Quantified Factory Worker: Designing a Worker Feedback Dashboard

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ABSTRACT
Factory work is changing towards knowledge work, demanding problem-solving skills and managing complexity. Providing factory workers the possibility to receive meaningful self-tracking feedback at work, could empower them to cope better with the increasing complexity of their work. We apply the Quantified Self approach to factory work by introducing the concept and prototype of a Worker Feedback Dashboard, which presents various automatically tracked well-being and work performance metrics to workers. Based on user interviews, we created user experience goals for the Dashboard, and identified the following design implications: *Keep positive (but truthful)*, *Give personal feedback*, *Enable reflection*, and *Do not disturb the worker*. After designing the prototype, we studied its user acceptance. Even though the interviewed factory workers' first reactions to tracking personal metrics at work were rather negative, the attitudes became more positive after presenting the prototype. The results encourage implementing the Worker Feedback Dashboard prototype to a functional application.

Author Keywords
well-being; factory workers; Quantified Self; human-centred design, Operator 4.0

ACM Classification Keywords
CCS - Human-centered computing - Human computer interaction (HCI).

INTRODUCTION
The fourth industrial revolution, enabled by advanced digitalization and other technologies, is assumed to change work on factory floor to resemble knowledge work, making the work more interesting and meaningful but also creating demands in terms of managing complexity, abstraction and problem-solving [4]. Already now, operating a highly automated manufacturing machine requires independent problem-solving skills, as a single worker may be responsible for a whole machine, and has to be able to handle problem situations quickly to avoid or minimise idle time in manufacturing.

The changing nature of factory work creates a need to receive feedback on one's performance and consider new aspects of workers' well-being. As one solution, we introduce the concept of a Worker Feedback Dashboard, which aims to empower workers by raising self-awareness of their performance and well-being. Worker Feedback Dashboard is envisioned as a personal digital application, which aggregates and presents automatically tracked personal metrics regarding work performance and well-being for each work shift as feedback to workers, and highlights improvements in personal performance. The concept of the Worker Feedback Dashboard originates from the Quantified Self approach, which promotes self-knowledge and self-improvements through numbers acquired with the help of technology, such as wearables and mobile devices. The ideology aims at providing insightful personal data, which has the potential to lead to positive behavioural changes [3].

Following the Quantified Self trend, wearing self-tracking devices for monitoring personal well-being has become increasingly common in everyday use [see e.g. 22]. Recently, the number of trials of self-tracking well-being metrics at work have also increased, but the impacts have not yet been systematically studied [2, 18]. As self-tracking at work is a relatively new concept and involves a variety of ethical issues [16, 18], it is especially important to involve the workers themselves in the development of new self-tracking solutions. In this study, we first interviewed the factory workers on their initial reactions to our concept idea, and later, we collected their feedback to the designed prototype concretizing the concept. In addition to involving users, paying attention to the user experience (UX) of work systems is important, as a way the user feels about using a system also shapes the image of oneself as a professional [9].

In this paper, the research questions are:
1) What kind of user experience should be targeted to in solutions providing meaningful self-tracking and production feedback for factory workers, and what kinds

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of design implications does the targeted user experience have?

2) What is the user acceptance of the Worker Feedback Dashboard prototype, which provides feedback of the worker's well-being and work performance in a factory context?

The targeted user experience was concretised as UX goals that were created based on the results of user studies with factory workers, discussions with our industrial partner and principles of the Quantified Self approach. They were the basis for design implications that were utilised when designing the Worker Feedback Dashboard prototype. The second research question is addressed by examining the user acceptance of the prototype by engaging factory workers and other key stakeholders in a participatory design process.

This study is a part of a wider research project (Factory2Fit) aiming to create empowering and engaging digital solutions to factory floor workers. The Worker Feedback Dashboard solution specifically aims to empower workers by providing them with new data-based information on their well-being and work performance.

The paper first presents related research and two key concepts: Quantified Self and Operator 4.0. Second, it describes our design process, methods and participants. The results define the central findings related to factory workers needs and concerns regarding the Worker Feedback Dashboard concept, list our UX goals and design implications, and introduce the prototype of the concept. In the discussion section, we highlight the practical implications and ethical questions related to the topic.

