Creating, Reinterpreting, Combining, Cuing – Paper Practices on the Shopfloor

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ABSTRACT
Despite the advent of a flurry of digital technologies, paper prevails on manufacturing shopfloors. To understand the roles and value of paper on the shopfloor, we have studied the manufacturing practices at two state-of-the-art automotive supplier facilities, applying ethnographic fieldwork, in-depth interviews, as well as photo and document analysis. We find that paper has unique affordances that today's digital technologies cannot easily supplant on current shopfloors. More specifically, we find four paper practices: (1) creating and adapting individual information spaces, (2) reinterpreting information, (3) combining information handover with social interaction, and (4) visual cuing. We discuss these practices and the unique affordances of paper that currently support shopfloor workers and also consider the limitations of paper, which are becoming increasingly apparent, since more tasks increasingly depend on real-time information.

Authors Keywords
Paper Practices; Shopfloor; Manufacturing; Affordances; Digital Artifacts

ACM Classification Keywords
H1.1; H.4.1; K.4.3; K.6.1

INTRODUCTION
Already in the 1980s, scholars and practitioners have discussed replacing paper on the shopfloor with digital technologies [5]. Proponents have argued that paper has significant limitations as a collaboration medium, because it is slow and has limited capacity (e.g. [10]). Recent literature also corroborates this view of paper, stressing the same shortcomings of using paper such as slow information transfer, high workload of managing paper documents, outdated information, and loss of synchronization (e.g. [19]). Nonetheless, many highly successful and profitable manufacturing companies still substantially use paper on their shopfloors. Why?

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Research into the substitution of paper by digital technologies brings to mind similar expectations of paper's future in office environments. At least as early as the mid-1970s, the *paperless office* was becoming a popular catchphrase, and many predicted that it was only a matter of time before our office environments would become paperless. But paperless office is still rather vision than reality [12].

The missing of the paperless shopfloor and the paperless office could be explained by reference to so-called *demographic factors*. In this view, paper continues to be used, because the generations of people brought up with paper documents find it difficult to move towards screen-based documents and new technological tools. As this generation gradually retires, it has been argued, digital documents will replace paper. Also, the argument goes, investment in technology and more user-friendly technology will ensure the eventual paperlessness of offices and shopfloors [29]. However, paper is still used heavily in today's office environments and studies indicate that there is very little evidence of a link between age cohort and preference for paper [29]. Also, (massive) investments in new digital technologies for working with documents have not eliminated the use of paper in collaborative work. This is true in both office environments and shopfloors.

The research suggests that the reason why paper continues to be key in collaborative work relates to its *interactional properties*, or the physical aspects of paper that shape the ways in which it can be used in a wide range of task types [6]. These may be thought of as the affordances of paper.

Based on insights from the literature on the affordances of paper in cooperative work, we investigate the affordances of paper in a particular setting type – the shopfloor of future *smart factories*. The manufacturing industry is moving towards smart factories: changing demands in global markets are increasingly leading manufacturing companies to transform previously mass-produced items into individualized products [20], making flexibility a key success factor of the 21th century [22].

For the shopfloor context, this requires less routine work, and dynamic and efficient collaboration by highly skilled shopfloor workers. That is, while much traditional manual shopfloor work is becoming automated, shopfloor workers in smart factories are gaining more autonomy as flexible problem-solvers and decision-makers [1]. We focus on the affordances of paper on the shopfloor of current or future smart factories.

The article's empirical material originates from two studies of shopfloor work at automotive suppliers seeking to move into the smart manufacturing paradigm: (1) ETOC, a company in Slovenia that manufactures large tools for sheet-metal transformation, and (2) a division of Mass Production Company (MPC) in Germany that manufactures mechanical parts for automotive engines. While both are in the automotive sector, ETOC manufactures one-off individual machine parts, while MPC mass-produces engine parts. Studying these two companies offers us a broad view across different manufacturing settings and at least some differences in cultural background. Without claiming completeness, both settings provide a broad spectrum of paper affordances across different manufacturing contexts. [1]

Our study highlights paper's affordances on these two factories' shopfloors, arguing that aiming to make these shopfloor types paperless is largely uncalled for. We also analyze paper's limitations on smart factory shopfloors, which for instance surface in the context of decision-making, when the process requires rapid distribution of large amounts of data. The upshot is that paper has a place on the shopfloor of modern smart factories provided that the usage of paper artifacts is appropriately integrated with digital tools.

