Roadmap for UX in future operational train traffic control

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Abstract: In this paper, we promote and motivate research on user experience (UX) in the domain of rail, more specifically for the workers engaged in the daily operational parts of executing train traffic. UX aspects have often been overlooked in the design and use of technology within the workplace, particularly in safety-critical work domains. Here, we provide an overview of current UX research at work and outline a roadmap with seven facets for future research within the domain of operational train traffic that is in alignment with the need for further investigation into UX at work. We hope future research will contribute to a deeper understanding of how positive experience at work provides additional means of enhancing engagement and improving safety management in workplaces in general and for the work in operational train traffic specifically.

Keywords: rail research; operational train traffic; control room; traffic control; train driver; safety-critical system; user experience; UX; work environment; socio-technical systems; engagement; meaningful technology.

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1   Introduction

It has been argued that rail is the forgotten branch of transport research (Wilson and Norris, 2006). However, the interest in studying and addressing rail human factors is rising as the task to plan and execute the net of traffic is becoming increasingly complex due to passenger and goods transportation constantly increasing, resulting in more trains running in the same envelope of time. The railway infrastructure has developed gradually over hundreds of years, but it is more recently that the challenges posed by the technical and organisational requirements in the rail industry have received increased research interest. This strand of research has focused mainly on parameters of optimisation, efficiency, and resilience and has brought task analysis and investigations of human reliability and human error into the rail domain, which nowadays has been questioned (e.g., Cort, 2021, Naweed, 2020; Wilson et al., 2012). The prevailing orientation towards human factors and cognitive ergonomics within the safety-critical domain of rail, such as supporting traffic controllers' rapid decision-making processes in the development of technical systems for enabling efficient planning and problem-solving (Andersson et al., 1998, Cort, 2021, Kauppi et al., 2006, Sandblad et al., 1997), is well justified and critically important. However, the ergonomics and human factors fields are not yet well-aligned with more modern understandings of technology interaction (Grundgeiger et al., 2021, Savioja et al., 2014). This has resulted in the neglect of user experience (UX) aspects when designing and interacting with various kinds of technology in the workplace (Simsek Caglar et al., 2022). UX has no general and commonly accepted definition and is, for example, characterised by Hassenzahl as: 'a momentary, primarily evaluative feeling (good-bad) while interacting with a product or service.' [Hassenzahl, (2008), p.12]. Another definition of UX states that it encompasses the 'user's perceptions and responses that result from the use and/or anticipated use of a system, product or service' (ISO 9241-210:2019). Moreover, Hassenzahl and Tractinsky (2006) stress three main factors that make up UX:

1   the internal states of the user

2   the designed product/systems characteristics, such as its purpose, complexity, and usability

3   the context for the interaction.

Hence, three main factors influence the UX: the system/product/service, the user, and the context of use. Being aware of these factors allows designing for a positive UX. Following the above ISO definition, UX includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours and accomplishments that occur before, during, and after use of a system or product.

It has been shown that experiences from leisure and work contexts are dissimilar in regard to the technology used, the activities in which they are used, and the social context (Clemmensen et al., 2020; Tuch et al., 2016). There are differences also when it comes to psychological needs and, for example, competence and security are to a higher degree connected to work experiences than pleasure and relatedness, which are more associated with leisure experiences (Tuch et al., 2016). Further, the digital tools of consumer products and services are mostly standalone products, which stands in stark contrast to UX at work that is shaped by the analogue and digital tools and policies of the work setting. The workspace usually includes multiple digital tools within the work structure and the distributed workflows and tasks, in which there is a need to focus more on the organisational culture, division of labour, rules and policies, managerial hierarchies and norms of interacting and expressing emotions and needs (Clemmensen et al., 2020; Tuch et al., 2016). The social context in leisure is usually a friend, relative, or partner, whereas in the work context, it could be a colleague, a customer, a client or a patient. In work contexts, UX aspects have been, and still are, neglected and it has recently been pointed out by several authors that this neglect is especially pronounced in safety-critical domains (Gramlich et al., 2022, Grundgeiger et al., 2021, Hohm et al., 2022, Laschke et al., 2020). There are several reasons for this and we list some of them below:

- There is a common belief that UX is only associated with seeking pleasure, fun, and stimulation when interacting with consumer products and applications (Simsek Caglar et al., 2022) and other conceptual aspects of UX, such as seeking competence, self-actualisation, and growth, are neglected or misunderstood.

- The concept of 'experience' commonly equates to something akin to a 'number of years of service' rather than the fulfilment of emotional and psychological needs (Hassenzahl and Roto, 2007).

- UX is commonly considered to be an umbrella term without a clear definition (Roto et al., 2011, Simsek Caglar et al., 2022) rather than a defined concept with work-related dimensions (Simsek Caglar et al., 2022).

It has been stressed that the consideration and improvement of positive UX for professional workers is well-aligned with the fundamental aims of standards on human factors and human-computer interaction (HCI) (Grundgeiger et al., 2021). Hence, it is not enough to ensure pragmatic qualities such as error reduction, effective performance, and reduced cognitive load. To maintain safe and high-quality operations over time, much more attention needs to be given to hedonic and eudaimonic qualities and needs in professional work (Hohm et al., 2022, Grundgeiger et al., 2021). Hedonic qualities

address the users' emotional and psychological needs and eudaimonic qualities concern life goals such as authenticity, meaning and personal growth, which are qualitatively different from the more commonly addressed aspects of satisfaction and acceptance of technology (Hassenzahl and Roto, 2007). Lately, Stephanidis et al. (2019) addressed that future and more omnipresent and persuasive technology also can be a means to promote psychological well-being through the fulfilment of one's personal life goals, i.e., eudaimonia, which exceeds the more traditional usability and UX aspects. These are UX qualities that are essential for preserving and augmenting the aspects of work that keep professionals fully engaged in their activities. Consequently, the concepts of 'well-being, health, and eudaimonia' have recently been articulated as one of the seven grand challenges in HCI (Hohm et al., 2022; Stephanidis et al., 2019), thereby suggesting increased attention to UX and related phenomena. Alarming Gallup reports point to tremendous problems with employees' work engagement worldwide, which implies an urgent need to focus on UX at work. Negative work-related emotions peaked in 2020, causing enormous losses for the global economy due to low work engagement in 2022 (Gallup, 2021, 2022). Although UX at work is only one aspect of work engagement, it is currently one of the least explored (Palanque et al., 2019; Roto et al., 2018, 2019).

This paper aims to describe and suggest future perspectives on incorporating UX in rail research, more specifically in the operational parts of the daily work of planning and executing train traffic control. We have extensive experience in our research group conducting research on the work practices involved in operational train traffic, as well as the work activities, tasks, and tools used in this domain throughout the years (e.g., Andersson et al., 1997; 1998; Andreasson et al., 2019; Axelsson and Jansson, 2022; Cort, 2020, 2021; Kauppi et al., 2006; Sandblad et al., 1997, 2010; Tschirner et al., 2013, 2014). To the best of our knowledge, UX has received very limited attention in rail research, both in theory and practice. It is from our previous experiences within this setting of work that we in this paper will describe and motivate the relevance to consider UX aspects in rail research. We acknowledge that this kind of research is currently in its infancy due to a lack of both studies and real-world cases to further explore the opportunities and challenges of various aspects of UX at work in such a safety-critical domain as operational train traffic.

Below, we present a background and some examples of relevant research on UX at work, particularly in safety-critical domains, an introduction to the domain of Swedish operational train traffic, and then outline a roadmap for the future of UX research within operational train traffic. We end with some concluding remarks. We focus on the professional roles of train drivers and the personnel in the traffic control room, primarily the traffic controllers and information officers, since these roles are at the very core of keeping the traffic running.

