Assessing Usability Attributes and Metrics: Causes and Causalities in SCADA Systems for the Forestry Industry

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***Abstract*—As operations and systems become more complex, usability and user experience become increasingly critical. Organizations invest significant resources to enhance usability, yet identifying context-dependent root causes remains challenging. This paper describes a usability study conducted by a Finnish forestry company on a Supervisory Control And Data Acquisition (SCADA) control system. The study utilized academic research to identify key usability attributes and metrics, which formed the basis of a comprehensive usability questionnaire. Analysis of survey responses underscores the importance of situational analysis and identifying cumulative and causal influences on end-user perceptions of usability.**

***Index Terms*—Usability; User Experience (UX); Industry survey; Usability metrics and attributes; SCADA Control/supervisory system; Root-cause; Causality**

I. Introduction

As information technology becomes more widespread, designing IT devices, applications, and systems to best serve end-users has become crucial. This is particularly evident in industry, where technological progress drives development and introduces new technologies into production [1]. However, these advances increase system complexity, adding features, functionalities, and data [2]. Consequently, as systems become more complex, their perceived usability declines, challenging the implementation of user-friendly interfaces [3] [2].

The goal of user interface design is to develop usability-focused interfaces. Usability refers to practical aspects that make a system easy to use, while user experience (UX) encompasses the broader, holistic experience of using the system [4] [5]. Software engineering defines usability through various attributes, with frameworks and measures provided by the International Organization for Standardization (ISO) in standards like ISO 9241 and ISO/IEC 25000:2014 [6] [7]. The challenge lies in finding metrics appropriate to the organization's context.

Organizations invest significant time and resources in improving system usability and need end-user feedback to make improvements. However, exhaustive surveys often fail to produce clear, measurable results. Instead, time and effort should be spent designing the survey and defining appropriate metrics. This is where academic research proves valuable. By aligning industry needs with academic methodologies, new capabilities and insights can be developed for the industry.

This paper describes how a Finnish forestry company evaluated the usability of its Supervisory Control And Data Acquisition (SCADA) system. The study, conducted in collaboration with the company, focused on the experiences of operators using the SCADA system. The purpose of this study was to evaluate the usability of the SCADA system and identify areas for improvement through an understanding of the root causes of usability issues. This paper addresses the RQ: How to measure SCADA system usability to better understand underlying usability challenges and enhance system usability development? First, academic research identified key usability attributes and metrics to assess the current state of the operational SCADA system. Second, an end-user survey was designed and deployed, with questions linked to these specific usability attributes. Third, the survey results were analyzed to uncover root causes and causalities behind the responses and end-user experiences.

This paper is structured as follows. In Section II, we present the results of the literature review. Section III presents the SCADA system that the forestry company wants to evaluate. In Section IV, we define the usability attributes that will be used to conduct the survey. In Section, V we present the results of the survey and analyse the survey responses. In Section VI, we discuss the findings of the study, the cause-effect relationships and the related causalities and cumulative effects. And finally, in Section VII the conclusion of the study.

II. Literature review

This literature review explores the existing research on defining and measuring usability attributes and metrics, focusing on their application to user interface design. The following search terms: "usability attributes," "user interface," "attributes," and "metrics," were used in the ACM Digital Library database to identify recent studies. The selection criteria included articles written in English, scientific in nature (excluding dissertations), related to usability metrics/attributes and user interfaces (excluding mobile usability), published between 2004-2024, and containing the search terms in the title. Initially, 35 articles were identified, which were then narrowed down to nine (article id: [8]–[16]) based on their relevance to the topic, assessed through a review of their titles, abstracts, and finally, the full articles. Where appropriate, the literature search was supplemented with usability-related standards, such as ISO standards, and well-known usability frameworks, such as the Nielsen's Usability Framework [17].

