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Review

Usability in Chemical Engineering

Christian Osterbauer*, Maximilian Lackner, and Gerald Weinberger
ProcessEng Engineering GmbH, Jörgerstraße 56-58, 1170 Wien, Austria

ABSTRACT

Usability can be defined as a measure of the ease with which a system can be learned or used, its safety, effectiveness and efficiency, and the attitudes of its users towards it. While usability has gained popularity in IT and has seen some applications in product development, where it brings strong advantages, industry by far does not exploit the full potential of usability. In the process industries and in chemical engineering specifically, Usability Engineering is a newly developing field with interesting prospects. In this review article, trends in Usability Engineering applied to production plants in the chemical, pharmaceutical, metal and cement industry are explored. This paper starts with an introduction to usability and Usability Engineering in general. Then, concepts of modern plant operation and control are presented. It is shown with several examples how Usability Engineering can increase safety, ergonomics and economics.

KEYWORDS: usability, Usability Engineering, Chemical Engineering, Chemical Usability Engineering, usability testing

INTRODUCTION

While it is taken for granted by many that ergonomics and "human aspects" in general are considered in industrial work places, reality often teaches a strikingly different story. For sure, today's chemical production plants look different from those half a decade ago, when hard labor was required. However, compulsory standards such as ISO 10075 or ISO9241-10 are often only followed to the minimum, and aspects of user-friendliness are neglected or even omitted. The advantages of having a system of high "usability" are intuitive, yet there is normally no structured process to consider usability aspects in the design and construction of chemical plants. A new trend, concurrent engineering [1], even goes into the opposite direction: By cutting down the time needed from engineering to commissioning, designer deprive the new plants of many opportunities where usability can be enhanced. This leaves the end user with a costly asset-typically to be used over the next 2 to 4 decades-that lacks user-friendliness. As will be shown in this paper, the price is a loss in efficiency and safety. By making Usability Engineering an integral part of plant design, engineering, construction and operation, significant benefits can be reaped as elaborated in this review.

Usability

Whereas the usefulness of a man-made tool or installation is related to user satisfaction, the term **us(e)ability** denotes the ease with which it can be deployed [2]. Usability is applicable to many different aspects of life. People are faced with an increasing number of possibilities and with an enormous level of complexity. So, even simple systems should be designed with usability in mind.

Usability in general can be defined as a measure of the ease with which a system can be learned or used, its safety, effectiveness and efficiency, and attitude of its users towards it. Usability also

*osterbauer@processeng.at

means bringing the usage perspective into focus. The best way to ensure usability is to treat human factors as an input to design, rather than merely evaluating prototypes or design documentation. Usability is successful when a strategy is developed which leads to key usability benefits. In many organizations usability was or still is ignored because there are no objective criteria for usability when developing and procuring products. Then again, many people and organizations now recognize the need for usability in interactive systems, and the benefits that usable systems deliver. More information on usability can be found in [2].

However, many people and organizations now recognize the need for usability in interactive systems and the benefits delivered by usable systems. The benefits of usability measurement are derived from evaluation procedures in ergonomics, software quality and quality management. Although usability has already gained wide acceptance in software development practices, almost nobody takes sufficient time to carry out actual usability tests with the actual user. Testing with real users is the most effective way of making a system usable; however, it requires much time and preparation to conduct such a test, e.g. try out a variety of tasks, control the testing environment, use measurement instruments (videotaping, recording keystrokes, etc.) or combine testing with other methods of data collection, such as interviews of users.

Usability Engineering

Aspects of Usability are increasingly used in industry, e.g. for the design of better consumer products. Usability Engineering can be considered as an approach to system or product development that is based on real user data and feedback. Usability Engineering is based on direct observation and interactions with real users to provide more reliable data than self-reporting techniques.

The first step within the Usability Engineering process is the conceptual phase with field studies and contextual inquiries to understand the functionality and design requirements of a system. Many systems are difficult to learn or require a long time to read the manuals. These facts increase support and maintenance costs, decrease productivity and user satisfaction.

Usability Engineering is iterative design and evaluation to provide user feedback on the usefulness and usability of a product's functionality and design throughout the development cycle. This results in systems or products that are developed to meet the users' needs. More information on Usability Engineering can be found in [3] and [17].

It is a challenge to develop a chemical system or process that is effective, efficient and satisfying from a user's point of view.

In this context, usability and usability testing are key issues for real success. However, in all types of usability testing, one thing must be kept in mind, i.e. that the system or the process, and not the user, is being tested. Users must be told in advance that they are indeed participants, not subjects, because the point of usability testing is to determine where the product design or the process fails.

Usability Engineering Lifecycle

The Usability Engineering Lifecycle consists of a set of Usability Engineering tasks applied in a particular order at specified points in an overall product development lifecycle and have been practiced since 1981 [18]. The lifecycle can be adapted to support internal, industrial, and chemical development projects of any size, complexity, time frame, and budget. It is also oriented towards development projects creating fairly new products (or processes), as opposed to reworking of existing projects. All lifecycle tasks will always apply, but they can be expanded or contracted depending on the requirements, characteristics, and resources of a project.