The contribution of this paper is twofold: Firstly, the paper presents prior research on UX at work in safety-critical domains, which serves as a foundation for providing insights into how future operational train traffic can be investigated and analysed from a UX perspective. Secondly, the roadmap addresses research gaps of UX at work, specifically in rail research, by providing seven facets of research and some initial suggestions on how these challenges could be studied empirically and theoretically to promote positive experiences and engagement at work for professional workers in the safety-critical domain of operational train traffic.

2   Prior UX at work research

Although research about UX at work is scarce, the studies that do exist indicate a complicated nature and they might challenge existing assumptions about what positive UX is (Simsek Caglar et al., 2022). Inspired by Grundgeiger et al. (2021), we present a focused selection of some examples that promote (positive) UX at work, especially in safety-critical domains.

There are several motivations for considering UX in safety-critical domains (Grundgeiger et al., 2021). First, it is argued that UX at work is a key characteristic of workers' ordinary usage of various tools and technical systems in the workplace. Therefore, it is of crucial importance that UX at work is well researched, especially considering aspects that characterise the ordinary and mundane of UX at work, and not only the extraordinary or critical situations (Clemmensen et al., 2020; Grundgeiger et al., 2021). Clemmensen et al. (2020) highlighted that although workplace studies were so dominant back in the 1990s, there is an identified need to take a closer look at both digital and analogue tools in the workplace of the future by incorporating UX at work. Similar lines of argument are presented by Grundgeiger et al. (2021) who emphasised that interaction per se entails an ongoing experience, implying that interaction with technology always has an associated UX, which is ubiquitously present whether or not it is explicitly addressed by researchers or designers (see also Hassenzahl and Tractinsky, 2006; McCarthy and Wright, 2005). This stance has several consequences. On the one hand, by acknowledging that technology usage always has an associated UX, it is not too surprising that UX is nowadays included in the ISO 9241-210 (2019) on Human-centred design for interactive systems. On the other hand, it should also be mentioned that the UX does not only occur during the interaction as it is ongoing. There is also an additional need to consider the periods before, during, and after the technology usage (Hassenzahl and Tractinsky, 2006; Roto et al., 2011). These time spans are dynamic and can vary depending on the situation and it is therefore vital to consider that several work tasks may be conducted at different timeframes, with varying frequencies, and with different tools.

Second, it is argued that more is known about usability and UX professionals in the literature than about UX in work contexts (Clemmensen et al., 2020; Simsek Caglar et al., 2022). It is highlighted that specific work domains are approached and discussed as mere 'application domains', rather than addressing the *unique UX characteristics and challenges in the actual work domain for professional workers of various skill levels*. Some positive examples exist, however, with various recent studies of UX in the industry context that have identified and shown several indicators and examples of hedonic qualities of technology usage (Clemmensen et al., 2020; Savioja et al., 2014). Savioja et al. (2014) studied UX aspects of the tool transformation process from an analogue to a digital one in the control room of a nuclear power plant. They developed five positive UX indicators, five psychological experience indicators, and five communicative experience indicators (Savioja et al., 2014). It was found that UX worked well as an indicator for the quality in use by its ability to reveal the professional users' experiences. Beyond developing more general UX goals, it is suggested that the 'do-goals' and the 'be-goals' (Hassenzahl and Roto, 2007) are central for UX at work, as exemplified in recent work on good UX for greenhouse workers (Clemmensen et al., 2020). They noticed greenhouse workers using a digitalised system may experience pragmatic product qualities when the system can assist certain 'do-goals', like the task of checking the temperature in a subsection of the greenhouse. They may also experience hedonic

product qualities when the system can assist certain 'be-goals', and enhanced professional identity, like being viewed as 'competent' by their colleagues for accurately mastering the climate-management system. Hohm et al. (2023) investigated and analysed technology usage in practice in acute care teams, focusing particularly on anaesthesiologists' positive and negative experiences with several kinds of technology. Their reflexive thematic analysis revealed four themes, which were divided into the roles of desirable and avoidable technology. The themes 'technology as problem solver and safety net' as well as 'technology as artificial limb' were considered as the desirable ones. On the contrary, the themes 'technology as necessary (evil)' and 'technology as second patient' were considered as the ones to avoid. They highlighted that both kinds of experiences should be examined carefully, and they emphasised that paying attention to these experiences may avoid technology from becoming necessarily evil, and instead provide support for a more successful interchange between users and technology in safety-critical domains.

Third, it has been argued that focusing on *UX at work contributes to the design of better technology in the workplace*. Designing for positive UX in work contexts has roots in prior research of workers' experiences in the workplace, like user satisfaction. Already when digitalised tools began to be frequently introduced in the workplace, it was revealed that workers often experienced frustration, which sometimes correlated with loss of time and decreased task performance (Clemmensen et al., 2020). During the development of digital tools, workers' domain competence, work experience, and tacit knowledge contribute to assessing the envisioned new tool's potential and efficiency to promote positive UX (Savioja et al., 2014). Zumburch et al. (2020) studied the development of clinical decision support systems (CDSS) for the administration of intravenous fluids (volume therapy) in intensive care units. They investigated what kind of work activities the nurses perceived as being beneficial for their well-being at work (Zumburch et al., 2020). These findings provided the basis for designing positive UX through the envisioned CDSS, with the purpose to fulfil the needs for experiencing competence and popularity at work. Recently, Gramlich et al. (2022) applied a UX-centred approach to the design of future tangible input and output devices for air traffic controllers. Based on the air traffic controllers' need for haptic feedback, several tangible interaction concepts were created, iterated and evaluated by air traffic controllers. Based on their findings, three main positive dimensions emerged that promoted positive UX at work, such as 'familiarity', 'efficiency', and 'engagement'. Klüber et al. (2020) investigated how psychological needs and embodied theories of UX, applied in the design of a CDSS, could reduce prior negative problems when using these tools for anaesthetic teams in the operation room. They iteratively developed a prototype of a CDSS to assist anaesthetics teams in crises, predominantly focusing on psychological needs and fluent interaction within the socio-technical system. A pilot evaluation via a medical simulation of handling a crisis as a team revealed that the prototype almost supported the fulfilment of the identified needs for 'autonomy', 'competence', and 'relatedness'. The prototype seemed to be mostly smoothly integrated into existing diagnostic practices (Klüber et al., 2020). Laschke et al. (2020) described how medical technologies are of relevance to radiologists' well-being at work. Instead of focusing merely on technology-related parameters like image quality, it was revealed via a case study that the functionalities of the advanced image technology could be designed more holistically to cultivate their well-being. By identifying current work practices that were experienced as especially beneficial, several insights were extracted that were transformed into future ideal

technology-mediated work practices. It was demonstrated how radiologists worked towards improving well-being through the development of meaningful technology, implying that technology is not neutral in itself; its features affect the design of meaningful technology-mediated practices, which has a positive impact on well-being (Laschke et al., 2020).