Definitions and Standards. Usability and user experience (UX) are fundamental concepts in human-computer interaction. Usability focuses on practical aspects like efficiency, effectiveness, and satisfaction, making a system easy to use. In contrast, UX encompasses the broader, holistic experience, including emotions, attitudes, and overall satisfaction. Although distinct, usability and UX are closely related and complementary, collectively defining how well a system meets user needs and expectations [4]. Several standards have defined and described usability attributes, with the International Organization for Standardization (ISO) being particularly notable. ISO 9241-11 defines usability in terms of effectiveness, efficiency, and satisfaction [6]. This standard was later expanded to include additional measures specific to computer software usability, as described in ISO/IEC 25023:2016 ([18]. These measures include appropriateness recognizability, learnability, operability, user error protection, user interface aesthetics, and accessibility [19]. The ISO 9126 standard [20] (now revised as ISO/IEC 25010:2023 [21]) also includes attributes such as learnability, operability, and accessibility. These standards provide a comprehensive framework for evaluating and improving usability across various systems and applications.

Measurement Approach. Previous research highlights various approaches to measuring usability. The concept of user experience (UX) has been introduced to take into account the emotions and attitudes of the user when using a particular product, system or service [22] [23]. Nielsen's usability model [24] [17] includes attributes such as learnability, efficiency, memorability, errors, and satisfaction [17] [25]. Learnability refers to how easy a system is to learn. Efficiency refers to system usage effectiveness. Memorability refers to how easy the system is to use and remember after having used it. Errors refers to the number of errors in using the system, the system's ability to recover from errors, and the potential for serious errors in using the system. Satisfaction refers to how pleasant the system is to use [24] [26]. These attributes provide a comprehensive framework and attributes for evaluating the usability of a system.

Application of Usability Measures Across Different Domains. Previous studies have effectively applied usability measures to specific domains such as e-learning [14] and e-commerce [15], demonstrating the versatility and adaptability of these metrics. In the context of e-learning systems, usability attributes have been assessed through user surveys to measure success and identify areas for improvement [14]. Similarly, in the domain of e-commerce, researchers have identified key factors that affect website usability and examined how these factors enhance user effectiveness and satisfaction [15]. Furthermore, previous studies have proposed various evaluation measures to assess specific elements of usability. For instance, the layout of a user interface can be evaluated to ensure clarity and ease of use [10]. Additionally, standards such as ISO 25010 have been utilized to transform quality models into explicit and interpretable measurement tools, providing a structured approach to evaluating and improving usability [16]. These examples highlight the broad applicability of usability metrics across different fields and the importance of using standardized measures to achieve consistent and reliable results.

Intuitiveness and Industry 4.0 Expectations in System Usability. Usability is significantly influenced by the intuitiveness of the system. The intuitive nature of a system is rooted in the user's prior experiences with similar systems, which makes an intuitive system easier to learn and use. This familiarity facilitates the quick adoption and efficient use of new systems [26]. Industry 4.0 expectations for system interfaces were also taken into account. These expectations include providing an up-to-date description of the system state, timely responses to changes in the system state, and clear, understandable notifications or messages to users about the system state. These features are designed to assist users in making informed decisions across various situations where the system requires them to react or take action [2].

The Gap between Academic Research and Industry in Usability. One of the major goals and challenges in software engineering is to bridge the gap between effective academic research and industry practice to create a meaningful impact on the industry [12]. Based on previous research, a common approach to evaluating usability involves asking participants to perform specific tasks and answer detailed questions about their characteristics, preferences, experiences, and learning. This method helps identify a set of categories and usability attributes to consider [8]. Measuring usability is widely recognized as one of the most challenging tasks for system development teams. Consequently, previous studies have identified usability attributes from existing usability models, incorporating insights from both practitioners and researchers [13]. Previous research has highlighted several key issues, including the limited focus on real business problems and the disconnect between research and practical application [9]. This disconnect often results in research that is not rooted in real-world settings, making the findings less applicable and scalable. To address these challenges, it is essential to develop context-driven research [11]. Such research should be grounded in the actual needs of each specific domain to ensure that the results are relevant, actionable, and capable of making a significant impact. This literature review informs the usability survey design, with details on the survey implementation and attributes discussed in Section IV.