RELATED RESEARCH

Quantified Self: From Meaningful Insights to Positive Changes

The term Quantified Self refers to self-monitoring of biological, physical, behavioural, or environmental data [28]. The term became known after Gary Wolf and Kevin Kelly launched the Quantifiedself.com website for sharing self-tracking practices in 2007. The term refers to the practice and trend of self-tracking and to the international community. The website is still in active use, but the trend has expanded. An increasing number of people practice self-tracking, using commercial wearable devices. For example, around 25% of Americans own a wearable wrist device for tracking their well-being and behaviour [22]. The trend of recording personal data for gaining self-knowledge has also been described using other terms such as lifelogging [see more in 5, 27], personal informatics [15] and personal analytics [17].

Even though the Quantified Self trend has become increasingly popular during the last ten years among both consumers and workplaces, most of the studies on self-tracking have only focused on the active members of the Quantified Self community [3, 19], web forums related to self-monitoring [15] or early adopters, for example sport enthusiasts or users of several trackers [24]. Nevertheless, these studies have revealed some user experience-related aspects and usage barriers that are likely to be applicable to a wider group of users.

Based on the analysis of the video posts of quantified selfers, Choe et al. [3] found that the common pitfalls in self-tracking included tracking too many things, which led to tracking fatigue, and not tracking triggers or context, which acted as a barrier to meaningful insights. Oh and Lee [19] studied the user experience issues of self-tracking tools used by quantified selfers based on the content posted on their web forum. The identified user experience issues included the controllability and integration of the data, data accuracy, data visualisations and simplicity of user input. Li et al. [15] identified barriers related to self-tracking based on the survey and interview data of self-trackers. These data showed that the main barriers to self-tracking were lack of time, insufficient motivation and forgetting to self-track. The barriers to reflection on the data included lack of time, lack of visualisations, scattered data, and missing context information.

The studies of early adopters emphasise the need for visualisations and the data's context information. Pantzar and Ruckenstein [20] also found in their study that data visualisations made the data more meaningful for the study participants, by proving the impressions they had had before, or demonstrating non-anticipated findings. Seeing graphs was motivating and gratifying. For example, the participants felt that housework activities gained a new value because they contributed positively to the exercise and heart rate data. Data visualisations proved and supported this, evoking satisfaction and a sense of accomplishment.

The goal of the Quantified Self movement is to gain meaningful insights based on personal data, which then lead to positive changes in behaviour [3]. Recording everyday life offers 'a possibility of breaking bad habits and turning one's life for the better' [27]. The goal is the same, whether self-tracking is practised during one's free time or at work. In general, the data tracked by wearable devices have the potential to provide personalised, immediate and objective feedback [21]. According to a study by Rooksby et al. [24], the motivations for self-tracking can vary from goal-driven tracking to documentary and diagnostic tracking, or to collecting rewards or fetishised tracking. Even though the number of experiments related to self-tracking at work has expanded during the last years [18], long-lasting impacts of the trials have not been reported [2, 18].

For gaining meaningful insights and even positive behavioural changes, the design of the self-tracking devices and applications plays a critical role. In this study, we aim to design an acceptable, interesting and useful solution to self-tracking in a factory context.

Operator 4.0

The fourth industrial revolution, often referred to as Industry 4.0, is already on its way, enabled by advanced digitalisation,

the industrial internet and novel interaction tools such as augmented and virtual reality [12]. For factory floor workers the industrial change brings opportunities to make work more interesting and meaningful but also creates demands in terms of managing complexity, abstraction and problem-solving [4]. Operator 4.0 refers to smart and skilled operators of the future, who are assisted by automated systems that provide sustainable relief from physical and mental stress and let the operators utilise and develop their creative, innovative and improvisational skills without compromising production objectives [23].

Operator 4.0 factory work will be qualitatively enriched and flexible and will require new qualifications to master the digital technology invading factories. Future factories should support current workers in learning new skills as well as tempt new workers who are already familiar with digital solutions. Operators' physical, sensory and cognitive capabilities evolve over time, but these capabilities may also vary according to the work context [23]. According to Hackman and Oldham [6], one important factor influencing job motivation is keeping employees aware of how well they perform in their work. Thus, for work motivation, it would be important to receive feedback on personal performance and competence development, but in work, which is becoming increasingly automated, this kind of feedback is not readily available.

DESIGN PROCESS, METHODS AND PARTICIPANTS

Participatory Design Process

Our design process followed a human-centred design approach [8], and the principles of the participatory design process, in which users and possibly other stakeholders are involved in the design [14, 25]. The design process began by gaining an understanding of factory work, the working context and the workers' initial attitudes towards self-tracking. In addition to the factory workers, the process also involved the management of the factories in terms of their expectations, potential concerns and practical issues.

