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Worker satisfaction with adaptive automation and working conditions: a theoretical model and questionnaire as an assessment tool

Valeria Villani [a], Lorenzo Sabattini [a], Dorota Żołnierczyk-Zreda[b], Zofia Mockałło[b], Paulina Barańska [b] and Cesare Fantuzzi [a]

[a]Department of Sciences and Methods for Engineering, University of Modena and Reggio Emilia, Italy; [b]Central Institute for Labour Protection – National Research Institute, Poland

ABSTRACT
This article focuses on methods and tools to measure worker satisfaction with reference to industrial automation. Despite technological advances in automation, the role of human workers on industrial shop floors remains crucial. To promote humans' roles, production systems should be designed and organized so workers are valued and get satisfactory jobs. The article presents a novel holistic model of worker satisfaction with adaptive automation and working conditions. The model takes into account psychosocial and physical working conditions and the characteristics of the automation system the worker interacts with and its user interface. We propose a questionnaire to be used as a practical tool to assess worker satisfaction with industrial automation, considering also the case of adaptive automation. The proposed version of the questionnaire is the result of pilot testing carried out among shop floor operators and takes into account adjustments derived from end-user feedback.

KEYWORDS
worker satisfaction; industrial automation; adaptive automation; questionnaire for worker satisfaction; inclusive work environment; anthropocentric automation

1. Introduction

Technological progress in automation has made available highly advanced machines, with exceptional throughputs, accuracies and flexibility [1]. Nevertheless, despite such advanced automation, humans still have a fundamental role in factories: they feed and supervise such machines, intervene in the case of faults and, in general, manage production [2]. Since the cognitive capabilities of humans are currently unattainable by robots and machines, human workers still represent the most valuable asset of every company [2]. They are a fundamental bootstrap for advanced sensing and the higher precision of machines and allow organizations to increase productivity and improve quality, while building more flexible, inclusive and safe workplaces and improving working conditions [3,4]. To this end, while in the last decades attention was paid mostly to the technological side, more recently the need to provide technological solutions that take into account the workers and their needs has been acknowledged. The traditional goal of automation to increase overall job efficiency is nowadays accompanied by the effort to increase operators' well-being and satisfaction with their job [5]. To promote humans' roles, then, it is of paramount importance that the factories of the future adapt their organization and production systems so workers are valued and get more meaningful and healthy jobs [2,6].

To this end, adaptive automation systems have been introduced. They adapt their behavior to the context or the worker. These represent the future trend of automation and include classical automation systems, where no adaptation is provided [7]. In particular, anthropocentric adaptive automation systems resort to user-centered design and adapt the behavior of the system considering the user's capabilities and comfort during the interaction [8,9]. To achieve this, adaptive automation systems can be seen as an interconnection of three modules, as shown in Figure 1: measurement of the user's capabilities (Measure), adaptation of interaction (Adapt) and teaching of the lacking competence (Teach). The Measure module is meant to provide information about the worker and determine her/his interaction with the system under analysis. This information is given as an input to the Adapt module, which adapts the behavior of the system accordingly [10]. Further assistance to the worker can be provided by an additional Teach module, e.g., in terms of offline training and online assistance. Further details can be found in the work by Villani et al. [4,6].

Moving along these lines, in this article we focus on the importance of including worker satisfaction in the design and use of automation systems, both for ethical motivations and also because worker satisfaction positively influences productivity. Specifically, we present a theoretical model of worker satisfaction that analyzes the different dimensions contributing to it. The model takes into account psychosocial and physical working conditions and the characteristics of the automation system the worker interacts with and its user interface. In accordance with ACE Factories Cluster [11], worker satisfaction is seen as the result of extrinsic factors, which are aspects of work in the environment and organization that are external to work tasks (e.g., colleagues, pay or working conditions, etc.), and intrinsic factors, which are aspects of work that are directly related to the performance of work tasks (e.g., recognition, control, responsibility, etc.). Additionally, building on the proposed model, we develop a questionnaire for the assessment of worker satisfaction. The questionnaire is meant as a practical tool to collect workers' feedback on existing automation systems and to guide the design of novel systems, if applied on early prototypes (see, e.g., Villani et al. [4]). Moreover, it is organized in a modular way and, as a consequence, can be easily scaled from adaptive automation systems to non-adaptive systems.

CONTACT Valeria Villani valeria.villani@unimore.it

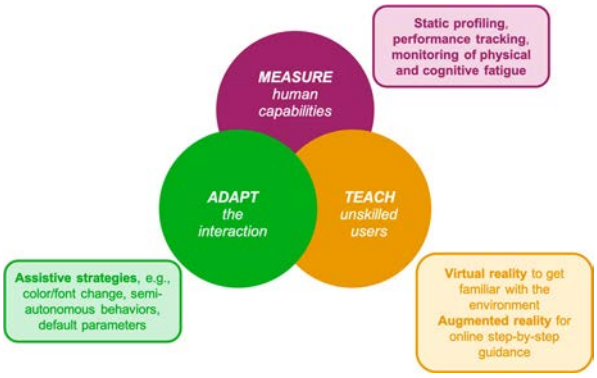

Figure 1. Modules of an adaptive automation system.

To sum up, in the remainder of the article we first present a review of the literature on the concepts of user satisfaction and system usability: indeed, the former somehow derives from the latter. We then review the methods and tools available for assessing these concepts. Subsequently, we present the proposed theoretical model of worker satisfaction and illustrate the proposed questionnaire for worker satisfaction with adaptive automation and working conditions. As discussed in the following, the presented version of the questionnaire is the result of pilot testing with shop floor workers in two industrial scenarios. Finally, we report some concluding remarks.

2. Literature review on methods and tools to measure worker satisfaction

In this article we focus on worker satisfaction with the interaction systems they have to use to accomplish their job tasks. According to the model we propose, worker satisfaction is determined by the system itself and other factors related to the work environment and job conditions. As a consequence, in this section, we first present existing literature on models for job satisfaction and, then, on usability of interaction systems and user satisfaction with them.

2.1. Job satisfaction concepts

The concept of job satisfaction has been largely investigated in industrial and organizational research. It is a factor that constitutes healthy and productive companies. Poor job satisfaction is related to mental-health problems and increases the risk of sickness absence and disability pension [12].

In 1969, Locke [13] proposed one of the currently most used definitions. He proposed that job satisfaction can be seen as 'a pleasurable or positive emotional state resulting from the appraisal of one's job or job experiences (p. 316)' [13]. Moreover, he stated that job satisfaction (and dissatisfaction) reflects the gap between what a worker wants from their job and what they perceive it as offering or entailing. Based on this definition, Hulin and Judge [14] offered a more articulated view of job satisfaction, which is seen as the combination of multidimensional psychological responses to one's job. In particular, job satisfaction is determined by cognitive (evaluative), affective (or emotional) and behavioral components. The affective component refers to an emotional feeling individuals have about their job, whereas the cognitive component accounts for a logical analysis of objective components, such as salary. The definition of job satisfaction proposed by Rafferty and Griffin [15] focuses on the affective component, since it is defined as 'an emotional reaction to the job' or as 'an individual's evaluation of the job, beliefs about the job, and affective experiences on the job' (p. 199).

A similar view to Locke's was also proposed by Porter and Lawler [16]. According to their theory of motivation, satisfaction reflects the gap between the actual and perceived equitable rewards. In other words, satisfaction is related to how a worker perceives equitable rewards for their performance. In turn, equitable rewards lead to an increase in performance. The link between satisfaction and performance is mediated by rewards: if received rewards are perceived as equitable, workers feel satisfied with their job and are motivated to increase their performance.

