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Analysing Factory Workers' Acceptance of Collaborative Robots: A Web-Based Tool for Company Representatives

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Abstract: Collaborative robots are a new type of lightweight robots that are especially suitable for small and medium-sized enterprises. They offer new interaction opportunities and thereby pose new challenges with regard to technology acceptance. Despite acknowledging the importance of acceptance issues, small and medium-sized enterprises often lack coherent strategies to identify barriers and foster acceptance. Therefore, in this article, we present a collection of crucial acceptance factors with regard to collaborative robot use at the industrial workplace. Based on these factors, we present a web-based tool to estimate employee acceptance, to provide company representatives with practical recommendations and to stimulate reflection on acceptance issues. An evaluation with three German small and medium-sized enterprises reveals that the tool's concept meets the demands of small and medium-sized enterprises and is perceived as beneficial as it raises awareness and deepens knowledge on this topic. In order to realise economic potentials, further low-threshold usable tools are needed to transfer research findings into the daily practice of small and medium-sized enterprises.

Keywords: collaborative robots; industrial human–robot interaction; acceptance; technology adoption; workplace; small and medium-sized enterprises

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1. Introduction

Employing industrial robots has been a popular means to realise a highly automated and cost-efficient production in enterprises during the last decades, leading to an increasing amount of industrial robots in factories [1]. In contrast, so-called collaborative robots (cobots) represent a relatively new technology that became commercially available around five till ten years ago [2]. Their implemented safety features enable humans to collaborate with cobots within a shared working space including direct physical contact which is for example necessary to realise handovers of work pieces or programming via hand-guiding. These features make a physical separation, e.g., by security fences, obsolete and establish innovative human–machine interaction [3]. Hence, they give enterprises the opportunity to implement human–robot interaction (HRI) applications. The usually lightweight design of cobots, their comparably low size and intuitive programming capabilities allow a flexible usage, which particularly provides benefits for small and medium-sized enterprises (SMEs), who typically produce many product variants in small lot sizes and thus require flexible, mobile and easy-programmable devices [4].

However, apart from show cases and pilot implementations, it is still hard to find successful HRI solutions in practice, especially in SMEs [5]. Hence, the question arises, why the adoption of this promising new technology progresses so slowly [6]. One possible barrier for the successful adoption of cobots is the insufficient acceptance among employees [7]. Technology acceptance describes the way people perceive and evaluate technology on an attitude-level, but can also be defined on a behaviour-level as the choice to voluntarily use a certain technology [8]. When employees only reluctantly use a technology or even refuse to use it, this can be interpreted as a significant sign for a lack of acceptance.

The framework of success factors for cobot introduction processes by [9] demonstrates that human-related factors like trust in the cobot are on the one hand considered as highly relevant by qualified company representatives. However, on the other hand, these factors seem to be less salient than more quantitatively measurable properties like costs or production-oriented key performance indicators (KPI) [9]. Additionally, particularly SMEs often lack structured or formalised approaches for promoting acceptance and addressing employees' fears. As industrial HRI (iHRI) is still a relatively new phenomenon and subject of research, findings on how to address acceptance issues are scarce [10,11]. This issue is particularly crucial because the cobot introduction process raises novel questions and poses new challenges in terms of human factors [12]. Whereas acceptance has been addressed with regard to other technologies for example by the popular "Technology Acceptance Models" (TAM) [13–15], the formation conditions for acceptance of cobots seem to differ, because cobots are not a typical instrument for automatisation and for substituting human labour but for providing collaboration opportunities [16].

Additionally, classical acceptance models have been criticised for their limited explanatory and predictive power, and their lack of practical value, because these models assume that employees are in a position to reject the usage of a certain technology, which does not hold true for the mandatory usage context at the workplace [10,17–19]. The interaction with a cobot therefore fundamentally differs from the interaction with information systems, which have been the traditional subjects of TAMs. Therefore the transferability of existing TAMs to the HRI context should be reflected critically [10]. Furthermore, in the workplace context, employees often switch between perceiving a cobot as either a supporting colleague or a superior competitor [20]. This makes it hard for decision-makers to predict employees' attitudes towards cobots and in turn the criticality of acceptance issues [21].

To sum up, the complexity of acceptance in the HRI context seems to hinder market penetration of cobots, especially in SMEs which require knowledge and practical support in order to establish coherent internal approaches adequately addressing acceptance issues. However, to the best of our knowledge, no such approaches with regard to employee acceptance when introducing cobots exist at date. Hence, our work aimed to conceptualise, implement, and evaluate (method similar to [22]) an intuitive, practical and easy-to-use employee acceptance tool. Therefore, our research goals are threefold. First, we seek to identify and structure the most influential acceptance factors in the HRI context as a basis for the acceptance tool. Secondly, we aim at implementing an interactive employee acceptance tool providing company representatives with an individual assessment of concrete needs for action paired with practical action recommendations. Thirdly, an evaluation of this tool's usefulness from the perspective of company representatives should make their demands more transparent. Thereby we try to answer the questions, which influential acceptance factors in the HRI context exist (Section 2), how these factors can be integrated in a tool for practitioners to address employee acceptance (Section 3), and how company representatives evaluate the tool's practical usefulness in the context of their daily business (Section 4).