Fourth, it is argued that *UX can support contemporary safety management in the workplace* (Grundgeiger et al., 2021). Workers in safety-critical domains express that the complexity of their work tasks results in them rarely being performed flawlessly but rather with several imperfections as a response to the dynamic nature of their work, entailing constant changes and unforeseen situations (Cort, 2021). Hollnagel et al. (2015) distinguished between Safety-I and Safety-II. In Safety-I, the focus is on achieving a state in which few errors occur. Professional workers can perceive and identify hazards, and manage the associated problems by properly eliminating causes and minimising errors (Hollnagel, 2015). Cognitive ergonomics approaches provide necessary and valuable methods to improve Safety-I (Grundgeiger et al., 2021; Savioja et al., 2014). However, modern socio-technical systems are often too complex and varied to easily identify safe courses of action in the web of hazards, which led to Safety-II. In Safety-II, the aim is to ensure that as many things as possible go right and that workers are not considered hazards but rather resources that enable the sociotechnical system to adapt to varying conditions (Hollnagel, 2015). Based on Safety-II, professional workers need to be supported to deal with varying conditions, instead of focusing on error reduction. Recent advances in UX can contribute to Safety-II by considering eudaimonic qualities (Grundgeiger et al., 2021; Hohm et al., 2022), and by cultivating workers' potential through hedonic experiences of feeling competent, efficient, related, and in control (Gramlich et al., 2022; Klüber et al., 2020; Laschke et al., 2020; Savioja et al., 2014; Zumburch et al., 2020). Huber et al. (2020) studied the changes in work practices when the paper flight strips used for presenting information to, and documentation by, air traffic controllers were transformed into digital strips in an effort to increase capacity and safety in aviation. Documentation speed was generally found to be faster with digital strips, but the controllers still perceived a lot of tacit information from the radio communication, which was combined with additional hints to make empathic decisions that occasionally were outside the standard procedure. Two types of operation modes, called 'standard advocates' and 'tinkerers' were identified. It was revealed that tinkerers experienced work satisfaction when 'aircraft in the final line up like pearls on a necklace', another controller said that he felt happy when he left work and saw a 'perfect final in the sky' (ibid. p. 28). Several studies from healthcare have reported that staff preferably is a resource that contributes to bridging the gap if a particular tool fails to assist certain work tasks (Grundgeiger et al., 2021; Hohm et al., 2022). Staff who experience competence in technology-mediated work seem to be better equipped to handle this gap, enabling them to keep processes running, and simultaneously maintaining safety.

Fifth, it is argued that *UX can contribute to organisational development beyond the individual*. The tools provided for professional workers are often mandatory in the organisation or company (Clemmensen et al., 2020), putting greater demands on technology to promote positive UX. Apart from being humanistic, hedonic qualities also have instrumental value. Wright et al. (2007) reported a strong correlation between psychological well-being and job performance, showing that job satisfaction alone is not sufficient for efficient performance. Psychological well-being is strongly connected with

the psychological needs that are commonly applied in UX, i.e., autonomy, competence, and relatedness (Ryan and Deci, 2000). The hedonic qualities are aligned with issues of the workers' acquired work-domain knowledge, computer proficiency, and their experiences of credibility and trust in the work tools used for supporting their decisions. Clemmensen et al. (2020) pointed out that workers may ask how adequate the underlying algorithms and models in the tools are, how transparent the suggestions made by the systems are, and what possible courses of action are provided by the system for colleagues with varying experiences and work-domain knowledge. Lundström and Lindblom (2018) studied the use of an agricultural decision-support system for the calculation of variable rate application files for nitrogen fertilisation from satellite images. The farmers and their advisors initially questioned whether they could trust the suggested nitrogen levels, although the images of the fields mostly corresponded to their understanding of the crop's condition. Farmers used the tool's visualisations to explore various scenarios and perceived them as interesting and amusing. Instead of arguing that they spent time 'playing around', their actions may have additional benefits like facilitating their decision-making and learning more about the fields, which in the long run may contribute to increased sustainability. This demonstrates the associations between how actions are carried out for pragmatic purposes, which then is embedded in the larger web of agricultural work practices, producing more food with less fertilisation, and hence caring for the land from a eudaimonia perspective. Laschke et al. (2020) revealed that medical technology provides some surprising, but added value to managers and other stakeholders, like improved quality of reports, employee retention, and increased attractiveness. Their study demonstrates the possibility for UX goals and business goals to be well-aligned to cultivate positive experiences, by implementing technology designed in a user-centred way. Similar thoughts are expressed by Clemmensen et al. (2020) and Savioja et al. (2014) who emphasised that work tasks encompass several experience dimensions simultaneously, ranging from the appropriate psychological experience of competence, engagement, and trust, to the shared related experience of being part of a community of practice.

3 Swedish operational train traffic

The way that railway traffic is organised and controlled differs considerably between countries, which is mainly due to history and the way the railway system has grown during the years (Tschirner et al., 2014). Organisations have developed differently across countries leading to large variations in safety systems, infrastructure, as well as equipment such as signal boxes, which can differ tremendously between countries (e.g., Golightly et al. 2013; Schipper and Gerrits, 2018). Our research covers the organisation of operational train traffic in the Swedish context, which include train traffic control, train driving, customer information, operational planning at railway undertakings and conduction of maintenance work. In this paper, we will focus in particular on the first three of these roles: traffic control, train driving and customer information.

To successfully plan and execute the Swedish train traffic is a complex task dependent on a multitude of humans cooperating with each other and with various tools and digital systems (Andreasson et al., 2019; Cort, 2021). At the very heart of this distributed safety-critical system are the traffic controllers, information officers, and train drivers. Traffic controllers are responsible for authorising and managing all movement on

the railway with the overarching goal to implement the planned timetable and maintaining an optimised traffic flow. They are located at a total of eight traffic control centres distributed across Sweden and each such centre is in control of the train traffic within a certain geographical area. The traffic controllers act as both dispatcher and signaller which means that they both reschedule the traffic plan in response to perturbations and disruptions and execute the plan by controlling train paths, points and signals. These roles are in most other countries separate and performed by different workers located at different workplaces (Tschirner et al., 2014). Accordingly, the traffic controllers are remotely monitoring the running traffic and controlling the movements of all trains in their area by manually adjusting signals and switches along the tracks. The traffic is deregulated and a multitude of private railway undertakings contribute to a mixed type of traffic with local commuter trains, long-distance freight transportation and everything there in-between. Approximately 4,000 trains run each day, and at certain hours there are just a few minutes between departures (Trafikverket, 2023). It is a carefully planned network of trains and as the system is running close to its capacity limits, it is sensitive to even slight delays and deviations from the timetable. When delays occur, the traffic controllers must swiftly handle the situation and re-plan the traffic so that the delay is kept to a minimum in terms of time and the number of trains affected.
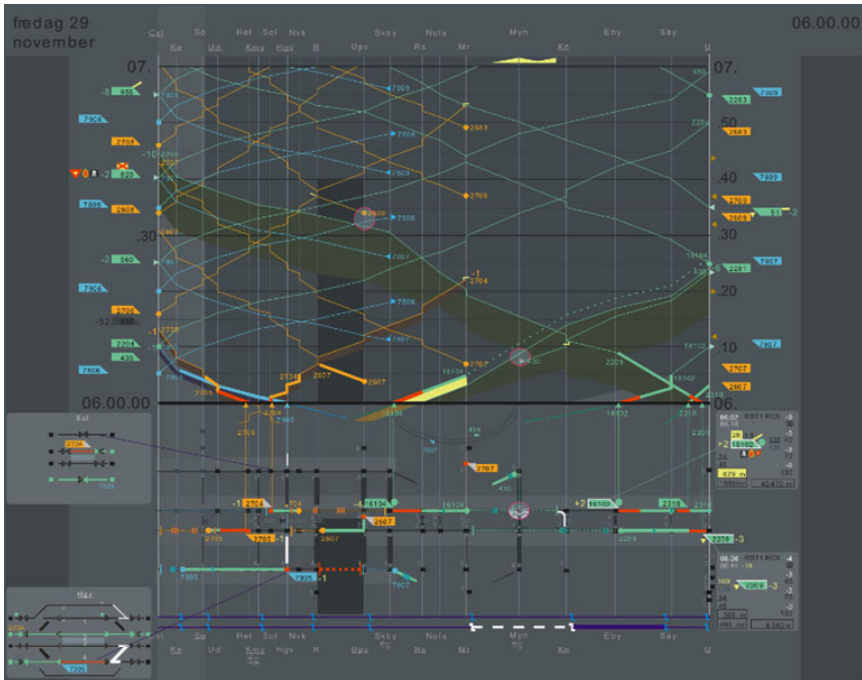
Side by side with the traffic controllers, co-located in the control rooms for train traffic, are the information officers. Their main responsibility is to make sure that the travellers have access to updated travelling information and they do this by controlling what information is displayed on information screens installed at train stations and platforms. The original timetable is displayed by default; accordingly, the information officers only work with announcing changes made to this original plan. They work in a proactive manner and try to anticipate delays and disruptions in traffic with the overarching goal to inform travellers well in advance.