More recently, Spector [17] has summarized job satisfaction as the extent to which people like or dislike their jobs. In spite of an apparently simplistic definition, this model suggests that many factors determine job satisfaction. Such factors include personal characteristics, such as personality, and job conditions, such as the nature of the job itself, leadership, fair treatment by the organization, relationships between employees and peers, compensation and rewards. Hence, job satisfaction is determined by both the individual and the job itself.

This model has similarities with the theory of work adjustment by Dawis and Lofquist's [18,19] and Herzberg et al.'s [20] model of work motivation. The former states that job satisfaction is determined by the individual and the work environment. In particular, the individual satisfaction with the job and the correspondence of the individual's skills to the skills required by the job environment (satisfactoriness) determine the individual's tenure in the job environment [18,19]. The latter, Herzberg et al.'s model of work motivation, consists of a two-dimensional paradigm of factors influencing people's attitudes toward work. In particular, the Herzberg et al. [20] motivation theory model, also called two-factor theory, argues that job dissatisfaction and job satisfaction are not the opposite, and to decrease the former and decrease the latter an organization has to adjust two different sets of factors. Hygiene factors, such as company policies, relationships with supervisor and peers, work conditions and salary, allow one to eliminate job dissatisfaction; on the other side, motivating factors create satisfaction – examples of motivating factors are responsibility, advancement and growth opportunities.

2.2. System usability and user satisfaction

The concept of user satisfaction with an interaction system derives from the usability concept. High system usability is a goal of users, employers, developers and researchers. It facilitates safe, productive and enjoyable work in the working environment [21]. Thus, to measure user satisfaction, one first needs to understand what usability means. Methods to measure usability, including subjective and objective evaluation by experts and end users, represent the groundwork for choosing appropriate metrics to be included in the worker satisfaction measurement.

Usability is a broad term with various definitions, depending on the concept or context. It was formerly introduced by Bevan et al. [22] as a multidimensional characteristic in the context of users performing tasks with a system in a specific environment. This concept was later specified by Preece et al. [23], who described usability as ensuring that interactive products are easy to learn, effective to use and enjoyable from the user perspective. This idea was shared also by the International

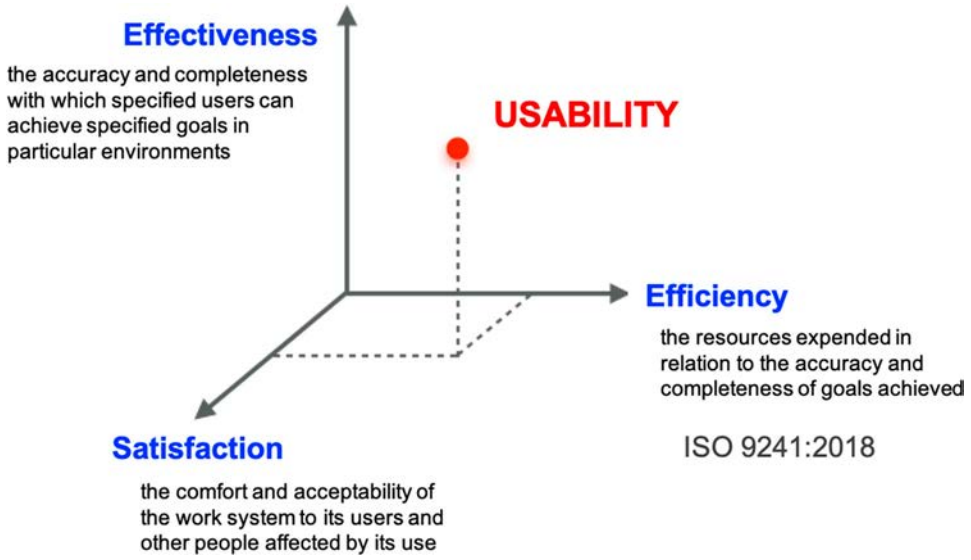

Figure 2. Usability according to Standard No. ISO 9241-11:2018 [24].

Organization for Standardization (ISO) [24], which set the most used definition of usability: the extent to which a product can be used by a specified user to achieve a specified goal with effectiveness, efficiency and satisfaction in a context of use. According to Standard No. ISO 9241-11:2018, usability is a three-dimensional concept that can be measured in terms of effectiveness, efficiency and satisfaction, as shown in Figure 2. Specifically, effectiveness means the accuracy and completeness with which specified users can achieve specified goals in a particular environment. Efficiency means the resources expended in relation to the accuracy and completeness of goals achieved. Satisfaction is defined as user comfort and user acceptability of the work system and in relation to other people affected by its use.

To guide in the design of usable systems, different usability principles have been proposed. The more recurrent are those by Nielsen, Norman and Yeh. Briefly, Nielsen [25] defined the following usability principles: memorability, errors, learnability, efficiency and satisfaction. Norman's [26] conception of usability included such principles as visibility, a good conceptual model, good mappings and feedback. Yeh's [27] usability definition included the following principles: ease, enjoyment and effectiveness.

In the attempt to create the most comprehensive approach, Wang and Huang [28] combined these three sets of usability principles. In particular, they proposed the following usability principles, which are summarized in Figure 3:

- visibility: instructions and information are clear;
- ease: the system is easy to learn and familiarize, time of learning is minimal;
- efficiency: once learned it is easy to use the functions of the system at full capacity;
- enjoyment: users are satisfied upon completing a task when using the system.

With specific respect to the context of human–computer interaction (HCI), Shackel [29] defined usability as 'the capability in human functional terms to be used easily and effectively by the specified range of users, given specified training and user support, to fulfill the specified range of tasks, within the specified range of environmental scenarios' (p. 340). Moving along the same lines, Preece et al. [30] stated: 'The goals of HCI

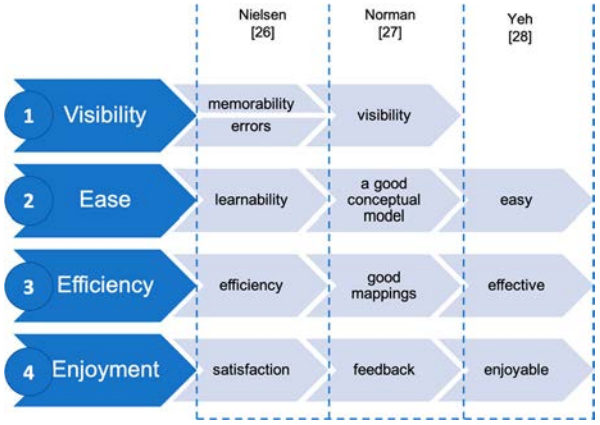

Figure 3. Usability principles [28].

are to develop and improve systems that include computers so that users can carry out their tasks: safely, effectively, efficiently and enjoyably. These aspects are collectively known as usability' (p. 14).

The definitions of usability introduced show that user satisfaction is very often seen as a facet of system usability. It has been mostly investigated with respect to information systems and, more generally, computing systems. Reviews on this topic can be found in the studies by Au et al. [31] and Jeyaraj [32]. Following Doll and Torkzadeh's [33] abstraction of the end-user computing environment, any automation system can be reduced to a computing system from the point of view of its user. Indeed, the use of an automation system is, in major part, done through its human–machine interface (HMI), which is a computing system.

In this context, it is noteworthy that user satisfaction is often considered the most prevalent measure of success of an information system thanks to its applicability and ease of use, and it is directly related to the system's success [34,35]. Moreover, Ovaska [21] reported that, the other way round, measuring end-user satisfaction is also a form of usability measurement.

One of the most established definitions of user satisfaction with information system was formerly given by DeLone and McLean [35], and states that satisfaction refers to the extent to which a user is pleased or contented with the information system, and is posited to be directly affected by system

use. Moreover, Doll and Torkzadeh [33] and Chin and Lee [36] defined user satisfaction as the affective attitude toward a specific computer application by someone who interacts with the application directly. This definition is augmented by Au et al., who also include a cognitive component. According to them, user satisfaction is the end user's overall affective and cognitive evaluation of the pleasurable level of consumption-related fulfillment experienced with the information system [31]. They precisely state that end users refer to non-technical personnel who use or interact with the system directly, as opposed to technical personnel who design the system.