2. Conceptualisation of the Employee Acceptance Tool

As part of the research project 'ProBot', we conducted 17 guided expert interviews with 19 company representatives as well as four workshops, each with six to ten production employees in four manufacturing SMEs, which gave us a vivid impression of possible factors influencing acceptance with regard to the introduction of cobots [23]. Furthermore, we conducted two online studies investigating success factors for the introduction of cobots on the one hand [9] and the influence of linguistic framing on employees' trust on the other hand [24]. An extensive literature review on the topic of employee acceptance in cobots enriched the findings from these studies resulting in six essential acceptance factors within the context of iHRI, namely (i) job security, (ii) (perceived) occupational safety, (iii) workforce structure, iv) corporate culture and appreciation, (v) changing work routines, and (vi) human-centred design. These factors provided the basis for our em-

ployee acceptance tool. In the following we will describe how these factors influence the acceptance.

2.1. Job Security

Traditionally, employees often see robots as a threat for employment and are concerned by automation possibly making humans superfluous by taking over their work [25]. According to a Eurobarometer survey, 70% of the 26,751 respondents from the member states of the European Union believe that the adoption of robots could lead to job losses [26]. Concerns of robots taking over human work are therefore a major obstacle for robot acceptance at the workplace [27], especially if employees themselves have experienced job cuts in the past as a result of the introduction of automation solutions. It is therefore important to differentiate between the introduction of conventional robots and of cobots, since the latter are intended to enable human–robot collaboration, that is, to complement an operator in collaborative scenarios rather than replace him or her [16,24]. Raising employees' awareness for this difference might increase acceptance, particularly if a company plans to introduce a cobot in such a collaborative or cooperative usage scenario. When deciding to introduce cobots, most companies aim at improving either job attractiveness, flexibility, or productivity [9,28]. Depending on this goal, different levels of acceptance among the workforce could be expected:

- Increased job attractiveness: In order to counteract the shortage of skilled workers in manufacturing, companies aim at increasing job attractiveness and at reducing risks for musculoskeletal disorder by introducing a cobot that relieves employees of monotonous, repetitive, unergonomic, or unattractive work (e.g., [29,30]). Improving the working conditions and the quality of work could foster the acceptance of the corresponding technology [27].
- Increased productivity: Companies aim at improving productivity by allocating different tasks according to the typical complementary strengths of human beings and cobots [9,31,32]. When cobots take over tasks of human beings in order to increase productivity, fears of job losses might arise quickly. However, if employees suffer from high workload for example due to an unexpected high number of orders, employees might regard the support of a cobot as a relief. Furthermore, investments in modern production technologies could be interpreted as a commitment to local production sites and thus represent a trend towards backshoring and re-concentration back from foreign locations to a concentrated production at a lead location [33]. In this sense, introducing a cobot could also be intended to guarantee jobs at a given production site.
- Increased flexibility: Unlike conventional industrial robots, most cobots can be easily programmed, quickly adapted, and relocated [34–36]. Compared to fully automated solutions, the human's cognitive component enhances the flexibility and responsiveness of the human-cobot system [37]. These advantages can motivate particularly such companies to buy a cobot that produce in smaller batches with larger number of variants [38]. Telling employees that cobots are primarily needed to increase flexibility rather than to rationalise jobs could alleviate fears of job losses.

2.2. (Perceived) Occupational Safety

Human's perception of automation technologies' characteristics and capabilities and in turn their attitude and initial trust is strongly influenced by prior experiences [39–41]. So far, the market penetration of cobots is still limited [6]. Most employees are therefore only familiar with traditional autonomous robots, which were not initially designed for interacting with humans [42]. Compared to cobots, conventional industrial robots typically move much faster, have greater force and sharp edges, and are physically separated from humans due to a lack of built-in safety mechanisms [9]. Although cobots are equipped with safety features, which are of highest priority when enabling HRI in close proximity [35,43,44], factory workers might still be unaware of these mechanisms. Furthermore, employees'

mental model of interactive robots may be influenced by external depictions in the mass media, the social environment or in movies and books [45–47]. As such, safety concerns about the cobot itself but also about the handled components [48] and the end effectors [45] belong to the key barriers for cobot acceptance in industrial contexts [49]. Thus, besides the safe design of a cobot to avoid injuries of the working staff it is likewise important that employees feel safe [43,50]. Thereby, it must be taken into account that perceived safety might differ from actual safety. Hence, employees should be given the opportunity to get in touch with the cobot in advance and experiment with it to foster building trust in its integrated safety functions. Even a few positive experiences can lead to reduced negative biases and fears, to a clearer picture of the cobot and in turn to a more positive attitude and an increased intention to work with it [5,51,52].