The Usability Engineering Lifecycle consists of several types of tasks, as follows:

- Structured usability requirements analysis tasks
- An explicit usability goal setting task, driven directly from requirements analysis data
- Tasks supporting a structured, top-down approach to the chemical/industrial process driven directly from usability goals and other requirements data

- Objective usability evaluation tasks for iterating design towards usability goals

Fig. 1 illustrates the three main lifecycle phases:

- Requirements analysis
- Design and testing
- Installation

Phase one: Requirements analysis

The User Profile task determines the characteristics and features of the target group (psychological, physical, job and task characteristics, knowledge and experience). To understand the current task and specification of underlying user goals, the Content Task Analysis (CTA) examine user's current task and work-flow patterns. (This task can be replaced by other appropriate usability methods.) The influence of environment attributes handles the Environment Capability and Constraint task. The General Design Principles task applies guidelines and general design principles.

All usability tasks shape the Usability Goal Settings: Specific qualitative goals, reflecting usability requirements extracted from User Profile and CTA, and quantitative goals, defining minimal

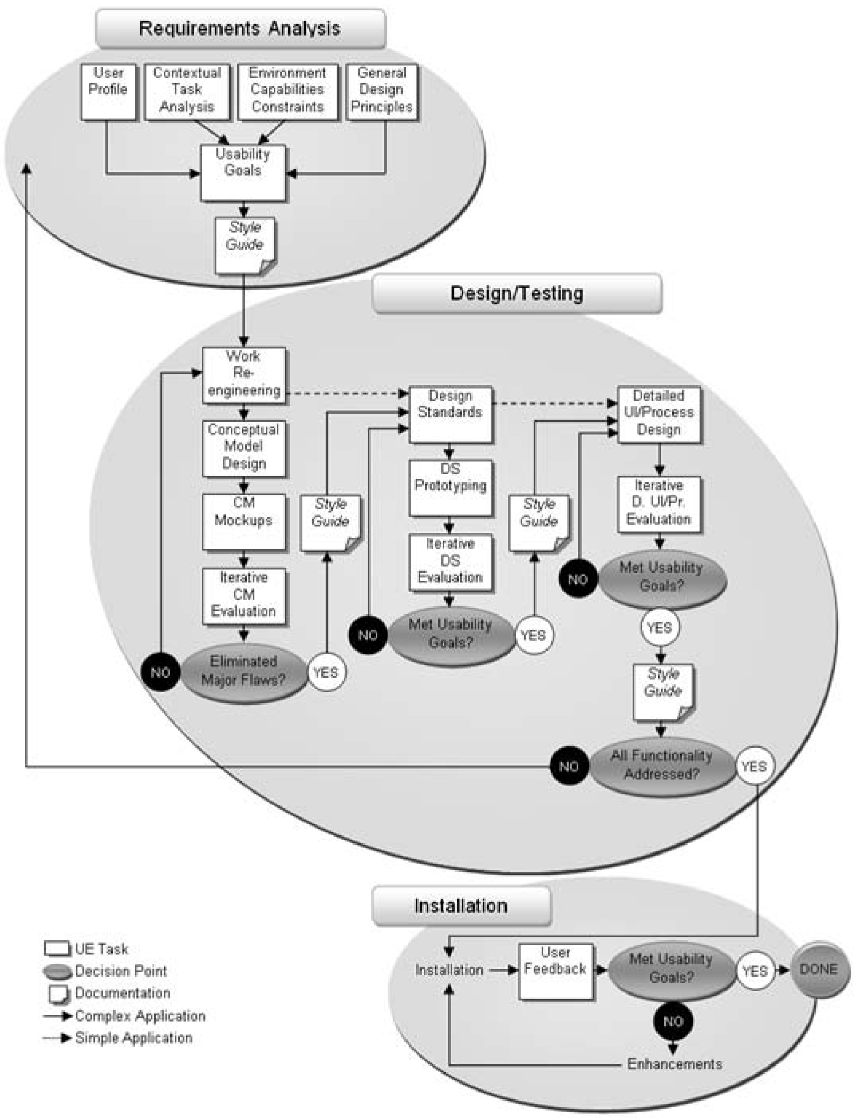

Fig. 1. The Usability Engineering Lifecycle (based on [18]).

acceptable user performance and satisfaction criteria. The analysis tasks are finally documented in product Style Guide.

Phase two: Design and testing

This phase is divided into three levels. Design level 1 contains high-level design issues, Design level 2 concerned with setting standards, and level 3 based on the result of the first two levels. (Simple Applications uses a shorter path through Phase Two as seen in Fig. 1).

Based on all goals of Phase One, user tasks are redesigned at the level of organization and work flow to streamline work (Work Reengineering). The Conceptual Model Design task generates initial high-level design alternatives which are represented in simple prototype mock-ups (Conceptual Model Mock-ups). The mock-ups are evaluated and modified through iterative evaluation techniques. All tasks are conducted in iterative cycles until all major usability issues are engineered. Tasks of level 1 highlight the efficiency of the developed application and minimize effort for learning the application.

Level 2 deals with setting standards: A set of product-specific standards and conventions for all aspects of the process based on any mandated industry and/or corporate standards. Tasks of level 2 guarantee coherence, consistence and simplicity of the developed interface design or process. During the Iterative Design Standard Evaluation task, an evaluation technique such as formal usability testing is carried out on the functional Design Standard prototype, and then redesign/re-evaluate iterations are performed to refine a robust set of Design Standards. As well as in level 1, iterations are continued until all major usability bugs are eliminated.