2.3. Methods and tools to measure usability and user satisfaction

2.3.1. Evaluation of usability

A thorough review of usability evaluation methods has been presented by Villani et al. [37] and is summarized in Figure 4. Specifically, the usability of a system can be evaluated by means of subjective and objective measurements: subjective evaluation includes interviews and questionnaires, whilst objective measures comprise behavioral or physiological measures. As a further distinction, subjective evaluation can be done via inspection methods, which involve expert evaluators, and test methods, which involve end users. Inspection methods identify usability problems and possibilities for improvement by checking them against established standards. This is typically done by external expert evaluators, usually in laboratory settings, and thus can be done on early prototypes of the system. Hence, these methods provide a predictive analysis of usability, since they predict usability problems that will likely arise when the system is in use and they allow one to take proper intervention with predictive corrective strategies. The most used example of these methods is heuristic evaluation.

However, a lack of end-user involvement in the process or a lack of a real industrial environment are clear disadvantages of these methods. Including users in the assessment of usability is of particularly high importance. To this end, usability test methods include testing usability with end users, also in the presence of expert evaluators [37,38]. This is typically done through structured observation of the users or presentation of surveys to collect their subjective feedback. As an alternative, objective indicators of the user's interaction with the system and performance with respect to a given task can be used to infer information about system usability. Although the subjective evaluation of usability tends to be neglected in favor of objective performance measures, the subjective measurement is most closely related to user behavior [39]. Other authors, such as Lin et al. [40], also suggested that less tangible factors of usability (e.g., enjoyment) are becoming of higher importance and should be incorporated into system usability testing. Finally, physiological parameters can also be used to infer information about system usability.

For the detailed description of the methods for usability evaluation reported in Figure 4, the reader is invited to read the survey by Villani et al. [37].

2.3.2. Evaluation of user satisfaction

The most popular and widely used tools are the computer user satisfaction (CUS) scale, the questionnaire for user interaction satisfaction (QUIS), the system usability scale (SUS) and the USE questionnaire, which are shortly described in the following. These are either specifically focused on satisfaction or refer to system usability and explicitly take satisfaction into account as a facet of usability. This is the case, e.g., for the computer system usability questionnaire (CSUQ).

The CUS questionnaire [41] investigates factors such as confidence in the systems, security of data, output format, convenience of access, personal job effects resulting from computer-based support, precision of information output and system flexibility. The authors found that the most important factors were accuracy, reliability, timeliness, relevancy and confidence

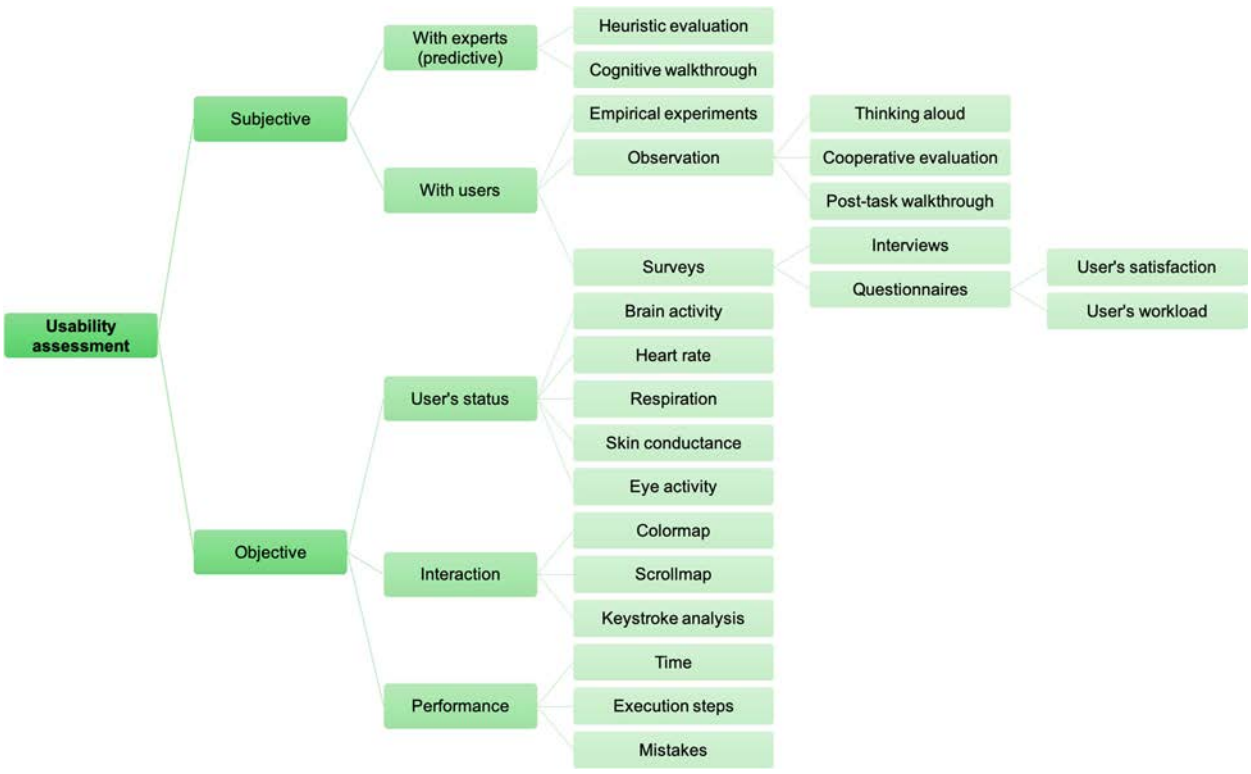

Figure 4. Overview of methods for usability assessment [37].

in the system. The factors of least importance were feelings of control, volume of output, vendor support, degree of training and organizational position of electronic data processing. Ives et al. [42] pointed out that the length of the questionnaire could result in errors of attrition.

The QUIS consists of four factors: screen; terminology and system information; learning; and system capabilities [43]. In addition, the overall reaction to the software is investigated. However, Lewis [44] strongly questioned the effectiveness of this tool.

The CSUQ investigates computer system characteristics such as ease of use, ease of learning, simplicity, effectiveness, information and user interface [44]. Example items include 'Overall, I am satisfied with how easy it is to use this system', 'I feel comfortable using this system' or 'The interface of this system is pleasant'. The questionnaire proved to be reliable and useful also in non-laboratory settings and is open to use by researchers.

The SUS is a validated tool for measuring the usability of a wide variety of products and services, including hardware, software, mobile devices, websites and applications [45]. It was designed to meet the need of a short, simple tool that could be used in industrial settings. However, there is no information on the usability/user satisfaction principles that would determine factors included in the tool. Results from the analysis by Bangor et al. [46] have shown that the SUS is a highly robust and versatile tool for usability professionals.

The USE Questionnaire is a public-access tool dedicated to measure the most important dimensions of usability for users, across domains [39]. It can measure usability of the interface, software, hardware, services and user support materials. The questionnaire covers the most important usability dimensions: usefulness, ease of use, ease of learning and satisfaction.

The following three questionnaires are less common.

The after-scenario questionnaire (ASQ) is another tool developed as a part of the IBM questionnaire set [44]. It contains only three questions corresponding to the following system usability satisfaction factors: ease of task completion; time to complete a task; and adequacy of support information. The exemplary item is 'Overall, I am satisfied with the amount of time it took to complete the task in this scenario'. The length of the questionnaire is an advantage but it is a questionnaire designed for the usability experts to answer using predefined scenarios and tasks. However, the questionnaire has been also validated in office-application studies. It has been shown that three ASQ items should be condensed into a single scale. That is why which usability dimension needs an improvement cannot be specified.