Figure 1   The workstation of a traffic controller includes the train traffic control system, the analogue paper-based time-distance graph and the telephone (see online version for colours)

Due to the remote nature of control room work, both traffic controllers and information officers rely on digital systems to access information about what is happening outside of the control room. The most essential of those systems for traffic control is the digital traffic control system and the analogue time-distance graph (see Figure 1).

Figure 2   A prototype of the digital graph that is intended to replace the paper-based graph (see online version for colours)

Notes: in the paper-based version, the timeline was shown horizontally but in the digital version, the time axis has been flipped from horizontal to vertical in order to make scrolling with a computer mouse easier and to match the orientation of track representations used in other digital systems.

The former is used to monitor the running traffic and to control train paths, switches and signals along the rail. This should be done in accordance with, or as close as possible to, the daily traffic plan, which is graphically shown as an aggregated view of each train's timetable in the time-distance graph. Deviations and conflicts due to traffic delays or short-term planned exceptions such as maintenance work are common in the traffic plan, which makes re-planning the traffic one of the main tasks for the traffic controller. The time-distance graph is then used as a decision support tool for the controllers to decide upon possible ways to re-plan the traffic. As soon as the traffic controller decides on a reasonable re-planning, the adjustments to the original traffic plan are documented in the time-distance graph, and signals and switches are changed according to the new plan, which is also communicated via telephone to the train drivers that are or will be affected by the changes made. For the information officers, the digital system that is of the most importance can best be described as a list of train numbers that present the current location of the passenger trains and a number that indicates whether the train arrived either early or late to that specific location. This train position image is updated in

real-time with information on the trains' positions as they pass sensors built into the infrastructure. Based on a train's current position, the information officer assesses if the travellers waiting on platforms and stations for this particular train need complementing or new information about that train and its current status. A delay in-between two stations do not always mean that the delay will last until the train arrives at its next stop. Accordingly, the information officers need to estimate whether or not the delay will last or if it is possible for the train driver to catch up with the timetable. If it is the former, the information officer needs to manually update the information announced to travellers, which is done remotely in the information display system. This decision process is very much dependent on learned skills and experiences and the information officers base the decisions on conversations with the traffic controllers who have frequent communications with the train drivers, geographical knowledge about the distance between the train's current position and its next stop, if it is down- or uphill, current weather conditions, and how all of these variables affect the train drivers' possibility to catch up with the timetable.

In the last decade, we have seen an unprecedented flow of new technologies aimed at improving safety and efficiency in the rail domain (Naweed et al., 2017) and although there are large discrepancies between countries (e.g., Golightly, et al., 2013) the Swedish context is no exception to this and has seen major changes to the digital landscape of operational train traffic during the last twenty years (e.g., Kauppi et al., 2006; Sandblad et al., 2010), mainly in the development of a new operational planning tool for train traffic control (Kauppi et al., 2006). A more recent example is the implementation of a digital graph intended to replace the analogue time-distance graph (see Figure 2).

Train drivers are responsible for safely operating trains in accordance with the signs and signals along the rail and to uphold the timetabled stops. The train's movements are restricted by the signals (which are manually controlled by the traffic controllers) and by an automatic train protection (ATP) system that will initiate emergency braking if a train violates speed limits or fails to stop at a red signal. The ATP is highly valued when it comes to upholding safety, however, the drivers are still required to operate the train carefully and attentively to avoid accidents in the unlikely case that the ATP should ever malfunction. Further, they should continuously adapt their driving in consideration of energy consumption and passengers' comfort and need to be constantly attentive to events outside the train such as changing weather conditions or obstacles on the rail (Andreasson et al., 2019).

Train drivers have access to the original timetable, either in a printed paper-based version or digitally displayed in a so-called driver advisory system, stating where the train should be at any certain time. Unlike paper-based timetables that tend to turn obsolete rather quickly due to the frequent perturbations and disruptions of traffic, the driver advisory system presents real-time information on traffic changes as well as some information about the status of other trains in the near surrounding. It also advises the driver on how to optimise their driving in regard to punctuality and energy efficiency by showing the geographical distance until the next stop, making speed recommendations accordingly, and calculating braking distances. Access to driver advisory systems has changed the work practice of train driving from what Jansson et al. (2005, p.40) described as driving in 'an informational vacuum' with access to little or no updated information. However, the drivers are still heavily dependent on the information presented by signals along the rail as well as on continuous communication with traffic controllers. The fact that train drivers and traffic controllers do not have access to the

same type and amount of information has been known to sometimes cause conflicts or miscommunication between the two roles (Andreasson et al., 2019; Cort, 2020).

As evident in the description above, traffic controllers, information officers, and train drivers have different responsibilities and rules and regulations to follow but their work is interdependent and the running traffic is a direct result of their continuously ongoing collaboration and coordination. Previous research has mainly focused on the role of the traffic controller but the socio-technical system and unit of analysis should be acknowledged as much larger than that. Work in the transportation sector spans individual, social, and organisational spheres, which is clearly demonstrated in the way work is organised and executed in operational train traffic.
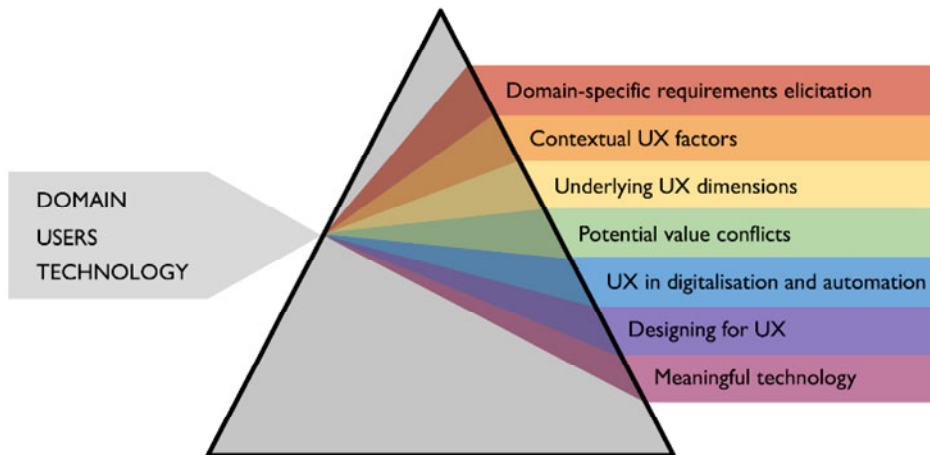
4 Roadmap: a future research agenda for UX in rail