At the end of level 1 and level 2, you have a validated and stabilized Conceptual Model Design and a validated and stabilized set of standards and conventions.

In Level 3, detailed design of the complete product is carried out based on last two levels (Detailed User Interface/Process Design). During Iterative Detailed User Interface/Process Design Evaluation, a technique such as formal usability testing is continued to expand evaluation to all subsets of functionality and categories of users. This task also refines the user interface and validates it against usability goals.

Comment to style guides

The purpose of Style Guide tasks is to bring together in a single document all previous Requirement Analysis and user interface design work products relevant to a particular product. Style Guides can be produced at different levels with different scopes (e.g. Platform Style Guide, Corporate Style Guide, Product Family Style Guide, Product Style Guide).

The Usability Engineering Lifecycle referring to a *Product Style Guide* and include: Introduction, Overview of Product Functionality, User Profiles, Contextual Task Analysis, Environment Capabilities and Constraints, Usability Goals, Reengineered Work Models, Conceptual Model Design, Input and Output Devices, Design Standards and Feedback. A Usability Product Style Guide does not include detailed user interface specifications.

Phase three: Installation

After the product has been installed, feedback is gathered for use in enhancement design, design of new releases, and design of related products (you will have a pool of actual expert users available). Depending on content, a set of different usability techniques are provided where you can choose from: usability testing, interviews, focus groups, questionnaires, and usage studies.

In order to achieve optimal usability, all lifecycle tasks should be carried out for every development project. A top-down, structured approach to design deals with high-level issues first, the detailed standards the complete design.

Usability Engineering in the chemical industry

Fig. 2, taken with permission from [6], shows a screenshot from a control room in a chemical plant.

It can be seen from Fig. 2 that operators will have to bear a high mental workload when controlling a process via such a screen: It is bilingual, and there is partial wrong labelling. Numbers in small print need to be compared to each other, in front of a low-contrast background, to determine deviations

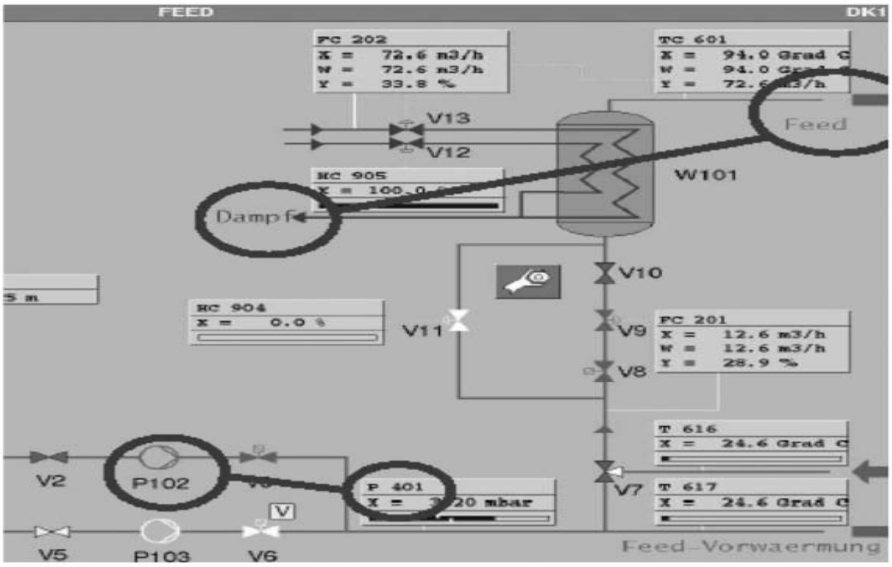

Fig. 2. Section of a control screen in the control room of a chemical plant [6]. 2 flaws are highlighted.

from setpoints. In case of an alarm, where fast reactions are necessary to stabilize plant conditions, such a visualization system will not lead to best performance.

The following list, modified from [8] and ISO 9241-10, summarizes several design guidelines to create state-of-the-art control room interfaces:

- Aesthetics
- Attention
- Display issues
- Feedback
- Error tolerance
- Metaphors
- Simplicity
- Help function
- User control
- WYSIWYG (what you see is what you get)
- Suitability for learning
- Suitability for individualization
- Suitability for the task
- Self-descriptiveness

These can be complemented by the characteristics of well-defined tasks as outlined in the international standard EN 614-2:

- Take operator experience, capabilities and skills into account
- Provide for task variety
- Provide for task identity
- Provide for feedback
- Provide for autonomy
- Provide for task completeness (hierarchy, sequence)
- Provide opportunities for competence development
- Avoid overload
- Avoid underload
- Avoid repetitive tasks
- Avoid social isolation

Frequently encountered shortcomings, collected from [6] and [8], are:

- Too complex screens
- Too little contrast
- Different layout on each screen
- Too many colors
- Mixed language
- Too small characters
- Only one window at a time
- System changes only visible after switching to the respective window.
- Static screen instead of predictions of process parameter developments

Alarm lists are a particular area of concern, as they are rarely structured.

An example of how Usability Engineering was successfully used in the control room of a steel mill can be found in [8]. A more general review is given by [14].