2.3. Workforce Structure

Prevalent stereotypes, which differ between different cultural, demographic and social clusters, lead to different conceptions of a robot [53]. However, most studies consider these characteristics as negligible for employees' acceptance of cobots [47]. In the following, we present some exemplary workforce-related factors that company representatives should consider for a human-centred and well-accepted cobot introduction instead of relying on oversimplified stereotypes:

- Prior experiences with robots: Prior experiences influence people's beliefs about and trust in automation solutions [39,40]. Experiences of interacting with robots can therefore result in less negative attitudes towards them [41]. In this sense, it is important to give inexperienced users the opportunity and time to gain experience in interacting with the robot, as stated in the previous paragraph.
- Enthusiasm for new technologies: If employees are excited and curious about working with cobots this can be a central driver for acceptance [53]. Therefore, company representatives should make sure to choose employees as pilot users who enjoy working with the cobot.
- Technical affinity: A person's technical affinity correlates positively with initial robot trust and acceptance before the actual interaction [24]. However, previous studies reveal a correlation between technological affinity and expectations [54]. A cobot failing to meet the latter can cause frustration and undermine acceptance.

2.4. Corporate Culture and Appreciation

Management support for the introduction of a new technology and approaches to actively involve operational staff in the introduction process expresses the importance and appreciation of efforts to design a successful rollout [55]. Additionally, the way colleagues think about one's work with the cobot plays an important role in a sense that working with the cobot has an impact on the employee's reputation. These beliefs of others, the so-called subjective norm, determine employees' behaviour in a fundamental way [56] and influence the intention to accept a technology [14]. Furthermore, it can be beneficial to communicate accompanying changes to opinion leaders of the working staff and include the union in the implementation, which represents the interests of the employees [11].

2.5. Changes in the Daily Work Routine

The introduction of a cobot might lead to multifaceted changes in the daily work routines, such as changes in workload, workflow, responsibility, or complexity of the task. Dependent on their current work situation, employees evaluate these changes in different ways. They might on the one hand appreciate a reduction of the mental and physical workload, for example if the cobot takes over repetitive and monotonous tasks [57]. On the other hand, decreased complexity can be perceived negatively if employees fear mental underload due to lower speed and longer waiting times [53] or if the lower complexity puts the social position of the employee at risk [58]. It is therefore essential in terms of satisfactory working conditions to take cognitive load and mental workload into account

when assigning tasks to humans and cobots [59]. While ambitious employees might see the changes at their workplace due to the cobot introduction as an opportunity for their career, other employees might have negative feelings about the changes. The latter might result from a general fear of job losses, but can also be attributed to the so called 'status quo bias', which refers to people's general change aversion [10,60].

2.6. Human-Centred Design

In terms of employees' work satisfaction, they should retain the feeling of self-determination and not get the impression to lose control due to the introduction of a cobot. For example, employees wish to still be able to control the speed of their work independently of the cobot [57]. The central question is: Will the cobot-system be designed in a way that fits best to the employee's work routine or in a way to maximise the efficiency of the cobot? These design goals do not necessarily conflict. However, the chosen focus can influence whether employees get the impression that the cobot is being adapted to the human or vice versa. A comfortable user experience is therefore an important goal when introducing cobots [61].

With this in mind, it is important to gather the employees' requirements at the workplace and involve them in configuration and programming if possible. If the employees working with the cobot change frequently, it makes sense to design the workplace in a way that it can be flexibly adapted to the needs and anthropometric data of different employees [62].

3. Implementation of the Employee Acceptance Tool

Acceptance and trust become increasingly relevant organisational issues with regard to cobot introduction in companies. However, the latter often fail to employ appropriate strategies for a human-centred introduction process [9,43]. In particular SMEs do not employ implementation strategies for the successful adoption of HRI solutions [28]. As the previous section revealed, acceptance issues can be manifold with complex interlinkages and multiple antecedents that should be taken into account. Fostering acceptance in the HRI context is therefore considered as a particularly challenging endeavour. We therefore developed a low-threshold web-based tool enabling decision-makers to assess factors within their companies that influence acceptance in order to identify needs for action. The employee acceptance tool is a part of the web-based SME Cobot Coach (kmu-cobot-coach.de, webpage will be launched at February 2022), which is supposed to support company representatives particularly from SMEs in introducing cobots. Apart from the employee acceptance tool, the SME Cobot Coach includes further tools to analyse the economic efficiency, the safety and risks, the feasibility and potential, ergonomics, and qualification requirements for cobot introduction. The interactive website is based on the popular content management system 'Wordpress'. The interactive form builder 'eForm' (see https://eform.live/, accessed on 17 November 2021.) was used as a plug-in for the implementation of the tools. We developed and implemented the employee acceptance tool over a period of six months (December 2020 until May 2020). The tool allows users to interactively jump between the pages. If several possible use cases have been identified and entered in a previous step of the SME Cobot Coach, one can select a use case for which the analysis will be performed before starting with the employee acceptance tool.

The tool addresses company representatives with knowledge about the planned cobot use case and about the employees who are supposed to work with the cobot in the future. The company representatives have to answer several questions regarding the situation in the company and the involved employees to finally receive an overview about the most critical acceptance issues paired with action recommendations to tackle them. Overall, it takes users approximately 15 min to complete the tool. If at some point internal information, e.g., from colleagues, are needed for further processing the tool, registered users have the opportunity to save the current state. The tool is also suitable for teamwork between management and operational staff. After submitting all answers, users can print the filled

form or export it in pdf-format. Additionally, logged-in users can view and revise the entered data again at a later time.