The computer satisfaction inventory (CUSI) is a scale developed by Kirakowski and Dillon (see [44]). It is a 22-item questionnaire containing two subscales: affect and competence. The competence factor addresses the user's feeling of mastery over the computer system. The affect factor addresses the user's feeling of fear or pleasure. It is designed to be used in a laboratory environment with tasks developed by researchers. Unlike the QUIS, researchers who wish to use the CUSI must purchase it from the authors, which limits its general availability and usefulness [44]. Also, Ovaska [21] stated that although this measure is validated, 'usability is much more than user friendliness or user competence and affect' (p. 56).

User information satisfaction (UIS) is a short form of the CUS questionnaire, developed by Ives et al.[42]. This questionnaire contains 13 factors with two ratings per each factor (instead of five) maintaining satisfactory psychometric characteristics. Unfortunately, the authors have not published the full version of the questionnaire but it is available upon request.

Finally, Zviran and Erlich [34] suggested that future studies on system usability should include modern world challenges, e.g., security of the system, as well as other dimensions receiving less attention, e.g., organizational support. Other factors that should be considered in the industrial environment are health and safety issues or the rapid changes in technology, allowing for adapting the interface to the user's capabilities and skills. The questionnaire proposed in this article is an attempt to include these factors.

2.3.3. Evaluation of job satisfaction

The most common method of measuring worker satisfaction is a questionnaire measurement, usually being part of working condition surveys.

One of the most extensively validated survey measures is the Minnesota satisfaction questionnaire (MSQ) [48], which refers to the theory of work adjustment by Dawis and Lofquist [18]. This questionnaire is a 20-facet measure of work satisfaction and considers intrinsic and extrinsic satisfaction. Global satisfaction is then given by the sum of ratings. The MSQ facets are ability utilization, achievement, activity, advancement, authority, company policies and practices, compensation, coworkers, creativity, independence, moral values, recognition, responsibility, security, social service, social status, supervision in terms of human relations and technical competence, variety and working conditions. It continues to be empirically and practically useful [18].

The job satisfaction survey (JSS) follows Spector's model of job satisfaction and aims to assess employee attitudes about the job and aspects of the job [48]. It is a facet-based measure that investigates pay, promotion, supervision, fringe benefits, performance-based rewards, operating rules and procedures, coworkers, nature of work and communication. Overall job satisfaction and dissatisfaction are found from a sum of these facets.

The European Working Condition Survey (EWCS) [49] includes a single-item scale of satisfaction with working conditions, which is considered a prerequisite for worker motivation. Answers are given on a 5-point Likert scale, ranging from 'not at all satisfied' to 'very satisfied'. The survey has shown that factors positively related to satisfaction with working conditions are good quality of management, good work–life balance and having career prospects. A supervisory role is also related to higher satisfaction with working conditions, which should remind about paying special attention to workers at the bottom of the organizational ladder. Factors that are likely to lead to low satisfaction with working conditions are adverse social behavior, feeling that one's health is at risk because of work, holding a temporary contract and having experienced restructuring in the company.

In terms of association with job quality indices, satisfaction with working conditions is most strongly related to social environment, prospects, and skills and discretion. The last factor – skills and discretion – is a foundation of worker's autonomy/control, which is one of most crucial aspects of maintaining employees' well-being (e.g., [50]).

Another single-item scale is also widely used in working condition surveys. This question is 'How satisfied are you with your job in general – all things considered?' [15].

The Copenhagen psychosocial questionnaire (COPSOQ) [51] measures work satisfaction with four items: asking about satisfaction with work prospects; physical working conditions; the way one's abilities are used; and the job as a whole, everything taken into consideration.

However, according to Rafferty's and Griffin's [15] review of studies measuring job satisfaction, the most popular job satisfaction measures have been the Michigan organizational assessment questionnaire and the job descriptive index (JDI).

The Michigan organizational assessment questionnaire [15] is a tool measuring the overall job satisfaction with three items, e.g., 'All in all, I am satisfied with my job'. This scale demonstrated sufficient reliability and is a part of an instrument measuring working conditions.

The JDI [15] measures job satisfaction with 72 items, assessing five dimensions of job satisfaction: satisfaction with work itself; pay; promotion opportunities; supervision; and coworkers. The aforementioned examples of methods and tools to measure job satisfaction in general vary between one-item and 72-item scales. This index is reliable and has an impressive array of validation evidence [14].

All of these instruments are widely used and validated. The choice of instrument should be dictated by the research goals, but the length of the scale is an important factor when the questionnaire contains other scales and should be respondent-friendly.

Worker satisfaction can also be measured by means of physiological parameter monitoring. The use of the objective measurement is based on scientific evidence, stating that a worker's well-being, including work satisfaction, is related to a physiological reaction on the level of the cardiovascular system, endocrine system or immune system [52] involved in the organism stress response. The stimulation of the nervous system is reflected, among other factors, by an increased heart rate and stimulation of sweat glands. Therefore, the changes in heart rate, galvanic skin response and skin temperature can be used to evaluate stress and, in turn, satisfaction level [53].

3. Proposed model of worker satisfaction

In the literature review, we presented the current approaches to the measurement of usability and user satisfaction with work in general. This review has shown that user satisfaction with the system (e.g., HMI) is a form of usability. The involvement of end users, i.e., the employees working with the system, is a fundamental part of usability evaluation, and we therefore decided to put emphasis on their assessment of automation systems by means of a questionnaire, instead of conducting external expert usability evaluation. However, the questionnaire needs to be tailored to real work environments and the characteristics of the system. Specifically, considering an adaptive automation system, a separate investigation should be carried out for the three modules: Measure, Adapt and Teach.

Moreover, traditionally, satisfaction with work is commonly measured as a combination of cognitive, emotional and behavioral reactions to one's job [14]. These reactions determine how big the gap is between what one wants in a job and what one has in a job [13]. However, in industrial working scenarios, it is important to refer also to work-related products or services implemented in industrial machinery, such as HMIs and other information and communications technology (ICT)-based solutions, and other aspects of work in the environment and organization that are external to work tasks, such as working conditions, salary, company policies and the hygiene factors of Herzberg et al.'s motivation theory [20].

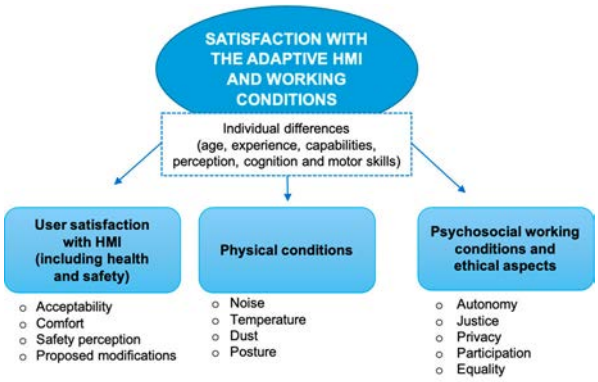

Figure 5. Proposed model of worker satisfaction.
Note: HMI, human–machine interface.

This is a more broad understanding than the classic approach presented in the literature review, although some of the reviewed tools considered the satisfaction with working conditions. Accordingly, in this article we propose a model of user satisfaction with the adaptive HMI and working conditions, understood as a worker satisfaction model. When developing the model of user satisfaction with working conditions and automation systems, we assumed that some other factors present in the workplace can influence its assessment or are particularly important in the context of an inclusive industrial environment. These are physical factors, such as noise, temperature, dust or posture, as well as psychosocial working conditions, such as autonomy, participation, justice or social support. Equally, as the system will process sensitive personal data, which disclose barriers of human capabilities, different ethical and legal requirements to protect the user against harm and disadvantages also have to be taken into account. Ultimately, the proposed model, shown in Figure 5, constitutes a comprehensive end-user evaluation framework, accounting for the core system usability principles as well as physical and psychosocial aspects of the working environment, and the end-user evaluation of the system-building modules (Measure, Adapt and Teach).