Plant operation and process control in the chemical industry

Synthesis of a chemical compound is rarely done by a scientist on a lab bench, who manually controls the process. In industry, chemicals tend to be produced on a large scale, in batch processes or continuous mode, typically in a production plant with shift operation. Depending on the process, the output and other considerations, one will find various degrees of automation. Safety-critical tasks tend to be automated in an attempt to rule our human error and misjudgement.

Process control is carried out partly automatically and partly by operators. The operators interact with dedicated machines in a complex manner (man machine interfaces, MMI). When advanced control systems are in service, visual display units (VDU) are deployed. In the past, character-based user interfaces (CUI) were common, whereas today graphical user interfaces (GUI) are frequenty used. Compared to switchboards, GUI condense information and have become a critical factor for safety and efficiency in chemical plants [4]. The design of MMI has been widely recognizes as a safety-critical factor [5].

There has been a general trend towards increased automation [6] and fewer operators. The design was mainly driven from an engineering perspective. However, in order to ensure optimum plant operation, also viewpoints from human science and social science need to be taken into account [7]. So in order to develop a “good” man-machine interface, not only engineers, but also end users, i.e. operators with experience, should be involved in the design.

In chemical plants, there can be local control panels for each machine. For large, advanced plants, typically a control room is used. With local control panel operation, one speaks about MMI, whereas in a control room, MCI (man computer interaction) prevails.

Fig. 3, taken from [8] with permission, shows the transition from MMI to MCI in the process industries.

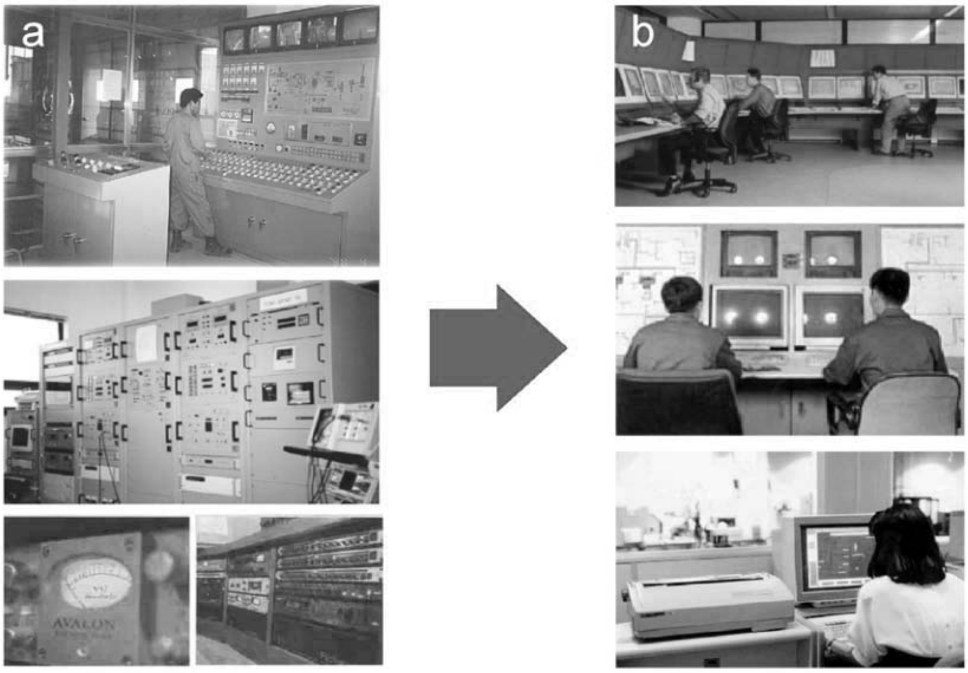

Fig. 3. Man-machine interfaces (left) and man-computer interfaces (right) in industrial plants.

One would expect that when moving from a MMI to a GUI, usability issues should be solved. This, however, is not automatically the case [10]. One such example would be that the old analog instruments are simply mimicked, in a small scale, on the computer screen.

A recent textbook on advanced process control is [9]. The German association for process control in the chemical industry (NAMUR) [11] also offers useful information.

Examples of Usability Engineering in the chemical and related industries

Usability Engineering, as mentioned earlier, can be applied at various stages during the lifetime of a chemical plant. In an optimum scenario, it is considered during the design and the engineering phase of a new chemical plant. Also, existing plants can be evaluated. This can be done on a regular basis, e.g. every 5 years, to take into account new developments. When a change is being implemented in a plant, it does not only have to be studied from a safety point of view, but also from a usability-angle. When analysing accidents or near-miss events [15], i.e. occasions that could easily have led to an accident, one typically finds that 75-90% of them are based on human error rather than equipment failure. Human error can be reduced by applying usability principles.

An example of a successful man-machine interface improvement in a steel mill is given in [8].

Fig. 4, reproduced with permission from [8], shows the screen of a control room PC before and after a usability check.

The difference in the two screens above can be seen very clearly. Operators will find the required information more easily on the improved screen.

How to consider usability in the chemical industry

Usability testing and engineering is an iterative process, which requires time and expert knowledge. Perceived value is sometimes low, especially to those who are not familiar with usability and Usability Engineering.