Based on the knowledge gained, we created the first version of the Worker Feedback Dashboard concept. The concept design was based on UX goals, that concretise the intended emotions or experiences that the solution is targeted to awake. Concrete, focused and shared UX goals help creating and maintaining UX mindset within the design team [9]. Kaasinen et al. [9] propose UX goals to guide the design of industrial systems. UX goal setting integrates the viewpoints of different stakeholders, thus committing them to the defined UX goals and emphasizing user experience as a strategic design decision. In our study, we defined the UX goals based on the results of the user studies, discussions with our industrial partner and principles of the Quantified Self approach. UX goals were used to concretise the targeted user experience, and they were interpreted into design implications as suggested by Roto et al. [25]. The derived design implications guided our design of the Dashboard prototype.

The user acceptance of the Worker Feedback Dashboard was studied by introducing the designed prototype to factory workers, who could express their feedback and further improvement ideas to it. After this, the prototype was revised according to the feedback.

Data Collection Methods and Participants

The first part of the study was conducted as individual factory worker interviews including several themes. The relevant theme for this paper was the workers' initial attitudes towards wearing a self-tracking fitness device and receiving well-being and performance metrics as feedback during the workday. In addition, we asked the interviewees what kind of feedback they currently receive of their work. The 1–1.5 hours of semi-structured interviews were conducted in a meeting room at the factory by two researchers; one mainly led the interview and the other made notes and posed additional questions. The interviews were audio recorded. The interviews were complemented with observations, where the researchers visited the actual workplace of the interviewees and observed their work, to obtain a contextual understanding of their tasks, work practices, the problem situations that occur, and the factory environment [see more about the context information in 10].

In this first part of the study, we interviewed altogether 13 factory workers from two factories of metal industry (referred to Factory A and Factory B). The interviewees were working in different roles: 6 as machine operators, 4 in managerial positions and 3 as development engineers. All the machine operators used a modern, highly automated, multipurpose manufacturing machine, which required problem-solving skills and managing the complex production process. The two factories were customers of our industrial partner, and this partner proposed these factories to the study. The interviewees were chosen to the interview based on their availability during our factory visits.

The involved factory workers can be seen as early representatives of the Operator 4.0 vision [23]. Even though also the managerial personnel were interviewed to gain an overall picture of the manufacturing process and factory work, the interviews of the machine operators provided the main material for the user requirements related to the concept development.

In the second part of the study, after creating the first prototype of the Worker Feedback Dashboard concept, we introduced the first draft to five machine operators of the same two factories who worked with the same machinery (one was also interviewed in the earlier theme interview). To three operators, the concept was explained as part of a wider 1.5-hour interview, and to two operators, it was elaborated in more detail in a one-hour feedback/co-design session dedicated to the concept. We also introduced the draft to a production manager and a development engineer of Factory A, where the management also wanted to participate in the design process.

The second part of the study focused on the participant's overall feelings towards the concept, their view on the relevant/irrelevant and potentially missing metrics, and their ideas for improvements. In addition, we studied user acceptance with a five-scale numeric feedback questionnaire. The questionnaire included five statements measuring 1) whether the content was easy to understand, 2) whether it is was interesting, 3) whether the data seemed personally valuable, 4) whether the appearance of the views was pleasant, and 5) whether the use of this kind of app raised any doubts. The evaluated aspects were based on the dimensions of the Technology Acceptance Model for Mobile Services (TAMM) [11]. The dimensions indicating acceptability were *ease of adoption and use* (S1), *value* (S2-3) *and trust* (S5).In addition, we had a UX question about the pleasantness of the appearance of the main view, as it is easy to evaluate already before using the solution.

In both phases of the study, the participants were emphasized that the participation is truly voluntary, and they signed the informed consent form. The personal data was treated confidentially in all research phases, and anonymised after the data collection.

Data Analysis

The data from the first interviews and observations were analysed qualitatively. To form a common understanding of the findings, two researchers first separately read through the interview data, and then jointly analysed them. The relevant pieces of data were identified and organised to form data-driven themes. The analysis of the wider interviews followed the principles of creating an affinity diagram, an analysis phase of the contextual design method [1]. The initial attitudes towards self-tracking at work and receiving feedback on it, as well as the comments on current feedback of one's work were analysed. In the second part of the study, the findings of the feedback/co-design sessions were jointly analysed by two researchers. The quantitative data of feedback questionnaires were used to complement the qualitative analysis.

