities to ensure the quality and

integration of the results; e.g. software developers should be involved in the design decision regarding the user interface to ensure acceptance of the underlying reasons.

4.3. The role of the ergonomist

It is important here to view E/HF as an engineering discipline, as it is the design and its properties that are the focus of the E/HF work. More specifically, the E/HF work objective is to design the human-machine system to achieve the intended effects. It is therefore important to clarify how E/HF relates to system performance and efficiency, both in the final product and in the development project. E/HF should therefore not be regarded as a Human Resource (HR) or an occupational health discipline, or be equated with operational competence (e.g. that users intrinsic have E/HF competence) . The E/HF professional should work in close collaboration with system engineers and system architects to maximise the benefits of E/HF activities. Also, since it is in the *use* of the product that much of value for the user/customer emerges, the E/HF professional becomes a natural link between the marketing and management functions, who focus on customer value, and the other engineering disciplines, who focus on the product. For example, Institoris and Bligård (2014) showed that Human Factors can contribute to Lean Product Development by offering an approach that continuously considers the user and the use throughout the whole product development process. To clearly analyse human behaviour as part of the value proposition for a product would benefit the final design of the machine. However, the E/HF professional should not carry out all the E/HF activities independently; instead, the majority of the work should be integrated into the development process and carried out together with the project team.

5. Concluding remarks

Clarifying the need for and purpose of E/HF activities, increasing opportunities to raise awareness of E/HF benefits and integrating E/HF work into development work mean that more competences can be effectively involved, that user- and use-centered decision support is better utilized, and that duplication of work can be avoided. To achieve this, it is important to have sufficient E/HF competences and staffing in the organization, and to recognise the guiding nature of E/HF activities. It is also important to regard E/HF as one of the engineering competencies, since E/HF helps with ensuring system performance and efficiency. In the end, doing this means that better machines (that reach the intended goals) can be developed more efficiently.

References

Berlin, C. & Bligård, L. O. (2016) An activity centered design framework for determining design decision levels in production systems. *Advances in Intelligent Systems and Computing*.

Bligård, L.-O. (2015) *Utvecklingsprocessen ur ett människa-maskinperspektiv - ACD3-procesen*, Göteborg, Chalmers tekniska högskola.

Bligård, L. O., Simonsen, E. & Berlin, C. (2016) ACD3 - A new framework for activity-centered design. Proceedings of NordDesign, NordDesign 2016.

Institoris, M. & Bligård, L.-O. (2014) Human Factors Engineering as a supportive tool for Lean Product Development. *NordDesign 2014*. Espoo.