Previous research on UX at work and work engagement in safety-critical domains is dispersed and underdeveloped (Fröhlich et al., 2020; Grundgeiger et al., 2021; Palanque et al., 2019; Roto et al., 2018, 2019; Simsek Caglar et al., 2022). In this paper, we are inspired by Fröhlich's et al. (2020) approach in their proposed research agenda on everyday automation experience to rely on the 'turn to practice' framework originally introduced by Kuutti and Bannon (2014). Kuutti and Bannon (2014) distinguished between the 'interaction perspective' and the 'practice perspective' in HCI research. Briefly stated, the former centres more on the interaction between humans and technology *per se* where the impact on the context can be separated, whereas the latter 'decentres' this view and instead consider the human-technology interaction as merely one aspect among several that are interesting and important. They empasised that 'practice' is considered as the ultimate context since the part and parcel of practices are interactions occurring in real life, arguing that the idea of interaction between human and technology has not vanished but that the need to consider how the technology fits into our everyday work practices has increased. They highlighted that researchers need to explicitly reflect on and articulate what kind of experiences that are captured since all studies utilise different theoretical foundations and approaches, research designs and methods as well as data-collection techniques (Fröhlich et al., 2020; Kuutti and Bannon, 2014). Consequently, these decisions result in capturing different features, kinds and dimensions of UXs. In this paper, we are thus following the practice perspective, focusing on various aspects of tool use in action within the cultural frame of operational train traffic, to articulate and structure different theoretical, analytical and methodological perspectives in our road map for UX in rail.

Explicit UX research in operational train traffic appears absent, although related work on experiential and psychological aspects of technology usage could offer a solid foundation to advance future research in this domain. Addressing these research gaps, we propose a roadmap with a total of seven facets for future studies on UX at work in the safety-critical domain of operational train traffic. We recognise that the identified facets are interdependent and to some degree overlapping, implying that they are not strictly ordered and should potentially be conducted in parallel. In an attempt to visualise our view of these facets, we use a beam passing through a prism to highlight the interdependencies and multiple dimensions of UX that underlie the identified facets presented in our roadmap (see Figure 3). What we see when we view a prism depends on how we hold it up to the light, which recognises the numerous facets of any approach to

studying the world (Janesick, 2000). In a similar manner, our roadmap is multifaceted and incorporates multiple aspects of UX in rail with the overarching goal to reach a deeper and multidimensional understanding of this work domain from a practice perspective.

Figure 3   An illustration of how the factors influencing the UX, represented for clarity by a beam, passes through a prism and is diffracted into a rainbow of colours illustrating the seven facets of our proposed roadmap (see online version for colours)

4.1   Develop and apply new methods and techniques to elicit domain-specific requirements

Studies of how operational train traffic is performed in practice have – as work in similar centres of coordination – predominantly been carried out using qualitative approaches like workplace studies and cognitive ethnography (Andreasson et al., 2019; Cort, 2020, 2021; Luff et el., 2018; Solberg, 2021; Suchman, 1995, 1997, 2007). Although the value of these findings is of major significance, there is an identified need to further develop the present qualitative inquiry approaches to elicit domain-specific requirements beyond mere descriptions of work practices, division of labour, and collaboration. We suggest that future research should continue on the previous path but also observe and report critical aspects such as shared experiences, norms, and values. This deepened level of detail may support the identification and formulation of domain-specific and critical UX aspects within operational train traffic that range from pragmatic to hedonic qualities and eudaimonia (Stephanidis et al., 2019). For example, individuals in the roles of traffic controllers, train drivers, and information officers may have different types of psychological and emotional needs, which subsequently have an effect on work engagement and wellbeing at work. It may also be the case that these aspects differ between various traffic control centres, including the work practices and cultures, available digital systems, and routines of the everyday handling of digital and analogue tools (Simsek Caglar et al., 2022).

We suggest that a tentative way forward to elicit these domain specific UX requirements, which may be unarticulated, is to take a closer look at new methodological approaches. Stilwell and Harman (2021) suggested an approach that mixes

post-cognitivist theories such as distributed cognition and cognitive ethnography (Hutchins, 1995; Williams, 2006; Solberg, 2021) with enactivism, here explained as how the workers (as senso-motoric biological organisms) have emerging and dynamic interactions and relations within and with their context (Varela et al., 1991). With roots in phenomenology and embodied cognition (Lindblom, 2015, 2020; Varela et al., 1991), Stilwell and Harman (2021) argue that enactivism can be used as a flexible resource in qualitative research, for investigating and analysing the emerging of first-person (subjective) experience and its meanings (i.e., the inactive concept of sense-making) in context. We suggest that this mixture can be applied within operational train traffic to reveal the underlying UX dimensions of the various work roles in operational train traffic. For example, Lebahn-Hadidi et al. (2023) described their enactivist ethnography as an integration of phenomenological interviews and cognitive video ethnography, which they used for disentangling the handling of a medication error by focusing on ordinary work practices. Moreover, Briedis (2020) applied phenomenological ethnography in radiology to elicit how experts enacted various diagnoses by focusing on their experiences and meaning at work, where several advanced digital tools were used. These above-mentioned approaches may provide ways forward on the request raised by Hohm et al. (2022), who argued that UX research in safety-critical domains needs to develop and apply new methods and techniques to elicit the domain-specific requirements. A tentative research question can be phrased as: How can UX at work, as an emergent phenomenon affected by the tasks, tools, 'lived body' and context, be captured?

4.2 Gaining a deeper understanding of the 'contextual' factors affecting UX in operational train traffic

Previous research has ethnographically studied the whole workscape of operational train traffic in terms of how current work tasks and activities are mediated by various analogue and digital tools, as well as the collaborative interdependencies that emerge between people and technology involved in operational train traffic (Andreasson et al., 2019; Cort, 2020, 2021). As the next step, it is essential to address these social and material aspects of work and particularly from the UX perspective. What effects does the particular context of operational train traffic bring to the experience of work and what contextual factors, for example, the division of labour, shared norms and values, tools and constraints in the operational train traffic practice, are relevant to acknowledge? Topics to include relate to the identification of what workarounds exist in this environment and what work practices support safety (Hollnagel, 2014) by distinguishing eudaimonia-related qualities such as competence and self-actualisation (Grundgeiger et al., 2021; Hohm et al., 2022; Mekler and Hornbæk, 2016). Eudaimonia and striving for value and meaningfulness not only bring personal benefits by supporting well-being (Huta and Ryan, 2010; Mekler and Hornbæk, 2016) but would also support safety and the worker's ability to be adaptable and to deal with unforeseen events and varying conditions (Hollnagel et al., 2015). Both traffic controllers and information officers are heavily dependent on the digital systems available in the control room but it has been shown that these systems sometimes fail to provide the support needed and that the workers use their acquired skill and expertise to 'close the gap' (Cort, 2020, 2021). One example is when an information officer notices that a train has been left unattended for a longer time than usual. By personally notifying the traffic controller about this, the

information officer supports the controller in ways that the technical systems do not in the task of keeping the traffic running. They apply their skill and experience to make up for when the technical systems fail to meet their needs from a holistic perspective. 'Staff who experience competence when interacting with technology may be better equipped to fill this gap, to keep a process going, to re-establish safety, or to enable safety in the first place' [Grundgeiger et al., (2021), p.5].