RESULTS

In the following, we first describe the factory workers' initial reactions to the idea of practising self-tracking at work and receiving feedback on it. Then, we present the identified UX goals and design implications, the design of the Worker Feedback Dashboard concept, the feedback received from the factory workers, and the revisions made to the design on the basis of the feedback.

Workers' Initial Reactions towards Tracking Personal Metrics at Work

When the interviewed factory workers were introduced to the idea of self-tracking at work, they had mixed, but mainly negative initial reactions towards it. They associated the personal feedback based on self-tracking with the workplace's current measurements related to the effectiveness of their manufacturing work. In their work, performance is typically reported in negative measures, such as the number of errors or the waiting time of the machine, and thus they associated also self-tracking with receiving negative feedback. The first comment of one operator was: *'Uhh. You get enough [negative] feedback already now'.*

Despite the mainly negative first impressions, obtaining data on one's stress level at work (e.g. based on heart rate) was seen as a somewhat interesting. However, the majority did not see the value of self-monitoring for themselves, and seemed to be worried about why the data was to be collected. One of the workers pointed out that the form of the feedback is also important: *'If you are frustrated and get a notification that you need to relax, you'll get even more frustrated'.*

When the workers told about factors having an impact on their job satisfaction, the key factor seemed to be high productivity of the work, which was appreciated also by the management. The operators explained that they enjoy their work most when the machinery works without disturbances: *'The best thing is when the machine rocks'.* This provides direct feedback on the productivity of work. Even though the workers made efforts to avoid interruptions to the manufacturing process, they felt that the management did not acknowledge or appreciate their efforts. They remarked that it was not typical to receive positive feedback: *'You never get to hear thanks from others, but when you make a mistake, you hear it right away'.*

Some of the workers were in the habit of checking the statistics related to machine usage time in the reports produced of the machine flow, but these data were not interesting to all workers. It seemed that the information on the reports was more relevant for the management, as it offered an overall picture of the manufacturing and highlighted any problems. For workers, more personal and encouraging information would have more potential to be beneficial and interesting.

Designing the First Prototype of the Worker Feedback Dashboard

Based on the understanding of the factory workers' working context and their initial reactions towards self-tracking at work, we designed the first prototype of the Worker Feedback Dashboard. The ideology of Quantified Self movement and the Operator 4.0 vision were also applied in designing the prototype.

Based on the results of the user interviews, we first set the following UX goals for the Worker Feedback Dashboard.

1) *Being empowered and encouraged*. The workers felt that they did not get much positive feedback on their efforts, and were afraid that self-tracking would lead to increased negative feedback. To encourage and empower workers, the dashboard should highlight the positive changes and accomplishments of the workday. To be valuable to the workers, this feedback still needs to be truthful.
2) *Getting personal feedback.* To enable striving for positive changes in one's work practices or in factors

related to one's well-being, the feedback needs to be based on personal data. This offers the possibility to have an impact on the factors tracked and the possibility to see one's development in work tasks. Personal feedback means also that only the workers themselves can access the data, which is in accordance with the Quantified Self approach.

We also defined two additional UX goals based on the key principle of the Quantified Self approach and the nature of factory floor work.

3) *Getting meaningful insight.* According to the Quantified Self approach, meaningful insights require personal reflection on the data. Different types of data may be valuable and interesting to different users. The design should offer the possibility to combine different types of data to enable the discovery of meaningful connections and trends. The user should feel making self-discoveries by linking different types of data to each other.
4) *Being undisturbed.* The solution needs to be quickly interpreted and must not take too much time from working or distract from work tasks. This is important for any kind of work, but factory work specifically requires attentive monitoring of machinery and quick reaction to problems. This is important for both productive manufacturing as well as for ensuring safety at the factory. The user should feel being fully able to concentrate on the workflow.

The UX goals were interpreted to four design implications: 1) *Keep positive (but truthful)*, 2) *Give personal feedback*, 3) *Enable personal reflection*, and 4) *Do not disturb the worker*. In the next section, we describe how these implications influenced the design.

Overview of the First Prototype

The Worker Feedback Dashboard was designed to include both well-being and production metrics, and to provide the user with the possibility to discover connections between these, such as the relation between sleep, mood and achievements at work. The feedback is intended for the personal use of the worker, and not to be shared with management or other employees. The feedback is presented visually via various graphs and charts, and it is based on data that would be collected automatically by a commercial wearable with an open application interface, and by the manufacturing production system. Well-being data would be collected through a wearable fitness tracker used by the factory worker and the performance metrics would involve manufacturing production data that are collected inside the factory into its ERP (Enterprise Resource Planning) system.