For a chemical company, possible ways to improve the usability of existing and future installations can be:

- Knowledge sharing across different locations
- Usability audits and studies (expert consultants, diploma students)
- Adoption of basic usability principles in corporate design guidelines
- Involvement of end users (operators) in the design of a new plant or unit
- Properly conducted design reviews prior to the start of construction

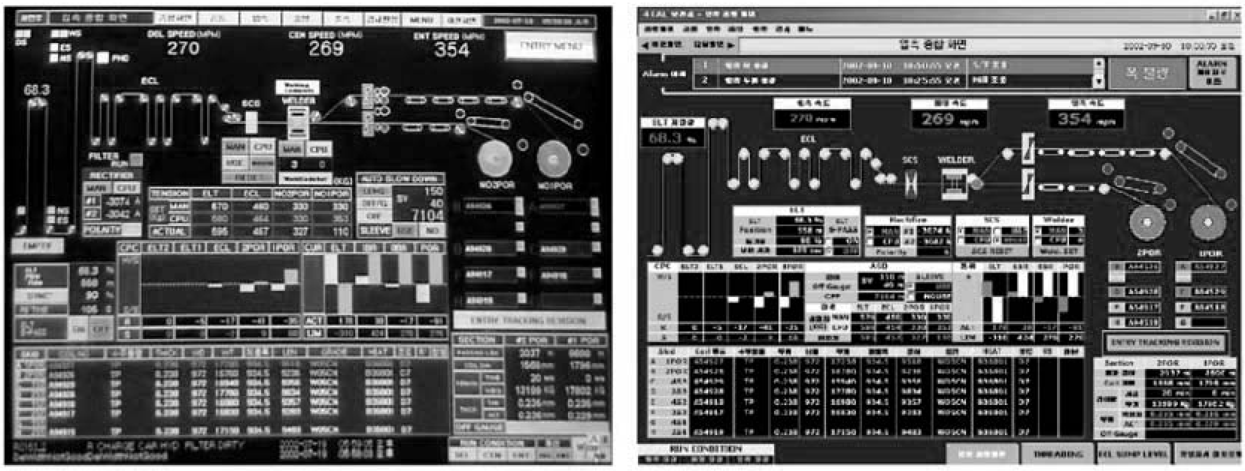

Fig. 4. GUI in a chemical plant before (left) and after (right) a usability check.

- Provision of a certain budget in any project to accomodate ergonomic and other human factors

Usability testing

One important part of the Usability Engineering Lifecycle is usability testing. Usability testing may serve a number of different purposes [20].

- to improve an existing product
- to compare two or more products
- to measure a system against a standard or a set of guidelines

We can also extend the purposes for chemical problems like

- to improve the safety of plants and its processes
- to optimize the maintenance
- to improve the performance of processes

Generally, we can say that a number of people are asked to carry out an experimental task. Usability testing is to observe the system prototype being utilized by real users. For example, if the intended users are chemical engineers, testing should be done with chemical engineers. On the other hand, if the audience is the population at large, testing should include a reasonable cross-section, with consideration given to age, education, language and (computer)- knowledge. However, it is not necessary to test with large numbers of people.

Often, using six to eight participants will generally identify the majority of significant issues. Indeed, after the first three or four, the same issues tend to come up again. With these facts even a single test can reveal important issues.

Tasks play a vital role in HCI (Human Computer Interaction). An understanding of tasks that users will perform gives developers an insight into the functionality which should be provided and how it will be used [21]. Tasks at all but the highest levels of abstraction involve manipulation of user interface objects (e.g. icons, menus, buttons). Designing for usability means understanding user tasks.

Most usability testing involves experimental tasks that reflect important or frequent uses of the system, which should be selected through contact with real users and work situations rather than by intuition. Participants are recorded as they engage in the tasks; problems and errors are identified. Interface changes to make these problems and errors less likely can then be proposed.

There exists some related work. Dumas and Redish [19] wrote a practical guide to usability testing. Nielsen [3] presents a more philosophical view of Usability Engineering in general, in an attempt to provide concrete advice and methods that can be systematically employed to ensure a high degree of usability in the final user interface. In Jeffries *et al.* [16], experimental evidence regarding the strengths and weaknesses of usability testing is provided with respect to other techniques for isolating usability problems. The outcome there was that many of the most severe design mistakes could only be identified with usability testing.

Characteristics of usability testing

Usability testing has the following characteristics:

Context-specific

Although the results of specific usability tests may be applicable to any number of similar design projects, the tests are designed to provide data to a specific project team about a specific audience and a specific set of goals. Thus, the methodology must be appropriate to and sufficient for the context of that project - not all possible projects - and project teams should resist the temptation to generalize their findings across projects. In addition, tests are conducted as far as possible under the conditions expected to prevail when the product is put into use.

Data-driven

The basis for design decisions in a usability-oriented design process must be data derived directly from observation and other methods, not from opinions or speculation. The design team uses every resource at its disposal, including opinion and speculation, to construct prototypes they consider likely to be successful, but they use data to find their errors and direct their design efforts.

Descriptive - not prescriptive

While helpful and necessary prescriptive principles are emerging in the field of human-computer interface design (“keep the user in control”), the usability process takes a descriptive approach. It is not presumed that a general principle will inevitably be proved under the conditions of use peculiar to this product, and it is not expected that the discovery of a design problem will automatically be accompanied by a clear remedy. It is this characteristic which renders the “pass-fail” approach to usability inappropriate.