As a consequence, based on this model we have developed a worker satisfaction questionnaire that would cover all mentioned sections and aspects. The questionnaire measures overall user satisfaction with the automation system, including specific satisfaction with its modules, and satisfaction with psychosocial and physical working conditions, taking into account individual variables, e.g., capabilities and skills. Thus, the worker satisfaction questionnaire consists of three sections: physical working conditions; psychosocial working conditions and ethical aspects; and user satisfaction with the INCLUSIVE system and its modules.

3.1. The questionnaire for measuring worker satisfaction

While the whole questionnaire for measuring worker satisfaction with adaptive automation and working conditions is reported in the Appendix, in the following we discuss its sections.

3.1.1. Questionnaire's preamble

This questionnaire starts with a preamble explaining the questionnaire's aim, which is the assessment of satisfaction with the

implementation of the adaptive automation system, as well as its general structure. In the questionnaire preamble, potential respondents are assured that the survey is anonymous and that their personal data will not be disclosed to any of their supervisors.

3.1.2. Occupational and demographic data

The first data to be collected in the questionnaire are related to the company, i.e., the approximate number of employees and job position structure.

To account for aging workers or workers with language fluency difficulties, the next set of items relates to such data factors as age, level of education, nationality and level of language officially used in the work environment.

We are also interested in the user's work experience, so questions about the length of professional work experience, including any training to perform current tasks, are also posed in this section.

From the point of view of interaction and system adaptability, some aspects related to the user's health and capabilities are also important [54]. Hence, users are asked questions on potential problems with vision, hearing, hand movements, precise movements, memorizing information, concentration or understanding and following instructions.

At the end of this section, the user is asked to assess her/his general health and how often she/he is being stressed during worktime. The notion of stress has been explained in order to familiarize the users with its meaning.

3.1.3. Working conditions

3.1.3.1. Physical working conditions. In this section, we ask users how frequently they are exposed to difficult working environment conditions such as excessive noise, extreme temperatures, dust or too bright/too dark light. We also ask whether the user's work requires maintaining an awkward body position, lifting, bending or hands up.

The answer format is a 4-point Likert scale, where 4 = *most of the time* and 1 = *never*.

3.1.3.2. Psychosocial working conditions. In order to cover all possible psychosocial conditions present in the workplace, we included the standardized and well-validated COPSOQ [51], introduced earlier. Conceptually, this includes the main dimensions of the most influential psychosocial theories at work, including the job strain, demand–control–support [50] and effort–reward imbalance [55] models, but also other theories and aspects ignored in previous tools, e.g., emotional demands or role clarity. This makes the COPSOQ useful in any workplace either in the industrial or the services branch. Among psychosocial risk assessment tools, the COPSOQ is unique because it includes population-based reference values to assess the need for action and to help the decision-making process on preventive measures in the workplace level. A strength of the COPSOQ is that it has been tested in many countries all over the world. These validation studies show the questionnaire's capacity and usability in the local context.

Trying to keep the questionnaire as short as possible, we did not include the entire COPSOQ scales but only chosen questions most appropriate to the working conditions present in automation.

We used questions assessing psychological work demands such as 'Do you have enough time for your work tasks?'. The aspect of learning new things was also included using questions such as 'Does your work demand that you are good at coming up with new ideas?' and 'Do you have the possibility of learning new things through your work?'.

The worker's influence on how she/he performs her/his tasks is assessed using questions like 'Do you have a large degree of influence concerning your work?'. Social support is another important aspect of psychosocial working conditions: in the questionnaire, this is assessed using questions like 'How often do you get help and support from your colleagues if you need it?' and 'How often can you get help and support from your nearest superior if you need it?'.

The meaning of work is evaluated using the question 'Do you feel that the work you do is important?', and management style in the organization with questions such as 'Do you feel motivated and involved in your work?' or 'Is your work recognized and appreciated by the management?'.

An important factor of worker satisfaction is also organizational justice, which is assessed with questions such as 'Are you treated fairly at your workplace?' or 'Is the work distributed fairly?'. Work insecurity specifically related to modern technologies could also be a significant predictor of the worker's fear and work dissatisfaction. In the questionnaire, this is measured with the question 'Are you worried about new technology making you redundant?'.

A potential discrimination could also significantly influence worker satisfaction. To this end, the following questions are introduced: 'Are you treated fairly at your workplace?' and 'Is there space for employees with various illnesses or disabilities?'.

3.1.4. Satisfaction with the adaptive system and its HMI

3.1.4.1. Safety. To check for safety in the working environment, we added questions about the safety functions (emergency stop, guard locking functions, indications and alarms) and the control buttons (manual reset, mode selection/muting, hold to run, enabling device function, two-hand control function, locking/unlocking of the panel). Specifically, the goal is to verify whether these are clearly visible and readily accessible. Similarly, error messages and warning messages are very important from the point of view of safety, so the question 'Are error messages and warning messages clear, informative/sufficiently?' is also included in this section.

The answer format is a 5-point Likert scale, where 0 = *strongly disagree* and 4 = *strongly agree*.

3.1.4.2. Satisfaction with the design/visibility of the interface. In this section, questions on characters, visibility and clarity of texts/messages, signs/symbols on the interface and buttons have been included. We also ask users about the sequence of screens, position of messages on the screen, the colors used in the HMI and the HMI layout. Example items on this scale are 'In general, the organization of information is clear' and 'The sounds of the HMI help me to better operate the HMI'.

The answer format is a 5-point Likert scale, where 0 = *strongly disagree* and 4 = *strongly agree*.

3.1.4.3. Satisfaction with ease. In this section, the user is asked about the ease of the system, one of the usability principles introduced earlier. This means that the system is easy to learn and become familiarized with as well as the time for learning being minimal. The items relate to the process of

becoming familiar with the system's functions and operations, memorizing the system's functions and operations, finding the information needed, performing tasks, etc. Example items are 'It was easy to memorize the system's functions and operations' and 'Use of terms throughout the system is consistent and understandable'.

The answer format is a 5-point Likert scale, where 0 = *strongly disagree* and 4 = *strongly agree*.

3.1.4.4. Satisfaction with efficiency. Satisfaction with efficiency is another section directly related to usability principles. In this section, the user is asked about system efficiency. The items cover the amount of information presented, the number of operations to perform the task, having sense of control over the system and cooperation with the machine/robot. Example items are 'The HMI provides excessive amount of information' and 'In general, the HMI helps me to be more productive in my work'.

The answer format is a 5-point Likert scale, where 0 = *strongly disagree* and 4 = *strongly agree*.

The following sections of the questionnaire expressly refer to the single modules of an adaptive automation system according to Figure 1, i.e., Measure, Adapt and Teach.

3.1.4.5. Satisfaction with the Measure module. This section covers users' reactions to monitoring their physiological parameters with distal or proximal sensors, such as an eye-tracker, wristband or speech detector. Items are preceded by a short explanation of the aim of the Measure module, i.e., enabling the system to detect higher stress levels and to react (Adapt). Example items are 'I feel that monitoring my strain can be beneficial for me' and 'I feel it can challenge my physical comfort'.

The answer format was a 4-point Likert scale, where 0 = *strongly disagree* and 4 = *strongly agree*.

3.1.4.6. Satisfaction with the Adapt module. In this section, users are asked about their reactions to the way the system adapts to their capabilities and skills. The items verify whether the HMI has been adapted to capabilities/mental states and user guidance. Example items are 'I can get started easily on the system's newly added functions', 'I feel I make less mistakes/errors using the adaptive HMI' and 'I feel more confident using the adaptive HMI'.