At the beginning of the employee acceptance tool the user is provided with information about possible consequences of missing acceptance, such as productivity losses due to employees actively undermining the cobot introduction process, manipulating the cobot itself or refusing to use it. Dissatisfaction and lower motivation among employees are further possible negative effects of a lack of acceptance. Afterwards, the user gets informed about the following process flow of the tool, that is the (1) query of key data about the potential cobot use case and company characteristics, followed by (2) an assessment indicating crucial acceptance issues and corresponding needs for action, and (3) individual recommendations based on this assessment (see Figure 1).

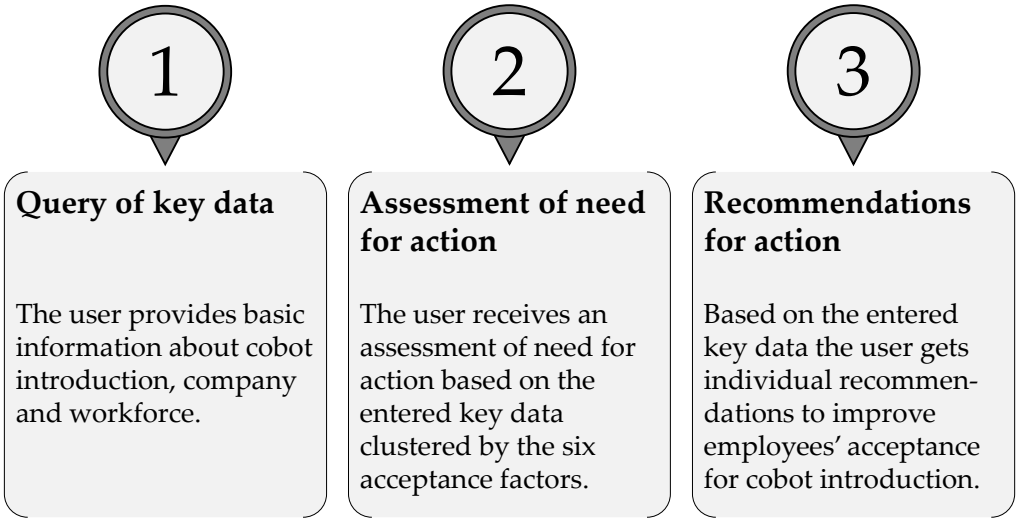

Figure 1. Process flow of the employee acceptance tool.

3.1. Query of Key Data

During the first phase users enter information about the use case like the planned type of interaction (cell, coexistence, cooperation or collaboration, e.g., [23,63]), the primary purpose of the deployment (increase in productivity, flexibility or workplace attractiveness, cf. [9]), the involvement of management, unions and workforce representatives (e.g., [11,55]) and the focus of the design of the human-cobot system, which can either be adapted according to anthropometric data of the employees [62] or designed to maximise efficiency. Furthermore, the tool asks about possible negative experiences related to similar technologies in the company, such as safety incidents or job cuts related to automation (e.g., [27,57]).

The users are also asked to anticipate the employees' concerns and fears, e.g., their safety concerns regarding the cobot itself (e.g., [49]), as well as its gripper (e.g., [64]), its movements (e.g., [65,66]) and the components handled by the cobot (e.g., [48]). In addition, users estimate changes regarding the employees' workload, work complexity, and responsibility due to the implementation of the cobot as well as factory workers' evaluation of these changes.

Although the tool includes questions about the age and gender of the employees, they do not influence the assessment of the need for action, but rather serve to raise awareness for these oversimplifying stereotypes [53]. Irrespective of the user's choice, the tool suggests focussing on individual employee characteristics, such as prior practical experience, general attitude toward technology, willingness to change, or affinity for technology, rather than generalist demographic characteristics such as age or gender.

The queried key data are subsequently used to assess the need for action clustered by the six acceptance factors. Depending on the selected option for each question, a

value between −2 and +2 is assigned as a basis for determining the need for action (see Section 3.2), with −2 representing a high and +2 a low risk for employee acceptance. Whenever available, we used validated, balanced verbal labels for the scales to query the basic data. For standardised five-level metric scales, we removed the middle rating to prevent users from dodging the decision. For example, when asking users to agree or disagree with statements, we used *completely disagree*, *slightly disagree*, *slightly agree*, and *completely agree* (see Figure 2), which were assigned to the scores (−2), (−1), (+1), and (+2), respectively. When no validated labels existed with respect to some cobot-specific questions, we were forced to assign the scores to the corresponding response options based on logical considerations. The translation of the given answers into these scores is indiscernible for users.