III. Introduction to SCADA System

SCADA is a system used to control and monitor industrial applications [28]. Key features of SCADA systems are to

TABLE I
USABILITY ATTRIBUTES AND METRICS IDENTIFIED TO EVALUATE THE USABILITY OF THE SCADA SYSTEM

	Attribute/metric	Description	Reference
1.	Effectiviness (ISO)	Achieved targets, performed tasks, errors in task performance, intensity of errors	[24], [27]
2.	Efficiency (ISO and Nielsen)	Time spent on the task, time efficiency, redundant activities	[24], [26] [6] [27]
3.	Satisfaction (ISO and Nielsen)	Overall satisfaction, satisfaction with features, use of features, user confidence, perceived comfort and convenience	[24], [26] [6], [27]
4.	Learnability (ISO ja Nielsen)	Simplicity of the system, time, completeness of instructions, default values for input fields, understandability of error messages, understandability of user interface	[24], [26]
5.	Memorability (Nielsen)	Ease of use, memorability after a break in use	[24], [26]
6.	Errors/User error protection (ISO and Nielsen)	Number of errors, recovery from errors, impact of errors	[24], [26] [19]
7.	Appropriateness recognisability (ISO)	Fitness for purpose	[19]
8.	Operability (ISO)	Consistency of functionality and layout, clarity of messages, customisability of functionalities and user interface, auditability, cancellation of actions, understandable categorisation of information	[19]
9.	User interface aesthetics (ISO)	Aesthetic satisfaction	[19]
10.	Accessability (ISO)	Accessibility for disabled users, supported languages	[19]
11.	Up-to-date information (Industry 4.0 user inferfaces)	Up-to-date representation of the process status	[2]
12.	Supporting the user in decision making (Industry 4.0 user interfaces)	Providing the necessary information to support the user's decision making	[2]
13.	Intuitivity	Intuitive to use	[26]

visualize physical production processes through the system, communicate information related to the production process, and remote control equipment related to the production process. SCADA systems are Cyber-Physical Systems (CPS). They connect physical devices, machines, and IT systems related to the production process into a coherent entity via a data network [29]. This integration enables real-time production data acquisition, data processing and transmission, and process management through a single interface. SCADA also enables fully automated controls that dynamically respond to the production process. [30] In the context of this paper, a SCADA system at a forestry company's production plant is responsible for controlling almost the entire production process of the plant. The primary control of the process is centralized in the plant's central control room but several SCADA interfaces are also located at the plant's physical production facilities. The SCADA interface is a traditional graphical user interface (GUI), keyboard and mouse. Interfaces located on the production floor have also touch screens. The forest company's production facility is divided into five departments and each department has a unique SCADA view(s).

IV. INDUSTRY SURVEY IMPLEMENTATION: DEFINING USABILITY ATTRIBUTES AND EXECUTING THE SURVEY

Conducting the study involved four main steps: 1) identifying usability attributes based on academic research and standards, 2) defining a usability survey based on these attributes, 3) conducting the survey within the company, and 4) analyzing the survey results (in Sections V and VI).

The first and most critical step was to compile the usability attributes to be evaluated during the study. The company recognized that a focused effort was needed to select the attributes that would best serve its objectives. This required familiarity with usability research and a combination of academic and business needs and insights. Based on the usability definitions presented in Section II, the study identified the following usability attributes to be used to evaluate the SCADA system (Table I):

- ISO 9241 and Nielsen: Effectiveness, Efficiency, Satisfaction, Learnability, and Memorability [6] [27] [24] [26]
- ISO 25023 and Karnouskos: Errors/User error protection, Appropriateness recignisability, Operability, User interface aesthetics, Accessability [18] [19]
- Industry 4.0 user interfaces: Up-to-date information and Supporting the user in decision making [2]
- Intuitivity [26]

The second step of usability research was to define the survey. Table I lists the usability attributes, their sources, descriptions and references. Based on this table, the questionnaire was designed and structured to ensure that each question corresponded to a specific usability attribute. The questionnaire consisted of 13 statements derived from the usability attributes and metrics, as well as the practical experience with the SCADA system in the forestry company.