Prior, and nowadays classical, work within computer-supported collaborative work (CSCW) has paid close attention to work practices in control rooms, and it has been revealed that work is often characterised by time-criticality, high-risk activities, and intense collaboration between humans and available technologies. Although prior research has revealed intricate use of technology in context (e.g., Luff et al., 2018), it is done without characterising the UX, and therefore we lack an understanding of whether and to what extent UX will change work practices over time. Relevant findings would be the pragmatic and hedonic qualities of the key mediating tools, how the roles in operational train traffic deal with varying conditions, what possible gaps need to be filled, and how workers ensure that trains are running safely and on time (Grundgeiger et al., 2021; Hohm et al. 2022). Once we have gained a deeper understanding of which experiences train traffic controllers and train drivers find meaningful at work, we can formulate central positive dimensions that promote positive UX, similar to what Laschke et al. (2020) and Savioja et al. (2014) did, and what is asked for by Simsek Caglar et al. (2022). Tentative research questions can be phrased as: What contextual factors affect the possibilities to explicitly consider UX in operational train traffic? What are relevant contextual UX aspects?

4.3   Identify and describe the underlying dimensions at the core of UX within the context of operational train traffic

To our knowledge, there are no explicit UX studies that have investigated what train traffic controllers, information officers, and train drivers appreciate and do not appreciate in their work roles. What makes the work feel meaningful and how do these roles apperceive that they are contributing to something valuable? What causes them frustration? Which of these dimensions of UX are shared among the three roles, and which are unique for each role respectively? We expect to find that much like air traffic controllers (Huber et al., 2020), also train traffic controllers find satisfaction in achieving perfection in task fulfilment, such achieving a constant traffic flow while simultaneously re-planning the train traffic in ways to avoid conflicts, queuing and unnecessary stops. However, there are likely also other domain-specific activities that fill the work with meaning. Similar hedonic qualities, closely tied to the pragmatic values of operating the trains can likely be identified also among train drivers. An example of this is when drivers challenge themselves to drive in such ways that they arrive at scheduled stops exactly in accordance with the timetable and the excitement they express when this succeeds (Andreasson et al., 2019). Studies from the London underground describe how train drivers use the sound of the closing doors to encourage passengers to either get on-board the carriages or to step away from the train (Heath et al. 1999) and similar strategies have been reported from the Swedish context where train drivers 'ventilates the engines', which results in a humming sound, in attempts to convey to indecisive passengers that the train is about to leave the station (Andreasson et al., 2019). From the control room context, information officers make use of video-surveillance at the

platforms to get eyes on the travellers to see their reactions to the information they receive from the traffic control room. These are all examples of practices that are not to be found in the formal work descriptions but rather contextually developed work practices that mirror how the train drivers and control room workers view themselves as professionals and the service they provide. These qualities constitute the target for UX design and we need to study people in their unique work contexts to learn what these are (Clemmensen et al., 2020). Hence, the first step is to identify what UX aspects and dimensions exist in this particular context of operational train traffic, and then compare and contrast them with existing UX aspects and dimensions from other safety-critical domains, preferably in other transport sectors. Which aspects and dimensions are commonly shared across the sectors and which are not? This approach is well-aligned with recent requests for understanding the hedonic qualities of different professional practices and to what extent these are similar to the previously identified and thematically grouped UX dimensions at work (such as connectedness, enthusiasm, and performance) (Simsek Caglar et al., 2022). It should be mentioned that paying attention to various aspects of the hedonic qualities, does not imply that we should neglect the pragmatic quality, like usability, since such an approach could result in 'throwing the baby out with the bathwater'. Similar thoughts were addressed by Hohm et al. (2023) who argued that there still is a fundamental focus on safety and efficiency aspects in safety-critical domains, and that usability, therefore, is crucial and has a strong influence on the users' work tasks. Although the necessity of addressing pragmatic qualities, Hohm et al. strongly emphasised the urgent need to expand human-technology research and design from merely usability to UX at work. Tentative research questions can be phrased as: What do the professionals enjoy in their work? What makes the professionals feel accomplishment?

4.4 *Identifying potential value conflicts within operational train traffic*

The operation of train traffic involves a multiplicity of interacting values, explicit as well as implicit. Safety, passenger comfort, punctuality, environmental sustainability, and economy are just a few of the values that have been explicitly mentioned by professionals within the domain (Andreasson et al., 2019; Cort, 2020). Positive experiences of the professionals involved in ensuring proper operation of trains is a value that may not have been acknowledged in prior development of systems and tools but nevertheless has implicitly always been there. All technology interaction implies UX, regardless if this is intended or accidental. By explicitly considering UX, psychological working conditions are acknowledged as a value, not only from an ergonomic point of view but also including the professionals' experiences of meaning, fulfilment, pride, commitment, etc. By acknowledging experiences as important, UX can also improve the fulfilment of other values. Fulfilling the basic psychological needs of autonomy, competence and relatedness (Ryan and Deci, 2000) has been found to increase engagement with tasks, a sense of responsibility and a feeling of ownership of possible problems (Gagné and Deci, 2005). Especially the feeling of competence has been identified as important in other safety-critical settings (Hohm et al., 2022). Within the safety-critical domains, conflicts between personal and operational/organisational goals are potentially fatal, so it is very important to acknowledge the former to avoid misprioritisation that could bring sub-optimisations and a negative impact on the overall process from a holistic perspective. In Swedish operational train traffic, the train drivers focus mainly on the

train they are operating and to uphold its time-tabled stops while traffic controllers are responsible for numerous trains in the overall traffic flow. This division of responsibility is mirrored in the information these two roles have access to and while the drivers have information mainly about their own train, the traffic controllers have access to comprehensive information about the overall traffic situation in all of Sweden, both in its current state and in regards to the hours ahead. This brings the traffic controllers an advantage when it comes to making strategic decisions for how the traffic should be executed, which sometimes puts the drivers in a situation where they feel left out and without control over their work situation. This has been known to sometimes cause conflicts and misunderstandings between the two roles (Cort, 2020) as well as situations where train drivers take initiatives and adapt their driving in ways that force the controllers to make changes somewhere else in the overall net of traffic (Andreasson et al., 2019). When it comes to balancing the fulfilment of different values, the agency following from being in control over what happens avoids negative feelings of helplessness. The time sensitivity of most decisions in traffic control makes it unrealistic for controllers to consult with all concerned drivers before implementing necessary changes to the traffic plan. But the fact that train drivers usually are informed when the decision has already been made risks taking away the drivers' feeling of agency and control. If a train driver would be asked to sacrifice punctuality to solve a larger traffic conflict, understanding the reason behind it likely avoids the feeling of not being part of the decision-making. There is also a challenge to align UX and business goals, which otherwise could result in conflicting aims. Tentative research questions can be phrased as: Are there conflicting values within operational train traffic that cause sub-optimisations? How are personal goals and values aligned with the values of operation?

4.5   *Addressing UX aspects in the ongoing digitalisation and automation of operational train traffic*

The rapid technological development in the rail domain offers new possibilities and constraints to how train drivers, traffic controllers and information officers interact with technology, especially when it comes to automation and artificial intelligence (AI) (Cort, 2020, 2021). This raises questions like how the workers will adapt to, or be transformed by, these continuous changes when the technologies are incorporated into their everyday work practices (Fröhlich et al., 2020; Huber et al., 2020; Savioja et al., 2014). One of the most central tools for operational train traffic is the analogue time-distance graph which supports the planning and decision-making process of the traffic controllers. However, this is currently undergoing replacement by a digital version (see Figure 2) (Cort, 2021) and given its foundational role in the conduct of work in Swedish operational train traffic, this digitalisation is expected to have a profound effect on the established work practices. This effect is most likely not only in the immediate interaction between the workers and the digital systems they use but also to be found in the communication and collaboration patterns in, and between, control rooms as well as in relation to both hedonic and eudaimonia UX aspects such as engagement and the worker's perception of one's autonomy and competence. The introduction of new technology in a complex socio-technical system such as operational train traffic always carries the potential for significantly changing the nature of work in ways that are unpredictable beforehand. Based on our knowledge of Swedish operational train traffic, a digital version of the time-distance graph is unlikely to completely replace the analogue graph and we see a

risk of the new system bringing a higher workload for the traffic controllers. The implementation of a digital time-distance graph is an interesting example of the ongoing digitalisation in the train traffic domain, and we suggest investigating and analysing the transformative development of new work practices as a result of the introduction and embeddedness of this key tool in the organisation of work. The envisioning of AI systems, like automated trains (AT), is another work engagement challenge from a UX perspective (Karvonen et al., 2011; Koskinen et al., 2021). Singh et al. (2021) mentioned that there are several advancements occurring in rail technology, which is envisioned to progress from no or partial automation to a full automation level in freight and passenger trains in the near future. There are four grades of automation (GoAs) for trains. These start with the lowest level or automation where the main train operations, such as starting, stopping, and operating doors, are dependent on manual handling by an onboard train driver. At the next level, some of these train operations are automated but an onboard driver is still necessary. In the third level of autonomous train operations, the train driver is on board but only to manage the train in case of an emergency, and in the highest level of automation, the train runs fully autonomously with no onboard driver/personnel.