Figure 1 shows the contents of the main view of the first prototype of the Worker Feedback Dashboard. This view presents an illustration of the data from one day or work shift, including well-being metrics, production metrics and a time series graph that presents selected well-being metrics together with certain work performance outcomes. By selecting a specific metric, the user can see its evolvement as a trend view.

The well-being metrics include parameters that can be automatically tracked by commercial wearable fitness trackers and the mood during the work day, as a self-reported measure. The mood information was included to enable a general evaluation of the user's feelings and to encourage users engage with the Dashboard. Step count at work, sleep duration of the previous sleeping period and the resting heart rate for the day were selected as other well-being metrics to be shown in the Dashboard.

The production metrics selected include the machine running time (utilisation rate of the machine), the longest continuous running period during the work shift, the recovery time after failures (the time taken to resolve the error situation), and achievements (number of finished orders and manufactured parts) during the shift. The time series graph shows the state of the machine (running, idle/waiting or failure) together with the data on the user's heart rate and steps. We selected these production metrics as they mirror the importance of the manufacturing without interruptions and quick solving of problems, which are the key objectives of the operators.

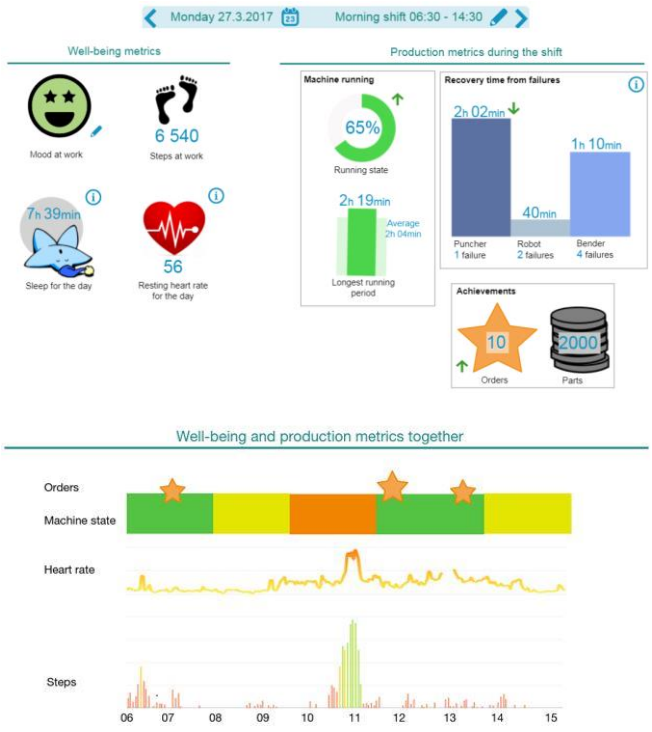

Figure 1. Main view of the first prototype of Worker Feedback Dashboard.

The design implications influenced the design in the following way:

1) *Keep positive (but truthful).* The production metrics of the work are designed to highlight the positive aspects and achievements of the workday. Instead of the

machine idle time or the number or duration of failures, the data highlights the periods of fluent work. The number of finished orders and manufactured parts may enhance the worker's feeling of achievement. The positive development of the metrics is indicated to the user with small arrows besides the metric.

2) *Give personal feedback.* The feedback is intended to be such that the workers can have an impact on it, and see their development related to their work tasks. Thus, it demonstrates the development in one's work competence. The feedback may also include more sensitive well-being related data, as they are not accessible by the employer or managers. Still, the employees will be offered a possibility to select which data is shown in the Dashboard and exclude data that they find too sensitive or irrelevant.
3) *Enable personal reflection.* The Dashboard shows the selected data and highlights positive accomplishments, but the user needs to discover the personally relevant relations between the metrics. After longer use of the Dashboard, the trend data (not visible in the main view) supports finding meaningful relationships related to one's behaviour and the metrics. In addition to automatically collected data, self-reporting of one's mood may drive the user to think about one's overall feelings at least once a day, and thus foster personal reflection.
4) *Do not disturb the worker.* The daily data are shown in the main view in such a way that they can be interpreted quickly. The idea is that the worker checks the data after or at the end of each work shift, or alternatively, during breaks at work. The first version shows only the summary of data, and does not give any real-time notifications of the user's state or the machine that could disturb the worker. If the worker wants to explore the data in more detail, it can be done via any device whenever the user wants, as the Dashboard is intended to be accessible as a web service.