Flexible and pragmatic

Sequences of tests may be outlined for various development situations, but the details and timing of usability activities must be tailored to the emerging circumstances of a project if they are to achieve their best impact. Since the results of the tests are not to be generalized, the emphasis is placed on obtaining valid and useful data to guide design efforts - not on controlling variables to pinpoint specific causal relationships, although many usability tests are constructed quite rigorously, particularly when a product must ultimately perform within very strict parameters.

In general, usability tests can be divided into three groups:

Low-impact tests

“Low-impact” does not mean low impact on the user interface but rather on resources and budget. Use low-impact tests to check the intelligibility of pieces of your application. For the application as a whole, use high-impact tests. Examples for low-impact tests are:

- card sorting
- questionnaires

High-impact tests

High-impact tests cost more money and time, but the impacts on usability by far outstrip the costs, provided, of course, that the tests are done well.

Examples are:

- cognitive walkthrough
- heuristic evaluation

Formal usability testing

Formal testing (what most people think of when they think of usability testing) is used to evaluate the ease of use and intuitiveness of your application. The application can be still in the design phase, in prototype or in beta. You can also test finished applications (you might test the latest release, for example, to act as a baseline for the next) or your competitor's applications.

The only presently feasible approach to successful design is an empirical one, requiring observation and measurement of user behavior, careful evaluation of feedback, insightful solutions to existing problems and strong motivation to make design changes.

A system under development must be modified based upon the results of behavioral tests of functions, user interface, help system, documentation, training approach. The process of implementation, testing, feedback, evaluation and change must be repeated to iteratively improve the system. No design is right the first time. Any design will be done iteratively.

Furthermore, during the design, the required or recommended changes can be identified with measurements made on intended users and the results compared against previously established behavioral goals.

First, we consider several general empirical usability test methods for measuring usability. However, these general methods are also suitable for usability in chemical engineering. In this article the word system is synonymous with process (chemical process) and product.

A usable system is one which includes the right functions so that the users can do the right things. We will not know whether the system functions properly until testing is started. So, from the very beginning of the development process, user testing should be adopted to ensure that the right functions are designed. Some methods for carrying out early user testing are listed below [22]:

- **Printed or video scenarios:** when the design team discusses the design proposal, it is a good way to use user scenarios. These scenarios can lead to discussions about required functions and how the functions should be organized. So, the designers can get informal data before even writing a line of code.

- **Mock-ups**: mock-ups and models can benefit the system design. The intended users' comments are beneficial for designing all parts of system. Mock-ups can also lead to the identification of issues that might not be as easily envisioned otherwise.
- **Early prototyping:** early prototyping can be made possible through the use of designer toolkits or user interface management systems. Prototyping the system can help designers find the users' reactions, get some feedback from the users, find the problems in the design of the system. Prototyping is expensive but necessary.
- **Early demonstrations:** giving the demonstration to the user early. It is important to observe the users' reactions. The purpose of demonstrations also is to get some feedback from users.
- **Thinking aloud:** let users think aloud when they try to test the system. It is a good way of getting useful information and feedback from end users. It also gives an indication to the designers of the usability of their system.
- **Make videotapes:** making videotapes of users attempting to use a new system is useful for measuring time, errors, user attitudes and management.

Empirical Usability Testing (with real users)

Let us consider some user-based methods for usability testing. At first, some basic empirical methods shall be considered.

When an empirical method is used, data is collected on an experimental basis to prove or disprove a hypothesis. Basically, in empirical methods a hypothesis is suggested on the basis of a set of objective measures for evaluation. This could be, for example, the number of correct responses and errors made by a user under controlled conditions. The next step is to find participants for the test. Then the data will be collected and analyzed to determine if the proposed hypothesis has been proved.

Advantages of such empirical methods:

- effective for finding cause and effect
- effective for addressing a specific question or problem through focused testing

However, this method also has some limitations, such as:

- a skilled practitioner trained in empirical methods is needed
- it can be time-consuming and expensive to conduct good experimental work

Methods in general

Let us consider some usability methods which are also applicable for chemical tasks. The information about users needed for evaluation is derived from various usability publications and will be considered as a point of reference.

Co-discovery learning

During a usability test, two test users attempt to perform tasks together while being observed. They are to help each other in the same manner as they would if they were working together to accomplish a common goal using the product. They are encouraged to explain what they are thinking about while working on the tasks. Compared to the thinking aloud protocol, this technique makes it more natural for the test users to verbalize their thoughts during the test.

Performance measurement

This technique is used to obtain quantitative data about the performance of the test participants when they perform the tasks during the usability test. Generally, an interaction between the participant and the tester during the test, affecting the quantitative performance data, will be prohibited. The test should be conducted in a formal usability laboratory so that the data can be collected accurately and possible unexpected interference is minimized. Quantitative data is most useful in comparative testing or testing against predefined benchmarks. To obtain dependable results, at least 8 users are needed, although more participants would be more desirable. The technique can be used in combination with retrospective testing, post-test.

interview or questionnaires so that both quantitative and qualitative data is obtained.