The answer format is a 5-point Likert scale, where 0 = *strongly disagree* and 4 = *strongly agree*.

3.1.4.7. Satisfaction with the Teach module. This section covers user reactions to the Teach module. As this module might include both an online and offline teaching system, items have also been developed to measure satisfaction with different teaching approaches. Example items are 'The chosen way of assistance (Augmented reality-based assistance, speech-based assistance, support assistance) in the online teaching was appropriate' and 'The offline teaching was helpful to master the HMI'.

The answer format is a 5-point Likert scale, where 0 = *strongly disagree* and 4 = *strongly agree*.

3.1.4.8. Overall satisfaction with the adaptive system. The final section covers the overall satisfaction with the adaptive system, which is measured with the question 'Regarding the adaptive system in general, how pleased are you with it as a whole, everything taken into consideration?'.

The answer format is a 5-point Likert scale, where 1 = *very satisfied* and 5 = *very unsatisfied*.

In order to ensure the engagement of workers in the design and adaptation of their workplaces to their needs, which is the prerequisite to ensure the attractiveness of these novel solutions for workers, the questionnaire includes collected user opinions and/or proposals on preferred modifications of the system design and its operating mode. Therefore, we ask two open questions: 'If you are satisfied, what do you like the most in the adaptive system and its user interface?' and 'What should be improved in the adaptive system and its user interface?'.

4. Pilot testing and adjustments to the questionnaire

The questionnaire for worker satisfaction presented in this article is the result of some adjustments resulting from pilot tests carried out with shop floor workers from industries. In particular, starting from the literature review and the model of worker satisfaction presented in Figure 5, a first draft of the questionnaire was released. Pilot tests were carried out to collect end users' thoughts and feedback about the questionnaire, before using it as an actual tool for measuring worker satisfaction.

The first release of the questionnaire consisted of the same sections as those hereby presented, i.e., working conditions and satisfaction with the adaptive HMI, and also surveyed skills and capabilities of the users. Nevertheless, it was much longer than the current version. The questionnaire was handed out online and translated into the local language of the testing sites, i.e., Italian and Greek. Indeed, the pilot tests were carried out at SCM Group, in Italy, one of the world's leading producers of woodworking machines, and at GIZELIS ROBOTICS, in Greece, a system integrator for highly advanced robotic solutions. These sites were chosen due to being responsible for use cases in the EU INCLUSIVE project [56]. A total of 19 participants were enrolled in the pilot study (eight shop floor workers from SCM Group and 11 from GIZELIS ROBOTICS). The questionnaire was tested on a prototypal version of an adaptive automation system, i.e., the INCLUSIVE system [4,56]. In addition to the questionnaire measuring worker satisfaction, to collect feedback about it the following questions were administered: 'Are the questions of the questionnaire relevant for your work?'; 'Are the questions of the questionnaire understandable?'; and 'Is the number of the questions of the questionnaire appropriate?'.

As summarized in Table 1, the participants of the pilot study assessed that the questions/items in the questionnaire were relevant and understandable.

As shown in Figure 6, the majority of our respondents (63.16%) found the questionnaire items relevant for their work to a large extent or even to a very large extent (5.26%).

The majority of respondents (73.68%) found the items to be understandable to a large extent, and 21.05% found the items understandable to a very large extent (Figure 7).

Table 1. Outcomes of two questions on the questionnaire.

Question	*N*	*M*	*SD*	Minimum	Maximum
Are the items relevant for your work?	19	3.47	1.02	1	5
Are the items understandable?	19	4.11	0.66	2	5

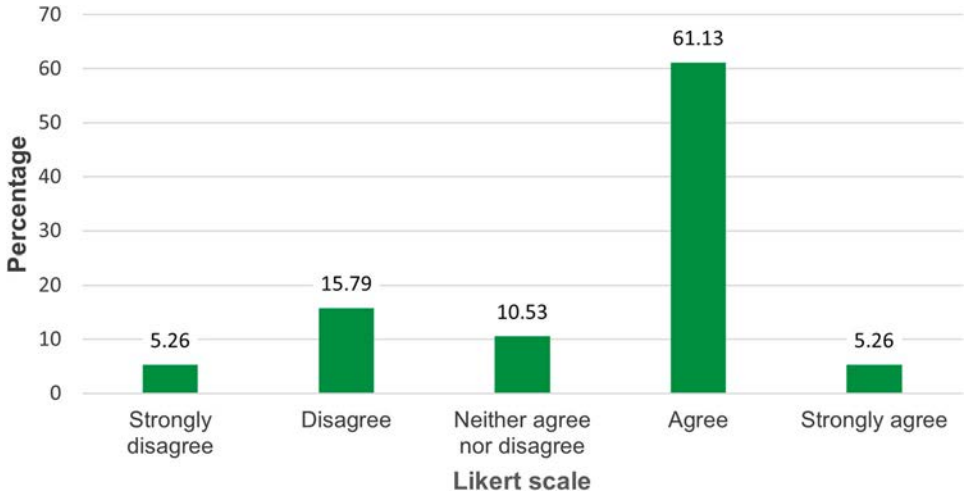

Figure 6. Percentage of respondents answering the question 'Are the questions of the questionnaire relevant for your work?'.

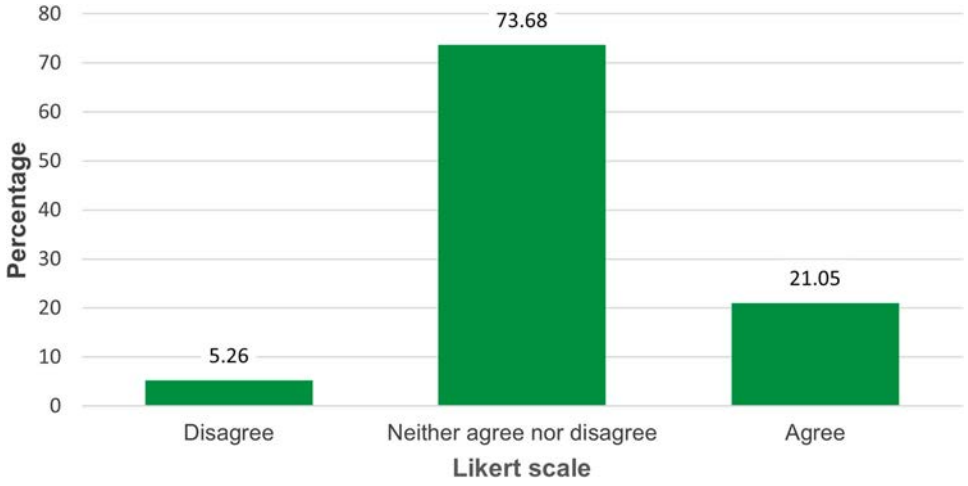

Figure 7. Percentage of respondents answering the question 'Are the questions of the questionnaire understandable?'.

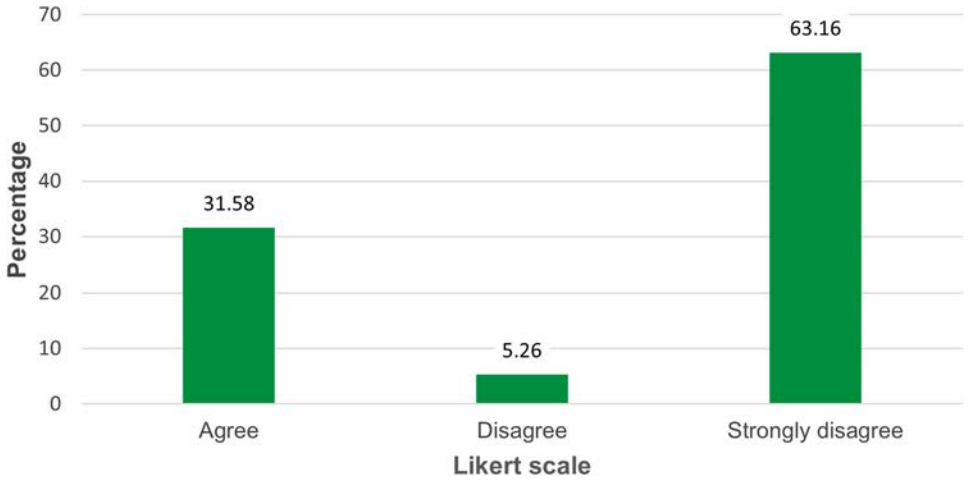

Figure 8. Percentage of respondents answering the question 'Is the number of the questions of the questionnaire appropriate?'