Feedback and Revisions to the First Prototype

When the first prototype of the Worker Feedback Dashboard was introduced to the factory workers, most of them perceived the idea of wearing a self-monitoring device and receiving feedback through the dashboard rather positively. Four of the five interviewed workers perceived the concept as at least somewhat interesting, especially the data related to heart rate and step count. One interviewee was more critical towards the idea and claimed that it is *'everyone's own business how they live, sleep and eat'*, and not the employer's. This may have related to a desire to keep work and free time apart. Even if it was emphasized that the measures are for the worker's personal use only, he seemed to have an impression that the data was accessible for the employer. This emphasized the need to ensure data protection and communicate it to the users clearly. The users should have a true freedom to choose not to participate in self-tracking and if possible, to select which metrics are tracked. Even though the reactions were not solely positive, the first impressions were clearly more favourable than in the first round of interviews.

In the co-design/feedback sessions, the factory workers highlighted which parameters they regarded as the most and least interesting. Of the well-being parameters, the participants were interested in the data related to their heart rate and step count. These users did not perceive the data on sleep and mood as very interesting, as they felt that it offered no new information. Especially, self-reporting of mood information was not seen as being worth the effort.

Of the production parameters, the participants perceived the machine operating time as the most relevant, as this was the most important parameter in production in these factories. The time for recovering from errors was also seen as interesting, as the current production reports did not directly give this parameter. The number of produced orders and items were not considered very relevant, as the workers felt they could not personally influence these metrics. The workers at Factory A also discussed the possibility of including the utilisation percentage of the metal sheets in the production metrics, as the production manager followed this. However, it was not a personally relevant metric for the workers, as the utilisation percentage realised during one's work shift was often determined during the previous work shift by a fellow worker. The production manager also highlighted that including this parameter on the Dashboard might encourage workers to prioritise this issue over the machine running time, which should not happen.

According to the numerical feedback (Table 1), the factory workers perceived the Dashboard prototype rather positively. The content was considered easy to understand and relatively interesting, and most of the respondents regarded it as personally valuable. The question of whether the use of this kind of solution raised doubts produced mixed responses: two of the five respondents had no doubts about the usage, but three saw its use as not completely indubious.

Feedback item	Evaluation median	Range of evaluations
Dashboard concept in general	4	3-4
Clarity of content	5	4-5
Interestingness of content	4	3-4
Perceived value of content	4	2-5
No doubts about usage	3	2-5
Pleasantness of appearance	4	3-5

Table 1. Numeric feedback regarding the user acceptance of the Dashboard prototype provided by five factory workers. Evaluation scale: from 1 = negative to 5 = positive.

Based on the interviews, the idea of the dashboard seemed promising, and we identified no need for major changes in

the design. However, as the self-reported mood information was not considered interesting, we decided to change the question related to the user's mood to a question on their attention ('How effortless did concentrating on your work tasks feel today?', see Figure 2). In the factory work context, the workers' perceived attention may be a relevant parameter to follow, and the users may find reflection on the sleep data, for example, interesting. Even though sleep data was not felt specifically interesting, we decided to include it in the design, as the personal value of it may be revealed later when linking it to other data. Furthermore, as working in a night shift is typical in factory work, the sleep information may prove to be interesting.

Figure 2. Revised view of well-being metrics.

Four of the five interviewees were interested in testing the Worker Feedback Dashboard as part of their daily work if they had the opportunity to participate. In Factory A, the production management was also willing to participate in the pilot. In Factory B, the management was not willing to participate, as the manufacturing work had urgent problems that the company needed to solve before undertaking new development projects.

DISCUSSION

This study explored the user acceptance of the Worker Feedback Dashboard concept in a factory context. Through a participatory design process, we first created UX goals and design implications and then the design solutions for the concept. The idea of the Worker Feedback Dashboard is in line with the Quantified Self trend, as it provides data-based feedback to factory workers to increase their awareness of the issues that influence their work performance and well-being. The study contributes to the existing literature by increasing the understanding of the acceptability of self-tracking at work, especially in a factory floor environment. As many studies have focused on the early adopters and active members of Quantified Self community [3, 15, 19, 24], it is important to extend the understanding to less tech-savvy users and employees who are offered the opportunity of self-tracking without being familiar with the idea in advance. Operator 4.0 factory work [23] offers an interesting context for applying quantification data, as it is assumed that the work of factory operators will involve an increasing number of problem-solving situations and complexity in the future.