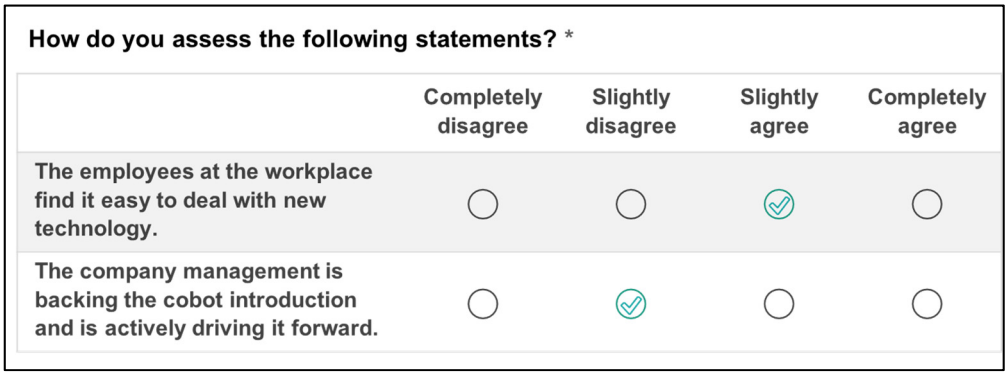

Figure 2. Example for the query of data in phase 1.

Appendix A contains a complete list of the basic data queried and the respective response scales.

3.2. Assessment of Need for Action

The stored scores based on the given answers are assigned to the six acceptance factors job security, occupational safety, workforce structure, corporate culture and appreciation, changes in the daily work routine, and human-centred design (cf. Section 2). If a selected response option had a positive effect on one acceptance factor, but a negative effect on another, it was assigned to both categories accordingly. For example, the choice 'collaboration' as 'type of interaction' is expected to positively affect the acceptance factor 'job security', as this suggests that human and cobot work supportive together, complementing each other in a shared environment rather than competing with each other or working independently and separately [64,67,68]. On the other hand, collaborative scenarios could for example evoke fears of being injured by the cobot [45], leading to a more negative evaluation of the acceptance factor "perceived safety". For each of the six acceptance factors, an average score between −2 and +2 is calculated based on the individual scores for all items belonging to this factor.

The assessment of the need for actions per acceptance factor is visualised by traffic lights. Red traffic lights indicate that the described circumstances pose a high risk, yellow traffic lights a medium risk and green traffic lights a comparatively low risk of severe acceptance issues with regard to the cobot introduction process in the company. This implies varying degrees of needs for action. A negative average score indicates that employee acceptance is at high risk ($-2 \leq score < 0$) and therefore results in a red light and a high need for action. An average value above one ($1 < score \leq 2$) indicates a relatively low risk of missing acceptance leading to a green light. Average values in between ($0 \leq score \leq 1$) lead to a yellow light with a medium risk for the respective acceptance factor. The uneven intervals of the assessment scale increase the probability to be confronted with a red traffic light and decrease the probability for green lights. Green lights might create the false impression that there is no need for further actions and could cause users to completely

overlook certain factors. Therefore, we decided to strive for a quite strict classification that highlights improvement potentials and raises awareness.

Users are provided with transparent information on the positive, neutral or negative influence of their answers on the assessment of the respective acceptance factor by clicking on the collapsible content element 'How did the assessment come about?' (see Figure 3).

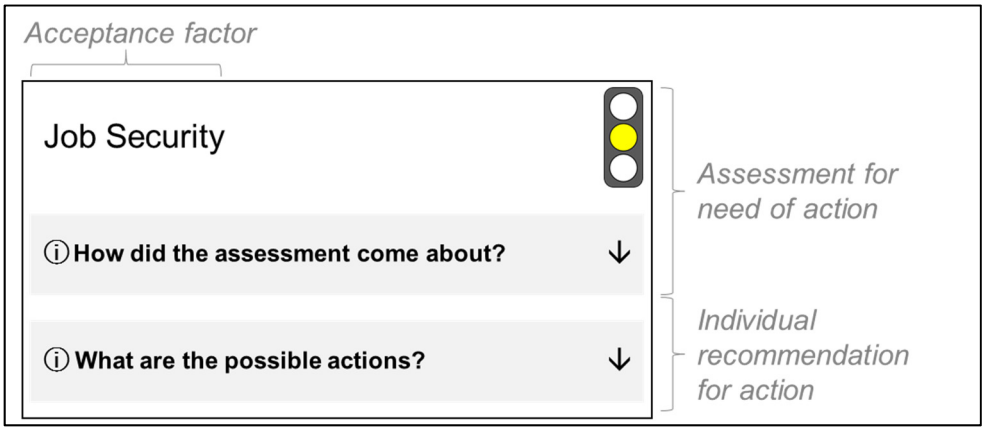

Figure 3. Example for the assessment of need for action in phase 2.

3.3. Recommendations for Action

After assessing the needs for action, the user receives recommendations on how to increase employee acceptance in the introduction process of cobots (see Figure 3). Some generic recommendations are independent of the chosen answers in phase 1. For example, within the category perceived occupational safety users are recommended to provide the employees room for experimentation with the cobot in the run-up to the actual implementation. This enables them to test the integrated safety mechanisms and to gather initial practical experience, so that anxieties are reduced and confidence in working with the cobot is enforced [5,51]. In addition, further generic recommendations suggest users to avoid being guided by stereotypes, to delegate responsibility to employees and express their appreciation towards them [55], to involve them in the introduction process, to give them enough time to settle in, and to communicate the objectives of the introduction in a timely and transparent manner [48,53,55].