The general procedure for this method is to define goals:

1. Define the goals for usability testing in terms of usability attributes, e.g.

- easy to learn
- efficient to use
- easy to remember
- few errors
- subjectively pleasing

2. Balance the various components of the goals and decide on their relative importance.

3. Quantify these usability issues by measurements such as those given below:

- the time users take to complete a specific task
- the number of tasks of various kinds that can be completed within a given time limit
- the ratio between successful interactions and errors
- the time spent recovering from errors
- the number of user errors
- the number of commands or other features never used by the user
- the number of system features the user can remember during a debriefing after the test
- the frequency of use of the manuals and/or the help system and the time spent using them
- the proportion of users who say that they would prefer using the system over some specified competitor
- the proportion of users using efficient working strategies in case there are multiple ways of performing the tasks

First, it is better to conduct a pilot test to make sure that the tools and techniques for data collection work well. During the test it should be ensured that there is no unexpected interruption. When possible, the test should be videotaped to support data collection so that some data can be collected or verified after the test by reviewing the video recording. Even though this technique is aimed at collecting quantitative data, it should be noticed that it is very important to collect qualitative data to uncover the user's mental process and other information behind the quantitative data and take this into account in drawing conclusions.

Questionnaires

Questionnaires are summaries of what people have done, said or thought. In general, questionnaires attempt to focus the respondents' minds to a particular topic and, almost by definition, to a certain way of approaching the topic. Professional usability studies use questionnaires that are designed to be analyzed statistically. Questionnaires will give you information on preferences, opinions and suggestions for improvement. One advantage is that a usability questionnaire gives you feedback from the user's point of view. Another advantage is that measures derived from a questionnaire are largely independent of the system, users or tasks to which the questionnaire was applied. Questionnaires are usually quick and therefore cost effective to handle and to score and you can collect a lot of data using questionnaires as surveys. Questionnaire data can be used as a reliable basis for comparison or for demonstrating that quantitative usability targets have been met.

Question asking protocol

During a usability test, apart from making the test users verbalize their thoughts as in the thinking aloud protocol, the testers prompt them by asking direct questions about the product in order to understand how they perceive the (model of the) system and the tasks and where they have trouble understanding and using the system. This is a more natural way than the thinking aloud method, i.e. letting the test users verbalize their thoughts.

Provide the test users with the product to be tested (or a prototype of the interface) and a set of tasks to perform. Ask the participants to perform the tasks using the product and to explain what they are thinking about while working with the product's interface. Also ask them pointed direct questions about the product, for example, "How would you send the e-mail message?" Their response, either in terms of the product being tested or in terms of other products from their past experience, will provide insights into how they perceive the product.

Retrospective testing

If a videotape has been made of a usability test session, the tester(s) can collect more information by reviewing the videotape together with the participants and by asking them questions regarding their behavior during the test. This technique should be used along with other techniques, especially methods where interaction between the testers and the participants is restricted. However, using this technique means that each test takes at least twice as long. Another requirement for using this technique is that the user's interaction with the computer needs to be recorded and replayed.

Review the recording of the usability test session with the test user. Ask the test user questions and let the test user describe what he/she is doing and why.

Thinking aloud protocol

In the course of a usability test the test users are asked to verbalize their thoughts, feelings and opinions while interacting with the system. This is very useful in capturing a wide range of cognitive activities. Two variations of the thinking aloud protocol technique are:

- **Critical response:** this requires the user to verbalize/comment what he is doing only during the execution of certain predetermined subtasks.

- **Periodic report:** this is used when the task is complex and makes it difficult for users to think aloud while at the same time performing the task. The user, therefore, verbalizes at predetermined intervals of time and describes what he/she is currently trying to achieve. The length of the interval depends upon the complexity of the task. As this technique is very time-consuming, it is recommended for subdivisions of a task.

First provide the test users with a prototype of the interface to be tested and a set of tasks to perform. Ask the test users to perform the tasks using the product and to explain what they are thinking about while working with the product's interface. Thinking aloud allows testers to understand how the user approaches the interface and what considerations the user keeps in mind when using the interface.

Although the main benefit of the thinking aloud protocol is a better understanding of the user's mental model and interaction with the product, there are other benefits as well. For example, the terminology the user uses to express an idea or function should be incorporated into the design or at least its documentation.

Focus groups

This is a data collecting technique where about 6 to 9 users are brought together to discuss issues relating to the system. A human factors engineer acts as moderator who has to prepare the list of issues to be discussed beforehand and seeks to derive the needed information from the discussion. This can lead to spontaneous user reactions and ideas evolving in the dynamic group process.

The following general procedure is used for conducting a focus group study:

- Locate representative users (typically 6 to 9 per focus group) who are willing to participate.
- Select a moderator.
- Prepare a list of issues to be discussed and goals for the type of information to gather.
- Keep the discussion on track without inhibiting the free flow of ideas and comments.
- Ensure that all participants contribute to the discussion. Guard against having a single participant's opinion dominate the discussion.
- Have the discussion feel free-flowing and relatively unstructured to the participants, but try to follow a preplanned script.
- Write a summary of the prevailing mood and critical comments of the session, including representative quotes.