Given paper's widespread uses in companies and private life, there are various possible perspectives on its uses and purposes. We look at paper practices as ways to create and maintain local information spaces, through which workers store, retrieve, and share information. *Information space* relates to "a set of concepts and relations among them" [23]. We consider which concepts of information space workers relate to and how they store, retrieve, and share them in their environment.

Our study is structured as follows. First, we account for related research on affordances in general and the paper's affordances in particular. Second, we account for methods and settings. Third, we introduce the two cases, followed by the analysis, where we unpack the affordances of paper on the shopfloor. We then discuss our findings in light of the literature and the notion of future smart shopfloors.

PAPER AFFORDANCES AND PRACTICES

The concept of affordances originates from ecological psychology, and was proposed by James Gibson [9] to denote action possibilities provided to an actor by an environment. In the late 1980s, Norman [24] suggested that affordances be taken advantage of in design. The suggestion strongly resonated with designers' concern about making possible uses of their products immediately obvious; the concept soon came to play a key role in interaction design and human-computer interaction (HCI).

Affordances are seen as a way to bring materiality back into the analysis by highlighting technology's physical characteristics without succumbing to technological determinism. Hutchby [16,17] underlines that technologies should be understood as artifacts that are both "shaped by and shaping of" [17:444] human practices. In line with this, he defines technology affordances as the "… functional and relational aspects which frame, while not determining, the possibilities for argentic action to an object" [17:444]. Further, affordances may differ between persons and between contexts, and are in this sense relational. For instance, a computer with a working integrated development environment (IDE) has the affordance of writing code, compiling it, and executing it, but only if the user is a skilled programmer that knows the appropriate programming language, and so on. Relatedly, the use of complex paper artifacts on the shopfloor also requires skills on the parts of the user, and certain affordances are only visible to the trained eye rather than a novice. This implies that individuals must first 'learn' affordances before they can gain awareness on them [16].

Research into paper practices [30] has for instance shown that paper affords ease of marking. This is important when people are reviewing a document's contents, allowing them to write and comment on the text as they read. Paper also affords flexible cross-referencing between multiple documents, allowing users to spread out pages in physical space and to read and write across documents. This is crucial when one seeks to compare and contrast between documents or seeking to extract and integrate information across documents. Paper also affords complex, two-handed navigation within and between documents. This enables readers to effectively 'get to grips' with a document's structure by allowing them to flick through quickly and get a feel for the content [25]. Paper also affords us opportunities to interact and communicate with one another by physically passing and delivering documents rather than e-mailing them [11]. Further, paper can be used to organize work in time and space, including being placed conspicuously in order to impress others [6]. It may make a significant difference whether or not an artifact is paper-based or digital [7,21]. For instance, in her seminal ethnography of paper flight strips in air traffic control, MacKay showed that replacing paper with digital tools in this safety-critical environment is a non-trivial challenge [21]. The affordance of paper contrasts with the affordance of for instance software applications to an extent where a one-to-one substitution may be impractical and in some cases undesirable [3,7,21]. Studies from other

[1] The continued development of smart manufacturing is especially important in Europe and in the remainder of the Western world, where the wage premium – compared to the emerging economies – is a disadvantage and every aspect of the manufacturing process must be improved so as to remain competitive. This study is based on EU funding for strengthening smart factory work.

domains, including for instance microfinance, have also pointed to paper's enduring value. For instance, the study of microfinance, Ghosh et al. [7] have shown that paper is able to deliver valuable context-specific information that derive from paper's affordances. This research may help explain why people generally use paper as well as in complex cooperative work settings, and why replacing paper with newer digital technology may be a challenge – if desirable at all.

In contrast to this research, scholars and practitioners have proposed to replace paper on the shopfloor with digital technologies [5,15,26] owing to paper's limitations. It has been argued that paper has significant limitations as a collaboration medium, because (1) the data streams are too broad to be transmitted by paper, (2) the feedback loops are too slow, (3) human input is too error-prone, and (4) the interpretability of information would rise to unacceptable levels [10]. Some recent literature corroborate this view of paper, stressing the same shortcomings of using paper such as slow information transfer, high workload of managing the paper documents, outdated information, and loss of synchronization [19].

With this short summary of the literature, we see that paper has unique affordances, but we also see that these affordances simultaneously shape paper usage's limitations. We will now explore paper's affordances in two cases of factory shop work, with the aim to provide a balanced view of paper's affordances and account for the opportunities of and challenges to its uses in future manufacturing settings.

METHODS

This study is a part of the international research project Facts4Workers [4], which seeks to create attractive and intelligent workplaces in a factory of the future. We initially studied how shopfloor practices can be supported via human-centered IT solutions. A deep understanding of workers' individual practices has been our basis to deliver suggestions (in the form of requirements) for sociotechnical solutions that support smarter work.