However, Singh et al. (2021) pointed out that one major challenge is to gain a proper understanding of all the tasks and responsibilities that are carried out by train drivers and how these can be implemented and handled in autonomously operated trains. A related challenge, beyond the safety and service quality issues during the transition to autonomous trains, is the situation that manually-driven trains will have to share the rail with the autonomous trains. This may create operational challenges related to the difficulty of fully automating the whole infrastructure of rail at the same time. It is argued that AI systems with high levels of automation will make human workers less involved but that their involvement becomes more critical (Palanque et al., 2019).

The envisioned development described above presents many unexplored and understudied UX challenges at work for train professionals. There is, for example, a risk that traffic controllers, information officers, and train drivers may run into being servants of AI systems, and how AI affects UX and work engagement in these workplaces is a surprisingly understudied research topic (Palanque et al., 2019). As digitalisation and automation permeate workplaces, operational train traffic included, it becomes more relevant now than ever to address consequences of the technical development in relation to not just work performance but UX at work and essential aspects such as engagement, wellbeing, and competence. It is a daunting task to both elicit current work practices and skills and to envision what aspects should be implemented and how the division of labour should be distributed between the automated system and the train professionals, as well as how to motivate and engage users at work when the work practices are altered due to new technological advancements. To succeed with this, it is of major importance to include the users from the very beginning in the design and development of autonomous trains in order to maintain safety and the quality of service. It should be emphasised that from a UX perspective, the whole work practice is the unit of analysis; not only the digital graph or the autonomous train technology, but all aspects that are related to, and interwoven in, the performance of keeping the trains running are under scrutiny as the old work activities and practices are changing or even disappearing when additional and new ones are emerging. Tentative research questions can be phrased as: How can care for the professionals' experiences be incorporated into the ongoing digitalisation and automation of train traffic?

4.6   Clarifying what UX design entails in the domain of operational train traffic

UX design in safety-critical domains like operational train traffic is not about designing glossier user interfaces, and not about making work 'fun' or 'simple'. It is about designing tools and systems so that they preserve and augment the aspects of work that keep professionals within the domain fully engaged in their activities. Arguably, when human lives are at stake, it would be offensive to, e.g., prioritise a train driver's amusement over the safety of the passengers. This, however, does not mean that the experiences of the train drivers are not important to consider. If the work did not entail any component of psychological needs satisfaction, it would likely reduce dedication, with several possible adverse consequences. UX design in this context entails acknowledging that professionals find satisfaction and meaningfulness in their work, be it achieving safe, efficient operation or satisfied passengers, and ensuring that new technological solutions that are being introduced do not interfere with this. Ideally, the tools and systems that professionals have at their disposal should augment the aspects that are important for successful train operations while fulfilling the professionals' psychological needs. Even though this may sound easy to set up as a program, in practice, it implies many non-trivial design decisions. For this to work, the design team needs to understand the different UX dimensions that have to be addressed simultaneously and how design affects these. Especially when considering automating parts of the work practice, challenges arise regarding goal comprehension, fragmentation of work, user control, vigilance, and deskilling (Bainbridge, 1983).

Another design aspect to consider is how the train traffic is perceived by different actors during operation. For train traffic controllers, the state of the world, i.e., the train traffic and relevant contextual information like weather conditions, is represented on computer screens via different forms of visualisations. This means that the relationship with the actual traffic is hermeneutic in the sense that it is perceived through instruments rather than being directly experienced (Ihde, 1990). This is not a problem per se, but it is important to be aware that, for the controller, this, to some extent, may come to constitute rather than represent the traffic and its dynamics. For train drivers, on the other hand, the relationship with technology is more embodied, in the sense that the available controls are not the focus of attention but instead become an extension of the train drivers' bodies, enabling them to control the speed of their train, and through that the comfort and safety of its passengers (cf. Hirose, 2002; Polanyi, 1966). Hirose emphasised the difference between being embodied and the act of embodying, i.e., the phenomena of body extension by various tools. This first-hand experience of the consequences of decisions enables a faster action-perception cycle with reduced cognitive effort. First and foremost, awareness of this aspect in the design process is important in order to not reduce this valuable experience for train drivers, but would it be possible or desirable to introduce more embodied relationships with train traffic also for the controllers? A hypothetical example of when this approach could be interesting to explore is for determining a safe speed of a train in difficult weather conditions. The train traffic controller needs to rely on mediated information (by instruments and verbal reports from the train driver) for what speed is appropriate. However, the first-hand experience could contribute to improving the communication between controller and driver, thus also planning possibilities. Furthermore, research has shown that embodied experiences contribute to fulfilling eudaimonia goals, like feeling competent in your profession (Grundgeiger et al., 2021). In conclusion, UX design in safety-critical domains entails acknowledging

professional users of technology as humans with psychological needs. Failure to acknowledge this in the design of technology risks leading to work that is perceived as less meaningful, with adverse consequences like reduced motivation and vigilance. Tentative research questions can be phrased as: How are UX qualities, like autonomy, competence, and relatedness, manifested and fulfilled in the design of new tools for operational train traffic? How can UX qualities be preserved in light of increasing automation?

4.7 Applying and developing additional theoretical lenses for grasping and explaining meaningful technology use and technology experience

Most prior research on technology and tools have taken an instrumental perspective or neutral perspective on the digital tools used. In operational train traffic, the deployment of the digital time-distance graph is one example that highlights the need to address the meaningfulness of technology similar to what Laschke et al. (2020) have done. In their research on radiologists, it was highlighted that technology can contribute to the experience of meaningfulness at work as it offered support for the work practices the radiologists experienced as meaningful in their professional roles, both individually and as teammates within the workplace. A striking characteristic of the approach to meaningful technology by Laschke et al. (2020) is that they neither considered technology use in isolation nor developed it from a distance. Instead, their starting point was the actual continued work practices and how technology could provide more than only mediate certain work tasks by studying them where they occurred and developing the additional features together with the radiologists and then studying how these new features would be situated with reference to the particular place, work collaboration and embedded in the historical context of the workplace. Hence, they applied a kind of practice perspective on meaningful technology development, but more in-depth research is needed on how meaningfulness at work can be realised via technology from a theoretical perspective, especially since UX as such still is an emerging subject that lacks a solid theoretical foundation. We hereby identify two overlapping theoretical endeavours that focus on meaningful technology use and technology experience at work.