The first-hand work experience of one of the authors with the use of the SCADA system in the forestry company was also used to define the statements. All statements in the questionnaire were closed-ended, 7-point yes/no Likert scale questions. Using a 7-point Likert Scale was chosen to provide more variation in the results of the questionnaire, thus providing more accurate results. In the questionnaire, a Likert scale of 1 indicates that the respondent strongly disagrees with the statement and 7 indicates that the respondent strongly agrees with the statement (Figure 1). For question 11, the

Likert scale was reversed and is therefore shown separately from the other questions (Figure 2). All questions in the questionnaire were mandatory. Open-ended questions at the end of the survey enabled participants to clarify their answers and provide additional comments on SCADA usability. Personal and background information of the users was fully anonymized. The survey only required respondents to specify their department within the plant and their SCADA experience duration (more or less than one year).

The third step was to collect the survey responses. The data collection process for the SCADA usability case study was conducted as an electronic Webropol-survey between 14.2.2023-11.1.2024. The questionnaire was open for voluntary participation by operators using SCADA in their operations. The questionnaire was sent out to a limited number of operators by a manager of the forestry company. This limited the number of potential respondents, but also improved the value and quality of the responses received.The questionnaire and the instructions on how to complete the survey were distributed to the operators in the forest enterprise through the internal communication channels.

V. Results of the Survey

The fourth and most significant step of the study was analyzing the results and identifying root causes and causality (in Section VI). All departments within the plant participated in the survey, resulting in a total of 19 responses on SCADA usability.

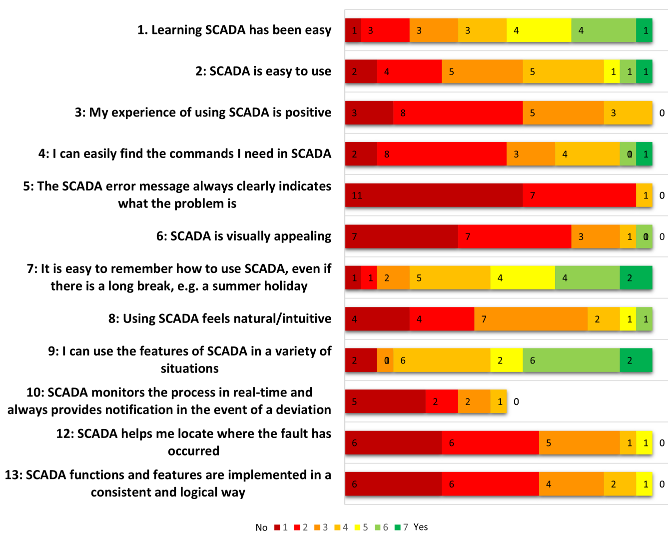

Figure 1. End-user survey questions and results

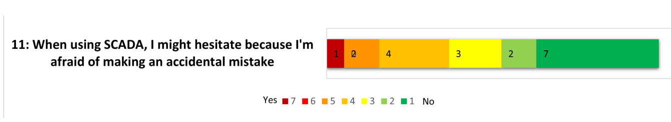

Figure 2. Survey results - Question 11 reversed scale

	Average	Question	Used attribute/metric (Table 1)	Observations
Usability achieved	5.21	11	Errors/User error protection (attribute 6)	
	4.68	9	Effectiveness (attribute 1)	
	4.58	7	Memorability (attribute 5)	
	4.16	1	Learnability (attribute 4)	
Identified areas for usability development	3.32	2	Operability (attribute 8)	1,3, 6, 7, 8, 10, 12
	2.94	4	Efficiency (attribute 2)	1, 4, 8, 11
	2.74	8	Intuitivity (attribute 13)	4
	2.42	3	Satisfaction (attribute 3)	2, 8, 10, 12
	2.26	13	Operability (attribute 8)	6, 7, 8, 12
	2.21	12	Supporting the user in decision making (attribute 12)	3, 9, 10, 12, 13
	2.11	6	User interface aesthetics (attribute 9)	10
	1.9	10	Up-to-date information (attribute 11)	3, 9, 10, 12, 13
	1.53	5	Supporting the user in decision making (attribute 12)	3, 9, 10, 12, 13