Finally, most of the respondents (63.16%) found the number of items too high, while 31.58% of respondents thought the number of items was appropriate (Figure 8).

The majority of the participants in the pilot study assessed that the items in the questionnaire were relevant (68.42%) and understandable (94.73%). However, most of the respondents (68.42%) found the number of items too high, so it was decided to adjust this measurement tool by reducing the number of items. From its original version, which consisted of 132 items in total, 34 questions were deleted. The deletion criterion was an average, non-discriminant answer level and its similarity to other questions. These adjustments led to the questionnaire about worker satisfaction hereby proposed.

5. Conclusions

In this article we have proposed methods and tools to measure worker satisfaction in scenarios of industrial automation. To

this end, the relevance of promoting worker satisfaction was highlighted with respect to the modern context of Industry 4.0 and, generally speaking, sustained technological progress. Based on a review of commonly used methods for assessing system usability, user satisfaction and satisfaction with work, and having analyzed the current automation panorama, we selected the relevant factors to be considered in a model of worker satisfaction: the model takes into account psychosocial and physical working conditions and the characteristics of the automation system the worker interacts with and its user interface. Furthermore, we developed a questionnaire to be used as a practical tool for the assessment of worker satisfaction with industrial automation. The questionnaire examines working conditions and user satisfaction with automation and is the result of adjustments suggested by shop floor operators during pilot testing.

While the presented model and questionnaire are hereby proposed as tools to assess worker satisfaction with existing interaction systems, as a further step they could be used as predictive tools to guide in the design of novel automation systems that inherently, or by design, guarantee greater worker satisfaction.

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ORCID

Valeria Villani http://orcid.org/0000-0001-7619-0101
Lorenzo Sabattini http://orcid.org/0000-0002-2734-5549
Paulina Barańska http://orcid.org/0000-0001-5680-1104
Cesare Fantuzzi http://orcid.org/0000-0002-8885-7951

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Appendix

1. Appendix – The proposed questionnaire for worker satisfaction

Questionnaire for worker satisfaction with adaptive automation and working conditions

Dear Participant!

This questionnaire is aimed at the assessment of satisfaction with the implementation of an adaptive automation system. Adaptive automation consists in changing the behavior of the machine and of its human-machine interface (HMI) depending on the status of the worker.

The questionnaire consists of two main parts: satisfaction with working conditions and satisfaction with the new adaptive system. **The survey is anonymous**. The individual data will not be available to any of your supervisors. We are really interested in what you think about the adaptive automation system. We encourage you to give your honest opinion!

Demographic DATA

1. Age ____________________
2. Gender: ☐ Man ☐Woman
3. Level of education:
   ☐ Primary school ☐ Secondary school ☐ University (Bachelor) ☐ University (Master)
4. For how long do you work in the company? ____________
5. How long have you been involved in the present work tasks? ____________
6. Did you receive any training to perform your current task? ☐ YES ☐ NO
7. Nationality? ... ...
8. Is your nationality the same as most your colleagues? ☐ YES ☐ NO
9. Your level of language officially used in your work environment is:
   ☐ Basic ☐Communicative ☐ Advanced ☐ Native speaker

HEALTH AND CAPABILITIES

1. I have problems with vision: ☐ YES (check below) ☐NO
   If YES: ☐ Near ☐ Far ☐ I am colorblind ☐ Other (please describe) ... ...
2. If an answer to the question 1 is yes, my vision with correction glasses/lenses is:
   ☐ Excellent ☐ Good ☐ Moderate ☐ Poor
3. I have problem with hearing: ☐ YES ☐ NO
4. If an answer to the question 3 is yes, my hearing with hearing aid is:
   ☐ Excellent ☐ Good ☐ Moderate ☐ Poor
5. I have problems with moving my hands:
   ☐ Not at all ☐ To a small extent ☐ Somewhat ☐ To a large extent
6. I have problems with precise movements (e.g. manipulating small objects):
   ☐ Not at all ☐ To a small extent ☐ Somewhat ☐ To a large extent
7. I have difficulties to remember things:
   ☐ Not at all ☐ To a small extent ☐ Somewhat ☐ To a large extent
8. In general I have problems with concentration:
   ☐ Not at all ☐ To a small extent ☐ Somewhat ☐ To a large extent
9. I have problems with understanding instructions and following instructions:
   ☐ Not at all ☐ To a small extent ☐ Somewhat ☐ To a large extent
10. In general, I would say my health is:
    ☐ Excellent ☐ Very good ☐ Good ☐ Fair ☐ Poor
11. How often have you been stressed* during the last 4 weeks:
    ☐ Every day ☐ Most of the week ☐ Once a week ☐ Never/Hardly Ever

* **Stress** means the situation when a person feels tense, restless, nervous, or anxious, or is unable to sleep at night because his mind is troubled all the time.

I. Working Conditions

PHYSICAL WORKING CONDITIONS

1. During work are you frequently exposed to difficult conditions such as:

a) Excessive Noise	☐ Most of the time	☐ Sometimes	☐ Rarely	☐ Never
b) Extreme Temperatures	☐ Most of the time	☐ Sometimes	☐ Rarely	☐ Never
c) Dust	☐ Most of the time	☐ Sometimes	☐ Rarely	☐ Never
d) Too bright/too dark light	☐ Most of the time	☐ Sometimes	☐ Rarely	☐ Never

2. Does your work require to maintain:

a) Awkward body position	☐ Most of the time	☐ Sometimes	☐ Rarely	☐ Never
b) Lifting	☐ Most of the time	☐ Sometimes	☐ Rarely	☐ Never
c) Bending	☐ Most of the time	☐ Sometimes	☐ Rarely	☐ Never
d) Hands up	☐ Most of the time	☐ Sometimes	☐ Rarely	☐ Never

e) Other

(Short description)

... ...

... ...

... ...

... ...

PSYCHOSOCIAL WORKING CONDITIONS

0 – Never/Hardly Ever 1 – Seldom 2 – Sometimes 3 – Often 4 – Always	Never/Hardly Ever	Seldom	Sometimes	Often	Always
1. Do you have enough time for your work tasks?	0	1	2	3	4
2. Does your work demand that you are good at coming up with new ideas?	0	1	2	3	4
3. Does your work require that you remember a lot of things?	0	1	2	3	4
4. Does your work require you to make difficult decisions?	0	1	2	3	4
5. Do you have a large degree of influence concerning your work?	0	1	2	3	4
6. How often do you get help and support from your colleagues if you need it?	0	1	2	3	4
7. How often can you get help and support from your nearest superior if you need it?	0	1	2	3	4
0 – To a very small extent 1 – To a small extent 2 – Somewhat 3 – To a large extent 4 – To a very large extent	To a very small extent	To a small extent	Somewhat	To a large extent	To a very large extent
8. Do you have the possibility of learning new things through your work?	0	1	2	3	4
9. Can you use your skills or expertise in your work?	0	1	2	3	4
10. Do you feel that the work you do is important?	0	1	2	3	4
11. Do you feel motivated and involved in your work?	0	1	2	3	4
12 Is your work recognized and appreciated by the management?	0	1	2	3	4
13. Are you treated fairly at your workplace?	0	1	2	3	4
14. Are you worried about new technology making you redundant?	0	1	2	3	4
15. Are conflicts resolved in a fair way?	0	1	2	3	4
16. Is the work distributed fairly?	0	1	2	3	4
17. Is there space for elderly employees?	0	1	2	3	4
18. Is there space for employees with various illnesses or disabilities?	0	1	2	3	4

OVERALL SATISFACTION WITH WORKING CONDITIONS

Regarding your work in general, how pleased are you with your job as a whole, everything taken into consideration?