All further recommendations are individually based on the entered key data. For example if the user reports relevant incidents in the company's past hindering acceptance like job cuts or industrial accidents related to automation, company representatives are encouraged to explicate the differences between cobots and previous automation solutions, as they have new integrated safety functions and are not primarily intended to replace employees [24].

By providing a transparent assessment of the risks for acceptance based on six influencing factors paired with recommendations for action, we aim at informing company representatives of SMEs about possible antecedents of acceptance within the context of cobots and to offer suitable approaches for a successful human-centred cobot implementation.

4. Evaluation of the Employee Acceptance Tool

4.1. Method

In order to assess whether the developed tool fulfils the demands of SMEs and is perceived as useful, we conducted a qualitative evaluation based on semi-structured interviews with five representatives from three German SMEs based in the state of Baden-Württemberg. Each company was particularly interested in introducing cobots within their production and belonged to a different industrial sector, namely pattern making and mould construction, metal processing and electronics, respectively. In preparation of the

interviews, a semi-structured interview guideline was developed. The topics addressed in the interview guideline were inspired by the categories of the usability norm [69], namely suitability for the task, suitability for learning, suitability for individualisation, conformity with user expectations, self-descriptiveness, controllability, and error tolerance. The interview began with an easy-to-answer introductory question, which served as an icebreaker in order to create a pleasant talking atmosphere. Leading questions were intentionally avoided. The order of questions was dynamically adapted to the course of the conversation in order to avoid interrupting the conversation flow of the interviewee and undermining his willingness to provide information.

The employee acceptance tool was supposed to be designed in a way that enables companies to use it on their own without professional guidance, even if they possess limited expertise regarding cobots and acceptance. In order to create a realistic usage scenario and foster high external validity, all interviewees were asked to use the developed tool on their own without the guidance and supervision of a researcher and afterwards take part in the interview session. They were instructed to reserve sufficient time to obtain further information within their organisation if needed. At the evening before the interview took part, all participants received a short notice via e-mail with the necessary information to access the tool. After they had finished using the tool, the involved researchers received the given answers to be able to individually prepare for the interviews and to address specific inconsistencies in the data during the interview.

All interviews have been conducted by two authors of this article using the online conference system Zoom. One researcher was responsible for conducting the interview, whilst the other researcher was primarily responsible to prepare a written record of the interview but could also take part in the conversation and ask further questions. The documentation of the interview in real-time ensured high reliability and made it possible to note the most significant and meaningful statements verbatim. After the interviews, the interview protocols were systematically analysed. The topics addressed by the questions within the semi-structured interview guideline represented the structure for analysis, so that the analytic approach can be regarded as primarily deductive. However, dependent on the statements by the interviewees we also allowed the generation of new categories from the text material, which is common practice in some qualitative approaches [70]. Like in the so-called content analysis by extraction, we focussed on what was said rather than how something was said, since we did not address highly emotional or personal topics [71]. The condensed primary material from the interviews was triangulated between the involved researches to reflect on individual perspectives and to guarantee a sufficient level of intersubjectivity [72]. The interviewees had different roles and responsibility in their companies, including department head, quality assurance, sales manager and operation manager. Hence, when interpreting their statements, their role context and the survey situation has been taken into account [73]. Each interview lasted approximately 30–45 min. In the results section, we include meaningful original statements by the interviewees in *italic* after having them translated from German language analogously.

4.2. Results

Although all company representatives agreed that acceptance is a crucial factor for successful technology adoption, they all denied having structured instruments or well-proven strategies in place to address acceptance issues. Consequently, the provided tool was a completely new approach to them to address acceptance issues in a more formal and structured way, which they considered "*generally interesting*". The companies did not see an urgent need for a specific tool, because they considered their intuition to be sufficient for introduction processes of well-known technologies, but they did acknowledge that a more structured approach could be necessary for such novel technologies like cobots. However, they also identified commonalities across the introduction of different technologies such as the employees' aversion and sceptical attitude towards unknown things, as represented in the statement: "*What you know, you also like*".

The interviewees appreciated the presentation of evaluation results via traffic lights, because this type of visualisation immediately highlighted the crucial issues and provided a good overview of the company's current state regarding employee acceptance. One interviewee considered the fact that his company did not reach green traffic lights as a sign for the high standard of the tool. He believed that the value-added would have been far smaller, if all traffic lights had been green: "*The tool is only useful, when I recognise gaps*". In this context, he stressed the importance of the provided dedicated action recommendations based on the conducted self-assessment, which leads to reflective questions such as "*Did I forget something?*" or "*Which issue do I have to reconsider and improve?*". These responses from the interviews reinforced our decision to provide rather stricter assessments with a higher probability of a red light to raise users' awareness for improvement potentials (see consideration in Section 3.2). Nevertheless, the results should be positive enough to avoid demotivation. A subsequent usage of the tool can be beneficial in the sense that it makes time-dependent change processes apparent and displays the distance-travelled towards the goal of an ideal acceptance level.

The interviewees also expressed their appreciation towards the direct linkage of the results to feasible action recommendations and the transparent presentation of which answers determined the results. The answers, results and recommendations were perceived as "*factual and issue-related*", application-oriented and well-comprehensible. Thereby, the overall design and wording fitted well the needs for rather inexperienced SMEs.