Our first research question aimed to identify the UX goals and design implications for a concept that provides meaningful self-tracking and production feedback to factory workers. Based on the user and context requirements as well as the Quantified Self trend, we ended up in four key design implications. The first, *Keep positive (but truthful)* highlights the importance of positive feedback. The second design implication, *Give personal feedback*, emphasises the opportunity to offer personal feedback, and thus enable workers to see their development at work. The third implication, *Enable reflection*, refers to providing an opportunity for the user to find the personally meaningful connections of the data. Finally, the fourth implication, *Do not disturb the worker*, reminds us of the factory work context, in which it is important that the technical solution does not distract the worker from actual work tasks. These design implications complement the current understanding of important user experience issues related to self-tracking, such as the benefit of visualisations [15, 19] and context information [3, 15], which foster obtaining meaningful insight of the data.

The second research question focused on the user acceptance of the Worker Feedback Dashboard. During the design process, the factory workers first perceived the idea of measuring workers negatively, but this perception became more positive when they could see the actual design and the purpose and content of the concept. There may be several reasons for this. Generally, it is often easier to accept less ambiguous and more concrete ideas, and engaging with the idea may make it more acceptable. However, the result also indicates that the design solutions as such were perceived as acceptable, and the workers also regarded most of the features of the concept as interesting and valuable for themselves.

Despite the rather positive feedback, not all the study participants considered using the Worker Feedback Dashboard as completely indubious. As the topic of personal measurements at the workplace is a sensitive one, the ethical aspects will be considered in the design and evaluation of the solution throughout the research project. We will use the proactive Ethics by Design approach [7, 13] to create an ethically sustainable solution. In addition, the ethical issues and the expected impacts of the solution will be discussed with the ethical advisory board of the project.

This study provides an initial understanding of the acceptability of self-tracking concepts in a factory context. In our research project, we will further develop the concept using the identified design implications, to create a prototype with the key features. The usage of the prototype will be studied in a study with approximately twenty machine operators in several factories including Factory A of this study. When recruiting the study participants, we will pay

specific attention to the ethical issues, such as the true voluntariness of participation and protecting the privacy of the user data.

The limitations of this study derive from its explorative and initial nature and the small number of participants. However, we expect the qualitative data of the thoughts of the factory workers, the identified design implications and the suggested design solutions to provide value to the HCI (human-computer interaction) community. Even though this study focuses on factory work, the design implications and a part of the design solutions are applicable to other occupations as well. As the quantification of the workers is a new and significant topic, we hope that in the future, other studies will also focus on the ethical aspects, design alternatives and user perspective of this subject.

CONCLUSION

This study sheds light on the acceptability of a concept for providing personal production and self-tracking feedback to factory floor workers. The results encourage implementing the introduced Worker Feedback Dashboard prototype to a functional application. In broader scope, the results encourage the design of self-tracking systems for workers and involving workers in the design process. We hope that the identified UX goals and design implications provide useful guidance for practitioners and inspire the HCI community members working on the area of quantification or self-tracking at workplaces.