Luff et al. (2018) studied work in a large multi-centred control room in London where co-located activities were mediated through technology. They argued that 'studies of everyday co-present work require both the attention to these details of how technologies are used as well as how the activities of individuals are shaped and shape the conduct of others, whether they are in the same space or elsewhere' [(Luff et al., (2018,) p.580]. They identify a lack of research focusing on the use of technologies, which was a bit surprising given that technology usage is usually considered part of the core in CSCW and HCI research. However, they neither explicitly focus on UX nor suggest any theoretical approaches for future work (Luff et al., 2018). Similar arguments have been put forward by prominent researchers in information systems and organisational studies, who argue that the manifestation of technology tends to be almost missing or even neglected (Orlikowski and Scott, 2008). They highlight the challenge of doing these kinds of studies without falling into the trap of simplifying or isolating tool use in action. They advocated a socio-materiality approach, which wants to bring the embedded digital technology to the foreground, but this is not unproblematic when users commonly are unaware or take for granted how materiality matters in their work and the embeddedness of it in the historical context (Orlikowski and Scott, 2008). Although they highlighted

technology use in context and provide a view on the entanglement of technology and work in organisations, they do not emphasise the experiences emerging from technology usage or how technology contributes to fulfilling the workers' preferences, psychological and emotional needs to promote meaningfulness at work. Hence, this is still an understudied research area (but see recent work by Ciborra (2006), Gherardi et al. (2019), Hultin (2019)).

Some theoretical inspiration for the future can be found from the prior 'turn to practice' approach in HCI (Kuutti and Bannon, 2014). As pointed out by Kuutti and Bannon (2014), the practice perspective focuses on the mutual role of *artifacts* for the emergence of *new practices*, but without ending up in the prevailing dichotomies of social versus material, body versus mind, and knowledge versus action. Accordingly, the practice approach aims to offer additional theories that are more suited to describe and explain the mutual relationships between these aspects without ending up in these dichotomies. Consequently, additional theoretical approaches to human cognition and technology-mediated interaction like activity theory (Kaptelinin and Nardi, 2012), distributed cognition (Hutchins, 1995; Solberg, 2021), embodied interaction (Varela et al., 1991) have been applied in the HCI context throughout the last three decades. More recently, these approaches have also been applied to investigate aspects of UX in safety-critical domains (Grundgeiger et al., 2021; Hohm et al., 2023; Klüber et al., 2020; Lindblom et al., 2020; Savioja et al., 2014). Both Andreasson et al. (2019) and Rosness (2017) have applied distributed cognition and activity theory lenses respectively in studies on train traffic control work, but they have not explicitly focused on the UX of technology use.

Some of the above approaches seem to be more fruitful for investigating and analysing UXs from a more theoretical perspective. Hohm et al. (2023), who applied several theoretical lenses in their study of how acute care teams use and experience technology, pointed out that embodied interaction was the perspective that provided the most support to gain a deeper understanding of the unique first-person experience of anaesthesiologists. More recent work in organisational studies has argued for an increased interest in mood and meaningfulness in socio-materiality studies of digital work practices (Ciborra, 2006; Gherardi et al, 2019; Hultin, 2019). There are currently similar trends of interest in enactivism having its foundation in its embodied actions and the role and relevance of one's lived experiences and the enactments that come from having a living body that is embedded in a socio-cultural and material context, in which several tools are manipulated (Varela et al, 1991; Lindblom, 2015, 2020). The embodiment turn in UX and HCI seems very promising, especially enactivism since it is relevant for socio-materiality as it shares a non-dualistic relational view on how individual and collective sensemaking enfolds while being situated within the material and social world. Enactivism seems promising for the lived experience which is well-aligned with UX, especially because it focuses both on the emerging of first-person (subjective) experience and its meanings (i.e., the inactive concept of sense-making) in the particular work context (Stilwell and Harman, 2021).

However, enactivism does not seem to pay that much emphasis on tools in action. Recently, several initiatives have been performed to further include the material dimension of enactivism into the equation, such as material engagement theory (MET) (Malafouris, 2019). MET is a relatively new development within cognitive archaeology and anthropology, but one that has important implications for many adjacent fields of research in phenomenology and UX, and consequently it seems to be relevant for our

research on meaningful technology use and technology experience at work. Briefly stated, advocates of MET argue that this approach provides a new outlook that frames the above issue of material culture from a new angle. MET is characterised as a cognitive approach that emphasises the constitutive role and relevance of the embodied and situated engagement of thinking and feeling with things over a time horizon, which is a process denoted by *creative thinging* (Malafouris, 2019). Malafouris pointed out that MET intends to contribute by changing the way we think about the relationship between cognition, affect, and materiality, by viewing these relations as dynamic *entanglements* that have the potential of altering the mutual relationships between humans and their environments. Malafouris (2019) highlighted that MET differs from phenomenology because it prioritises subjective experience over the situated action (Suchman, 2007). However, it is still too early to tell whether MET would contribute to grasping and explaining UX at work in accurate and complementary ways, beyond the above theories.

Similar to what Hohm et al (2023) did by applying several theoretical lenses in their study on acute care teams, we are inspired by Halverson (2002) who took a closer look at what CSCW and HCI researchers could expect from theories. She emphasised that in practice, researchers consider and adapt the value of theories mainly depending on how well a theory can provide support in shaping an object of study and by highlighting relevant aspects and subsequently insights of the object of study, and in this case UX at work. Accordingly, Halverson (2002) compared the usage of theories to a pair of dark glasses, which tint the world in a way that brings some objects into sharper contrast, while it makes others fade away. Rogers (2012) presented a similar perspective in HCI and mentions that the role of theory has broadened beyond how a theory was originally used as a significant aspect of the scientific method, to stretching it in many ways and levels to describe, conceptualise, explain, and critically discuss various phenomena, and in this particular case, UX in operational train traffic. Tentative research questions can be phrased as: How can technology in action in operational train traffic be grasped and explained from complementary theoretical perspectives? What kinds of theories grasp and describe accurately how technology provides meaning and added value? How can theories explain how workers are augmented by technology in action to fulfilling their needs and provide meaning from a UX perspective?

5   Concluding remarks

To conclude, we want to emphasise that positive experience at work matters greatly. Promoting the successful implementation of UX in rail will increase the engagement and well-being of workers, contribute to the meaningfulness of technology use and experience and, in the long run, improve the safety of both workers and passengers. This roadmap offers initial steps in this direction by viewing rail research from an explicit UX perspective, without dismissing prior cognitive ergonomics' safety and efficiency research. We aim to conduct future investigations and analyses on the specific and interrelated dimensions of work that train traffic controllers, information officers, and train drivers experience as meaningful and engaging at work, to generate the requested context-specific knowledge (see Simsek Caglar et al. 2022) in relation to the safety-critical domain of operational train traffic.

We hope our roadmap will be applied and implemented in trans-disciplinary rail projects aiming to answer the research questions addressed in the seven facets, perhaps

even throughout the design and development process of the train traffic control systems of the future. Indeed, addressing the research questions presented in adjunction with the facets in the suggested roadmap could add central pieces of knowledge aiming to grasp a deeper understanding of the understudied topic of UX in rail. We want to emphasise that we are aware of the complexity of the overall phenomenon of UX in operational train traffic and the challenges we will encounter when attempting to systematically study, describe and explain UX and its related aspects, dimensions, the users, and stakeholders. It should be pointed out that the safety directives, regulating policies and legislations on national and international levels must be included on this journey. The intended contributions of this paper are to address the need to study UX in rail by considering meaningful, technology-mediated work practices in operational train traffic, and to offer initial steps on how this can be approached. Hopefully, the impact of this roadmap will provide insights into the constantly ongoing technological and societal change and aid the sustainable development of the rail domain.

Acknowledgements

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