According to the interviewees' opinions, the results from the tool could be used as some kind of checklist, e.g., for a kick-off meeting of a project to introduce cobots. This would foster reflection on aspects that otherwise would not be present in the mind of the decision-makers. Some acceptance factors and the side-effects of some decisions with regard to acceptance could otherwise be easily overlooked, particularly due to the superior importance of economic aspects when it comes to a particular investment decision. In case of an expected positive return on investment from an economical viewpoint, acceptance issues could become important and soft factors like an expected increase in employee satisfaction could serve as additional rationales to justify an investment. However, experienced project leaders overestimating their soft skills might be prone to consider the tool as useless. This prompts to the ascertainment that all users must be willing to use the tool seriously and believe in the added value of tool usage. If a company representative is forced to use the tool, he/she can easily answer the questions in a way that the final assessment of the tool indicates a low level of employee acceptance. Hence, the tool can be used in a manipulative way if someone seeks to prevent a certain technology from being implemented by answering the questions accordingly.

Consequently, it was considered crucial to choose an appropriate company representative responsible for using the tool, such as the department manager, team lead or a lead worker. A strong integration into operative work and a high degree of familiarity with the needs, concerns, attitudes, and personality of the relevant workers are key criteria for suitable tool users. HR representatives, which seem to be predestined for human factors like acceptance, have not been considered as suitable candidates because they lack sufficient experience and expertise with relevant production technology. Hence, they would probably fail to anticipate the meaning of the introduction of a certain technology for the affected employees and their daily working routines. Furthermore, involving representatives of the work councils could also be a "*double-edged sword*" because they might not answer all questions objectively. Nevertheless, one interviewee highlighted that given answers are always to some extent "*hypothetical*", because they are based on "*vague intuitions*" that anticipate the behaviour of other employees. The user's knowledge of human nature and of the employees' attitudes are therefore crucial determinants of the correctness of the given answers and the corresponding recommendations for further action suggested by the tool.

Despite the perceived usefulness of the tool, the interviewees stressed that it does not come up with a definite optimal decision for a certain design opportunity, but instead accompanies and supports the process to come to a decision. Hence, the company

representatives are not prone to overrely on the tool's outcomes and recommendations, but they consider it as "*not bad as a guideline*". That is also in line with our intention to enable SMEs to assess their status quo and to make informed choices without prescribing decisions. A one-fit-for-all-approach would neglect the heterogeneity and relevance of company-specific circumstances. Accordingly, one representative said that he would only partly rely on the results of the tool, because they must be reflected against the background of company-specific circumstances.

During the interviews, an additional function of the tool became apparent, namely, to trigger discussions with employees and to stimulate reflections on whether they have been well-enough integrated into the process, which is especially beneficial at the beginning of a project. The employees of one company explicitly expressed that they would have changed their practice in a current cobot introduction process if they had had the chance to use the tool at the beginning of the process. They described that it takes the employees some time to get familiar with a certain technology and with the idea to collaboratively work with it. Additionally, due to the learning effects associated with tool usage they would have started earlier with identifying appropriate staff members for the project, with offering them adequate trainings to acquire necessary competences and with the adaption of recruitment criteria. This highlights the interlinkage between acceptance issues and more general staff-related human factors. In line with that, company representatives that had gone through the tool together stressed that joint usage stimulated relevant discussions and made concerns, possible areas of conflict, deviating assumptions and opinions apparent. Furthermore, reflecting on the most likely changes raised interest amongst workers for the project. Tool usage could hence be the starting point for the deployment of a serious participative design and implementation approach to technology introduction. Company representatives were not concerned that fears and anxieties amongst employees could be raised by explicitly addressing them on the course of tool usage or a kick-off meeting.

Regarding the usability of the tool, interviewees did not report any issues or challenges. The overall structure, the web-design, the wording, and the order of the questions was considered as straight-forward. Additionally, the handling of the survey was easy and intuitive, so that no employee did experience any difficulties to get along with the tool. No special preparation was necessary, not even for users with low technological affinity or skills.

Finally, one interviewee considered "*a very high percentage, approximately 90%*" of the questions and the logic of the presented tool to be generalisable to introduction processes of other technologies such as automated guided vehicle systems (AGV). Hence, our approach could serve as a template for similar tools and as an inspiration for SMEs to consider these issues also in terms of other introduction processes, whenever the company believes that acceptance represents a crucial issue.

Overall, the evaluation yielded a positive impression of the tool that was considered likewise useful and easy-to-use by the interviewees. The evaluation results provided us with valuable insights into the circumstances, opportunities and limitations of its usage in real-life settings within SMEs and pointed to crucial requirements for a gainful application in daily practice, e.g., with regard to users' roles within the company. We especially recognised the tool's ability to foster discussions and participative approaches as well as to raise awareness and provide knowledge transfer for important human factors that otherwise might be addressed insufficiently or even forgotten.