☐ Very satisfied ☐ Satisfied ☐ Neither satisfied, nor dissatisfied ☐ Unsatisfied ☐ Very unsatisfied

II. Satisfaction with the adaptive system and its human-machine interface (HMI)

SAFETY

0 – Strongly disagree *1 – Disagree* *2 – Neither agree nor disagree* *3 – Agree* *4 – Strongly agree* *5 – Not applicable* According to your opinion:	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Not applicable
1. Safety functions (Emergency stop, guard locking functions, indications and alarms) are:						
b) Clearly visible	0	1	2	3	4	5
c) Readily accessible	0	1	2	3	4	5
2. The control buttons (Manual Reset, Mode selection/muting, Hold-To-Run, Enabling Device Function, Two-hand control function, Locking – unlocking of the panel) are:						
e) Clearly visible	0	1	2	3	4	5
f) Readily accessible	0	1	2	3	4	5
3. Error messages and warning messages are:						
g) Clear	0	1	2	3	4	5
h) Informative/Sufficiently detailed	0	1	2	3	4	5
4. Overall, the adaptive HMI fulfills all the safety functions	0	1	2	3	4	5

SATISFACTION WITH THE DESIGN/VISIBILITY OF THE INTERFACE						
0 – Strongly disagree	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Not applicable
1 – Disagree						
2 – Neither agree nor disagree						
3 – Agree						
4 – Strongly agree						
5 – Not applicable						
According to your opinion:						
1. Characters are easy to read.	0	1	2	3	4	5
2. The signs/symbols on the interface are unambiguous/clear	0	1	2	3	4	5
3. The interface buttons (options) are visible on the screen	0	1	2	3	4	5
4. Sequence of screens is appropriate	0	1	2	3	4	5
5. Position of messages on the screen is consistent	0	1	2	3	4	5
6. The colors used in the HMI help to better perceive the information on the screen	0	1	2	3	4	5
7. The HMI layout is aesthetic	0	1	2	3	4	5
8. In general, the organization of information is clear	0	1	2	3	4	5
9. In general, the layout of the adaptive HMI is appropriate	0	1	2	3	4	5
10. The sounds of the HMI help me to better operate the HMI.	0	1	2	3	4	5
11. The changing interface distracts me	0	1	2	3	4	5
12. I can easily operate the adaptive HMI using my hands	0	1	2	3	4	5

SATISFACTION WITH EASE						
0 – Strongly disagree	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Not applicable
1 – Disagree						
2 – Neither agree nor disagree						
3 – Agree						
4 – Strongly agree						
5 – Not applicable						
According to your opinion:						
1. The system is easy to learn.	0	1	2	3	4	5
2. It was easy to memorize the system's functions and operations.	0	1	2	3	4	5
3. Use of terms throughout system is consistent and understandable.	0	1	2	3	4	5
4. The signs/symbols on the interface help me to navigate through the HMI	0	1	2	3	4	5
5. I can easily find all the information I need.	0	1	2	3	4	5
6. I can easily return to the earlier steps.	0	1	2	3	4	5

SATISFACTION WITH EFFICIENCY						
0 – Strongly disagree	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Not applicable
1 – Disagree						
2 – Neither agree nor disagree						
3 – Agree						
4 – Strongly agree						
5 – Not applicable						
According to your opinion:						
1. The HMI provides excessive amount of information.	0	1	2	3	4	5
2. The number of operations to perform a task/to achieve a goal/to set up a process is optimal.	0	1	2	3	4	5
3. The HMI helps me to more efficiently cooperate with the machine/robot.	0	1	2	3	4	5
4. In general, the HMI helps me to be more productive in my work.	0	1	2	3	4	5

SATISFACTION WITH THE MEASURE MODULE

Please answer the subsequent questions considering the following scenario: The working machines are equipped with sensors that are able to track strain of a working person by real-time measurement of her/his physiological parameters, e.g. heart rate, blood pressure, etc. If the measured strain indicators are too high, the human-machine-interface adapts to the situation resulting in a lower stress level.

How do you feel about monitoring your physiological parameters (e.g. using a wristband, eye tracker, etc.)?

0 – Strongly disagree 1 – Disagree 2 – Neither agree nor disagree 3 – Agree 4 – Strongly agree 5 – Not applicable	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Not applicable
1. I feel it can challenge my physical comfort	0	1	2	3	4	5
2. I trust the system and that my personal data will not be abused	0	1	2	3	4	5
3. I feel that monitoring my strain can be beneficial for me	0	1	2	3	4	5

SATISFACTION WITH THE ADAPT MODULE *0 – Strongly disagree* *1 – Disagree* *2 – Neither agree nor disagree* *3 – Agree* *4 – Strongly agree* *5 – Not applicable* According to your opinion:	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Not applicable
1. I can get started easily on the system's newly added functions	0	1	2	3	4	5
2. I feel the adaptive HMI adjusts to my actual capabilities/mental states	0	1	2	3	4	5
3. I feel I can be easily guided when I get lost/commit an error	0	1	2	3	4	5
4. I feel less stressed using the adaptive HMI	0	1	2	3	4	5
5. I feel more confident using the adaptive HMI	0	1	2	3	4	5
6. I feel I make less mistakes/errors using the adaptive HMI	0	1	2	3	4	5
7. I feel less exhausted after my shift when using the adaptive HMI	0	1	2	3	4	5

SATISFACTION WITH THE TEACH MODULE *0 – Strongly disagree* *1 – Disagree* *2 – Neither agree nor disagree* *3 – Agree* *4 – Strongly agree* *5 – Not applicable* What do you think about the on-line and off-line training?	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Not applicable
1. The chosen way of assistance (augmented reality-based assistance, speech-based assistance, support assistance) in the on-line training was appropriate.	0	1	2	3	4	5
2. The way the on-line training system presented the information was adapted to my current work task.	0	1	2	3	4	5
3. The information in the on-line training system was easy to read and perceive.	0	1	2	3	4	5
4. I would have needed more detailed instructions to complete my tasks.	0	1	2	3	4	5
5. The on-line training system was adequate in relation to my skills and capabilities.	0	1	2	3	4	5
6. The on-line training system was helpful to master the HMI.	0	1	2	3	4	5
7. I would have needed more detailed instructions from the off-line training systems to learn the task successfully.	0	1	2	3	4	5
8. The off-line training system could replace teaching-in by a trainer for this procedure.	0	1	2	3	4	5
9. The off-line training system was adequate in relation to my skills and capabilities.	0	1	2	3	4	5
10. The off-line training system was too complex.	0	1	2	3	4	5
11. The off-line training system was helpful to master the HMI.	0	1	2	3	4	5

OVERALL SATISFACTION WITH THE ADAPTIVE SYSTEM

Regarding the adaptive system in general, how pleased are you with it as a whole, everything taken into consideration?
☐ Very satisfied ☐ Satisfied ☐ Neither satisfied, nor unsatisfied ☐ Unsatisfied ☐ Very unsatisfied

If you are satisfied, what do you like the most in the adaptive system and its user interface?

What should be improved in the adaptive system and its user interface?

Thank you for your answers!!!