Figure 3. SCADA usability findings

Usability findings from operators
1. Slowness, stuttering, navigation is sometimes confusing and difficult
2. SCADA also has a lot of good things
3. Slowness of user interface in case of failures e.g. when moving from one page to another, you get used to using SCADA when using the system, it is easy to find the causes of failures
4. Requires learning by heart, no information is available when looking for a new thing and you have to rely on other operators
5. Needs further development
6. The system is confusing
7. Slow, illogical, production lines poorly outlined
8. System is confusing, difficult to find information, not enough information, several buttons not working or missing, slow to move from one page to
9. Operators are not consulted enough and requested changes are not implemented, fault locations are not clearly and accurately displayed
10. Poor visual appearance, poor navigation, poor alarm indication, some buttons missing, some buttons not working
11. Too much time spent moving from one page to another to access information and functions
12. Alarms poorly targeted, alarms can only be displayed on certain pages, alarm indication in main view should be better, not all information is accessible, SCADA implementations differ in views and functionalities
13. Operators have not been consulted enough and requested changes have not been implemented, and fault locations are not displayed clearly and accurately enough

Figure 4. The operators' observations and comments

Many respondents shared their own experiences, highlighting various usability issues. Specifically, 14 operators provided detailed opinions, user experiences, and usability observations in the survey's open comment field. Among the survey respondents, 93.8% had over a year of SCADA experience, lending credibility to their feedback. However, the small number of respondents per department prevented a comparative analysis of usability between production plants departments. Consequently, SCADA usability was analyzed at a holistic system level. This approach was validated by operator comments, which consistently highlighted similar experiences and usability observations across different departments.

SCADA usability was examined by dividing the survey statements into two categories based on average score (Figures

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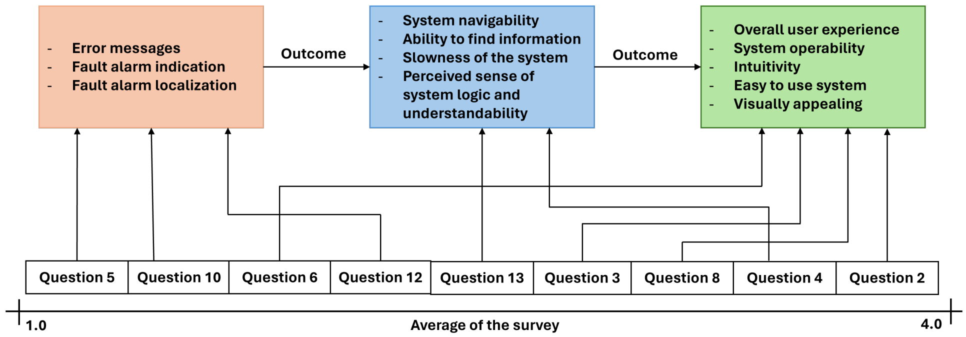

Figure 5. Root cause analysis of the cumulative effect resulting from process deviation

1 and 3): achieved usability characteristics (more than 4) and areas for improvement (less than 4). A Likert scale of 4 for neutral opinion was used as the cut-off value. For question 11 (Figure 2), the average was inverted because it was asked on an inverted Likert scale compared to other items. Figure 3 shows how the statements were distributed. The same table also shows which usability attribute or metric in Table I is referenced by the statement and which observation in Figure 4, provided by the operators, clearly refer to the statement.

The results in Figure 3 show that the average dispersion is weighted well below the neutral average, suggesting there is room for improvement in SCADA usability. The operator comments in the Figure 4 also reflect this observation. Although the averages are generally weighted below the neutral average, the responses to many of the survey and figure statements vary widely between the two extremes. This is an indication of the high degree of subjectivity in the user experience, especially in the areas around these statements.

Questions 1, 7, 9, and 11 exceeded the neutral average and are therefore considered functional and successful in describing their SCADA usability characteristics. Based on these statements, SCADA has been successfully implemented in a fault-tolerant manner so that human errors or their effects do not negatively affect the usability of the system (Q11). Operators also feel that they can use SCADA in a wide range of work situations (Q9). Furthermore, the system is easy to remember (Q7) and not challenging to learn. The operators' comments do not contradict these findings.