5. Conclusions

Technology acceptance represents an important organisational issue that gains complexity due to the increasing interaction opportunities of modern technology like cobots. These opportunities often evoke ambivalent attitudes towards robots, which can be perceived either as a welcomed device that relieves employees from undesirable work or as a possibly substituting technology which threatens employees' jobs. Company representativeness are usually aware of the importance of acceptance issues regarding the success

of technology adoption processes. However, they often lack knowledge about acceptance factors and thus fail to implement coherent and elaborated organisational approaches to foster acceptance.

Consequently, there is significant demand for low-threshold usable tools, especially to address the requirements of SMEs, which are often interested in cobot solutions, because their design fits particularly well to SMEs' production processes. However, at the same time they lack experience with regard to technology adoption processes of such complex and novel technologies. As our application demonstrates, the most important acceptance criteria can well be implemented within a web- and survey-based tool. Answering the questions forces users to reflect on the current situation in the company and on possibly arising challenges and improvement potentials on the course of forthcoming technology adoption processes. The side-effect of users acquiring relevant knowledge when using our tool, was evaluated as highly valuable, apart from the value-added by the provided analysis outcomes and the corresponding recommended actions. The implemented traffic light logic proved to be easily comprehensible, provides immediate feedback and can well be used to get an impression about the company's current situation. It thereby contributed to fulfil the special requirements of SMEs for such tools like low-threshold usage, comprehensible wording, immediate and application-oriented recommendations, and low time investment.

However, our approach is limited in a sense that the list of factors is indeed based on an extensive literature review but has not been empirically validated and thus, it cannot be ensured that the list is exhaustive and that all included factors are relevant in practice. Additionally, the evaluation of the tool's usefulness is based on a comparably small sample of five representatives from three German companies. However, involving real-life users in such a research activity requires strong involvement and buy-in from companies which represents a practical obstacle. In that sense, the evaluation results based on real users' assessments are still remarkable.

Whilst the presented employee acceptance tool represents a good example for low-threshold tools suitable for SMEs, its practical usefulness should be more extensively validated in further studies relying on a larger and more representative sample of companies that use the tool over a longer course of time in their daily business. This would increase the representativeness and external validity of the evaluation results and increase the robustness of our findings

Furthermore, future work should seek to develop further complementary approaches to disseminate research findings on technology acceptance into the daily practice of companies. Therefore, the requirements of different types of companies should be thoroughly assessed and incorporated during the implementation process of the tool. Whilst we focus on the practical needs of SMEs, it is worth exploring how they differ from the requirements of larger companies and what this means for the relevance of certain acceptance factors. The outlined approaches are particularly needed to support the introduction of complex and novel technologies that pose a challenge to SMEs but also to larger companies. Thereby, future work could help to avoid economic potentials to remain unexploited.

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Appendix A

Questions		Answering Scales			
Purpose of the cobot deployment		Increase in productivity	Increase in flexibility	Increase in workplace attractiveness	
for 'Increase in productivity'	Current trend of the order situation	Declining	Stagnating	Increasing	
Type of interaction		Cell	Coexistence	Cooperation	Collaboration
Job cuts due to automation in the past of the company		Often	Sometimes	Seldom	Never
Industrial accidents due to automation in the past of the					
Perceived safety in the planned use case	The cobot itself could be perceived dangerous.	Completely disagree	Slightly disagree	Slightly agree	Completely Agree
	The components to be handled could appear dangerous.				
	The gripping system could raise safety concerns.				
	The movements could intimidate the employee.				
Cobot takes over dangerous tasks		Yes	No		
Technical competence	Employees at the planned cobot workplace find it easy to deal with new technology.	Completely disagree	Slightly disagree	Slightly agree	Completely Agree
Enthusiasm	Employees at the planned cobot workplace are easily inspired by new technology.				
Employees' prior experience with robots at the planned cobot workplace		No prior experiences	Few prior experiences	Many prior experiences	
Age of the employees at the planned cobot workplace		Predominantly younger employees (<45 years)	Predominantly older employees (>45 years)	Mixed or not yet known	
Gender of the employees at the planned cobot workplace		Predominantly female employees	Predominantly male employees	Mixed or not yet known	
Brisance	The introduction of the cobot is highly controversial and will be discussed critically among employees.	Completely disagree	Slightly disagree	Slightly agree	Completely Agree
Management involvement	The company management is fully behind the introduction of cobot and is actively driving it forward.				
Workforce representitives	Representatives of the workforce support the introduction of cobots.				
Change in the reputation of the employees resulting		Much worse	Somewhat worse	Unchanged	Somewhat better	Much better
Changes in the working situation	Workload	Decrease	No change	Increase	
	Complexity of the work task				
	Responsibility				
Estimated attitude of the employees towards...	Increased/decreased workload	Negative	Neutral	Positive	
	Increased/decreased complexity of the work task				
	Increased/decreased responsibility				
Changes of procedures and habits at work		Completely disagree	Slightly disagree	Slightly agree	Completely Agree
Do employees themselves configure and program of the cobot?		No	Not, but they are involved	Yes	
for 'cooperation' or 'collaboration'	Aim of the design of the cobot workplace and workflow	Optimal functioning of the cobot	Optimal workflow for the employee	Weighing up both goals	
Number of different employees working with the cobot		Many employees	Some employees	One employee	

Figure A1. List of queried basic data and respective response scales.

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