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REFERENCES

1. Hugh Beyer and Karen Holtzblatt. 1997. *Contextual design: defining customer-centered systems*. Elsevier.
2. Kathryn Buchanan and Dan Lockton. 2015. Understanding human connectivity and the Quantified Self. *Working Papers of the Sustainable Society Network+*.
3. Eun K. Choe, Nicole B. Lee, Bongshin Lee, Wanda Pratt, and Julie A. Kientz. 2014. Understanding quantified-selfers' practices in collecting and exploring personal data. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*, 1143-1152.
4. Dominic Gorecky, Mathias Schmitt, Matthias Loskyll, and Detlef Zühlke. 2014. Human-machine-interaction in the industry 4.0 era. In *Industrial Informatics (INDIN), 2014 12th IEEE International Conference on Industrial Informatics (INDIN)*, IEEE, 289-294.
5. Cathal Gurrin, Alan F. Smeaton, and Aiden R. Doherty. 2014. Lifelogging: Personal big data. *Foundations and Trends® in Information Retrieval* 8, 1: 1-125.
6. Richard J. Hackman and Greg R. Oldham. 1975. Development of the job diagnostic survey. *Journal of Applied psychology* 60, 2: 159.
7. Veikko Ikonen, Eija Kaasinen, and Marketta Niemelä. 2009. Defining Ethical Guidelines for Ambient Intelligence Applications on a Mobile Phone. *Intelligent Environments (Workshops)*, 261-268.
8. ISO 9241-210: 2010. Ergonomics of human system interaction-Part 210: Human-centred design for interactive systems. *International Standardization Organization (ISO).* Switzerland.
9. Eija Kaasinen, Virpi Roto, Jaakko Hakulinen, Tomi Heimonen, Jussi PP Jokinen, Hannu Karvonen, Tuuli Keskinen et al. 2015. Defining user experience goals to guide the design of industrial systems. *Behaviour & Information Technology* 34, 10: 976-991.
10. Eija Kaasinen, Franziska Schmalfuß, Cemalettin Özturk, Susanna Aromaa, Menouer Boubekeuer, Juhani Heilala, Päivi Heikkilä, Timo Kuula et al. 2018. Empowering industrial workers with engaging factory adaptation solutions. Submitted to *Computers & Industrial Engineering*.
11. Eija Kaasinen. 2009. User Acceptance of Mobile Services. *International Journal of Mobile Human Computer Interaction* 1, 1: 79–97.
12. Henning Kagermann, Wolfgang Wahlster, and Johannes Helbig. 2013. Securing the future of German manufacturing industry. *Recommendations for implementing the strategic initiative INDUSTRIE 4.0*, final report of the Industrie 4.0 Working Group, Forschungsunion.
13. Eleni Kosta, Olli Pitkänen, Marketta Niemelä, and Eija Kaasinen. 2010. Mobile-centric ambient intelligence in health- and homecare-anticipating ethical and legal challenges. *Science and Engineering Ethics* 16, 2: 303-323.
14. Sarah Kuhn and Michael J. Muller. 1993. Participatory design. *Communications of the ACM 36, 6*: 24-29.
15. Ian Li, Anind Dey, and Jodi Forlizzi. 2010. A stage-based model of personal informatics systems. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 557-566.
16. Deborah Lupton. 2016. The diverse domains of quantified selves: self-tracking modes and dataveillance. *Economy and Society* 45, 1: 101-122.
17. MIT Technology Review: Stephen Wolfram on Personal Analytics. Retrieved June 19, 2017 from https://www.technologyreview.com/s/514356/stephen-wolfram-on-personal-analytics/

18. Veronica P. Moore, and Lukasz Piwek. 2016. Regulating well-being in the brave new quantified workplace. *Employee Relations* 39, 3: 308-316.

19. Jeungmin Oh and Uichin Lee. 2015. Exploring UX issues in Quantified Self technologies. *Eighth International Conference on Mobile Computing and Ubiquitous Networking (ICMU)*, 53-59. IEEE.

20. Mika Pantzar and Minna Ruckenstein. 2015. The heart of everyday analytics: emotional, material and practical extensions in self-tracking market. *Consumption Markets & Culture* 18, 1: 92-109.

21. Lukasz Piwek, David A. Ellis, Sally Andrews, and Adam Joinson. 2016. The rise of consumer health wearables: promises and barriers. *PLoS Medicine* 13, 2: 1-9.

22. Rock Health. 2016. Digital Health Consumer Adoption: Report, December, 2016. https://rockhealth.com/reports/digital-health-consumer-adoption-2016/

23. David Romero, Peter Bernus, Ovidiu Noran, Johan Stahre, and Åsa Fast-Berglund. 2016. The Operator 4.0: human cyber-physical systems & adaptive automation towards human-automation symbiosis work systems. *IFIP International Conference on Advances in Production Management Systems*, 677-686. Springer, Cham.

24. John Rooksby, Mattias Rost, Alistair Morrison, and Matthew Chalmers. 2014. Personal tracking as lived informatics. *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*, 1163-1172.

25. Virpi Roto, Eija Kaasinen, Tomi Heimonen, Hannu Karvonen, Jussi PP Jokinen, Petri Mannonen, Hannu Nousu et al. 2017. Utilizing Experience Goals in Design of Industrial Systems. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 6993-7004. ACM.

26. Douglas Schuler and Aki Namioka. eds. 1993. *Participatory design: Principles and practices*. CRC Press.

27. Stefan Selke, ed. 2016. *Lifelogging: Digital self-tracking and Lifelogging-between disruptive technology and cultural transformation*. Springer.

28. Melanie Swan. 2013. The quantified self: fundamental disruption in big data science and biological discovery. *Big Data* 1, 2: 85-99.