Questions 2-6, 8, 10, 12, and 13 are below the neutral average. Based on the usability characteristics described by these statements, the areas for improvement in SCADA usability are related to: system error messages and their understandability (Q5), fault alarm indication (Q10), perceived aesthetic satisfaction (Q6), fault alarm localization (Q12), perceived sense of system logic and understandability (Q13), negative user experiences (Q3), system intuitiveness (Q8), system navigability and ability to find information or commands (Q4), and difficulties of using the system (Q2). Issues that are clearly related to these statements also appear in the operators' comments, in Figure 4. A new finding of usability that emerges from the operator comments is the slowness of SCADA (operator observations 1, 3, 7, 8, 11). The survey results particularly indicate that the most important areas for improvement in SCADA usability are related to system performance under fault conditions (Q5, Q10, Q12).

Figures 1-3 provide a clear and easily interpretable overview of SCADA usability successes and areas for improvement. These are supported by the operator usability findings presented in Figure 4. However, the identified usability improvement areas must also be viewed in the context of the SCADA being a complete control system in operation and meeting its operational objectives.

VI. Discussion: The Importance of Understanding Context, Root-causes and Causality

The results were analyzed using personal first-hand SCADA experience and contextual insight into how SCADA systems operate. The small sample size (19) limits both the generalizability of our findings and their applicability in other operational environments accross different industries. The study shows that, across departments, SCADA usability issues primarily involve system performance under fault conditions, including error messages, fault alarms, navigability, information retrieval, and system slowness (questions in Figure 3: 5, 10, and 12, and operator observations in Figure 4: 1, 3, 7-13). Faults typically involve situations where the control system automatically responds to process conditions and stops production. In this case, the control system also requires the operator to make a decision or take an action before the process can resume. This can mean controlling the process via SCADA or physically working on the production line. Faults are caused by deviations in the automated production process, and in these cases the operator's task is to return the production process to its normal state and resume it as quickly as possible. The operator faces both problem-solving and time pressure, impacting perceived usability. It is crucial to note that usability results under fault conditions reflects only these specific situations, not the system's overall uptime performance.

The primary usability challenges that follow a production process deviation are error messaging, fault alarm indication, and fault alarm localization. These are related to the system's capability to provide initial assistance to the operator in making decisions related to the ongoing process deviation.

Consequently, problems with these primary usability challenges, if not mitigated, lead to secondary challenges, which in this case are system navigability, ability to find information, system slowness, and perceived sense of system logic and understandability. This illustrates the underlying logical and contextual relationship between different usability challenges (RQ).

Similarly, it can be interpreted that the causal relationship can also have a cumulative effect on other areas of perceived usability: overall user experience, system operability, intuitivity, system ease of use, and visual pleasantness (questions 2-4, 8, 13). Figure 5 illustrates the causal relationship and cumulative effect between usability challenges. Another finding related to this interpretation is that the averages in Figure 3 closely support the development of this cumulative effect. This shows that the primary usability challenges may be root causes that have a cumulative and cascading effect on other aspects of the user's experience with the system (RQ).

The goal of this study and industry survey was to establish robust measurement criteria based on academic research, which is critical to accurately assessing usability issues. By analyzing the results with industry insights, we can identify root causes and causal relationships, enabling targeted development activities to improve usability and address gaps. These results demonstrate that understanding the context of use is crucial for making accurate observations and drawing valid conclusions. Additionally, the cumulative effect and root-cause hypothesis offer a valuable perspective for usability analysis. This approach shifts the focus from merely interpreting usability metrics to understanding causality, making it highly practical and beneficial for the industry.

VII. CONCLUSION

This paper presents the results of a SCADA usability study conducted in the Finnish forestry company, highlighting the challenges of achieving optimal usability. The study revealed that despite the achievement of system goals and the successful implementation of the system, there can be a significant gap between the actual usability experienced by the end user and the way the system performs. An important finding is that understanding the contextual aspects of the user experience proved to be critical. While the attributes and measures used in the study generally capture various aspects of usability effectively, the findings highlight the importance of a thorough understanding of the operating environment and workflow to accurately identify and address usability issues.

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