Usability testing especially for the chemical industry

The US Chemical Safety Board (CSB) [12] regularly publishes reports and videos on major Chemical accidents, in an attempt to prevent reoccurrence by broad knowledge sharing. More often than not, the root cause of serious and sometimes even fatal accidents can be tracked back to usability deficiencies, i.e. a situation where an operator was not able to see or obtain all relevant data. However, instead of finding out in retrospect that a process was poor in usability is not an acceptable situation. This needs to be done during the design and/or regularly during operation, particularly if the plant is being modified. There exist several methods to test the usability of a given piece of equipment in a chemical plant. They can be simple or advanced, one of them being protocol analysis. Researchers conclude that "human factors do not play the role they deserve in the design of process control systems". [6].

Fig. 5, reprinted with permission from [13], shows a proposed experimental setup for usability testing in a control room.

Two common techniques are heuristic reviews and cognitive walkthroughs. Protocol analysis is a very simple method to analyse the interaction of an operator with a control unit. Using cameras as shown in Fig. 5 is a state-of-the-art technique to gain as much information as possible. A review that compares different usability evaluation methods is provided by [16].

Methods to verify the usability of a given man-machine interface include

- Rating by the operator on a graded scale (e.g. from 1 to 10)
- Performance measures
- Psychophysiological data such as heart rate and heart rate variability (HRV)

An example of the latter is shown in Fig. 6, taken with permission from [6].

The mental (emotional) strain of the operator (compare Fig. 6) will be lower when the usability of the system is better.

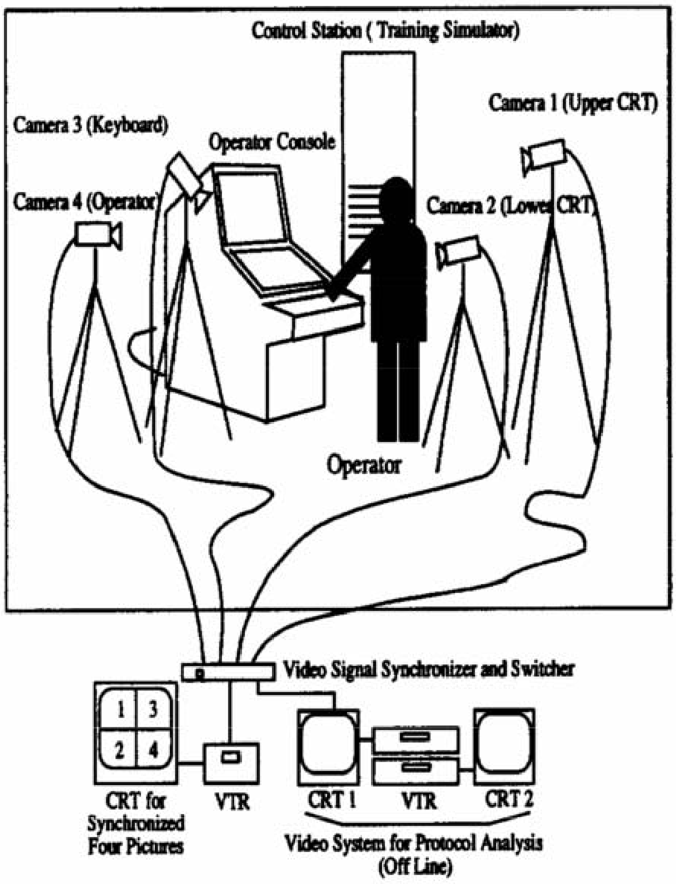

Fig. 5. How usability can be tested in a control room. Taken from [13].

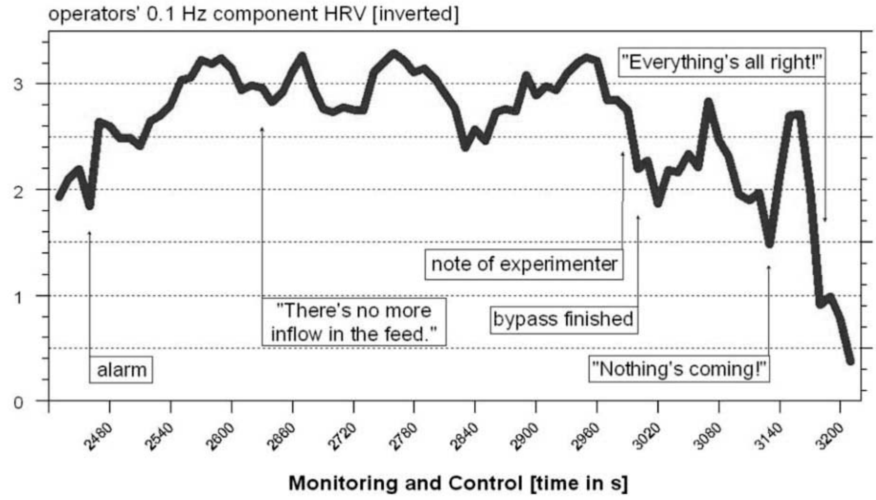

Fig. 6. Heart rate variability (HRV) measurement as a real time indicator for mental (emotional) strain of an operator. In this example, reproduced from [6], a sieve failure occurred and was handled by an operator.

CONCLUSIONS

In this review article, the authors have summarized the current level to which usability aspects are being considered in chemical plants. It can be concluded that practice differs from what can be regarded as state-of-the art. By including Usability Engineering in the design, engineering, construction and operation of chemical installations, safety and efficiency can be improved.

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