Our study is based on ethnographic fieldwork oriented to informing design of information technology. The development of technologies for cooperative work, in our case smart factories, is ultimately what our approach is about. Applying ethnographic methods may afford us insights into practices that we would otherwise be unaware of. This is a key justification in that we cannot know in advance what a practice's relevant features are, let alone how they are relevant for technology development and prospective users. Analytical findings based on ethnography may ground a technology development process by providing a framework in which it can be conducted, explored, critiqued, and evaluated. Sociotechnical theory is an apparatus of the mind, a technique of perception and reflection that helps its processors see, discuss, and ultimately act on phenomena [2]. In this vein, this study's ethnographic findings are (partly) intended to ground possible future technology development processes in a context that may make designers sensitive to certain phenomena such as the affordances of paper and may provide a vocabulary or conceptual apparatus for thinking about design opportunities and design challenges.

Our study is based on ethnographic fieldwork collected over 14 months, conducted as several multiday, on-site data collection sessions from February 2015 to April 2016. (Further data collections are ongoing but don't form part of this study). Our data collection followed the principle of triangulation [31:291]. We obtained data from observations, field notes, focus groups, and interviews.

The fieldwork at ETOC included observations of shopfloor work, eight employee interviews (with an average length of about 40 minutes), two focus groups, and the collection of documents such as bills of materials, technical drawings, and component lists. The study of MPC's shopfloor included 12 days of observations of shopfloor work, eight interviews with workers, and four interviews with management (with an average length of about 38 minutes), three focus groups with management, and the collection of documents spanning the machines' information spaces. During the interviews, we adopted the role of neutral observers [32]; although we know this does not make us unbiased, we sought to obtain answers from different perspectives that were as frank as possible. Whenever the interviews were conducted in other languages, we translated these into English.

Our data analysis and interpretation followed the principle of the hermeneutic circle, which suggests that "we come to understand a complex whole from preconceptions about the meanings of its parts and their interrelationships" [18:71].

CASE STUDY 1: ETOC

Case Context

ETOC is a Slovenian manufacturer of tools for sheet-metal transformation. Its customers insert these tools into large presses on their properties and use them to stamp sheet metal to create automotive metal parts (i.e. parts of cars' bodywork). The tools can have dimensions of up to 6 metres by 4 metres. Consisting of two assemblies, the matrix and the stamp, a finished tool houses up to several hundred individual components and sensors.

Figure 1: ETOC's Shopfloor

Except for some large cast-iron frames and some standard parts, the components are all manufactured in-house using both computer numeric control (CNC) machinery and manual operations (see Figure 1). Given these products' highly application-specific natures, the company has an engineer-to-order process. Normally only a single unit is designed and manufactured for any given order. A condensed overview of the production of a sheet-metal transformation tool on the shopfloor of ETOC may look something like this: After the design phase, the build process starts with the arrival of the large cast-metal frames from an external supplier that will later house all the components. These frames are first machined to close dimensions, as they later provide the support structure for all other parts. In parallel, the workshop begins to machine the custom metal parts, which will later be mounted on the cast-iron frame.

This process is time-consuming and involves several complex machining steps such as laser-cutting, milling, drilling, turning, hardening, and grinding. As soon as parts are finished on the machines, assembly workers begin to assemble the parts. There is no separate warehouse involved – either the assembly workers pull the components directly from the machine operators, or they are stacked beneath the assembly workplace. The same holds true for all standard parts, which are ordered from external suppliers.

Paper Affordances and Practices on ETOC's Shopfloor

At several junctures in this process, paper and its affordances are key to this shopfloor work. That is, key shopfloor operations are managed with paper. Documents are mainly printed by employees in project management or production management. The printouts are based on data available from the computer-aided design (CAD) or enterprise resource planning (ERP) system. Documents include for instance large-scale assembly drawings and bills of materials (BOMs) for assembly workers and production orders for machine operators. The printouts are then handed to the shopfloor workers and later, where appropriate (e.g. completed production orders), recollected, filed, and imported back into the ERP system so as to update the data. Thus, updates in the ERP system can easily be delayed for up to 24 hours.

A use of paper we observed was the creation of individual, ad hoc information spaces. We found that paper has unique properties that facilitate this process: It is very malleable and can be attached to objects or bent around them, is available in large sizes, can be cut into pieces and is always readable if there is sufficient light. These are some of paper's properties. Workers place paper where it seems appropriate to them and stack paper documents upon each other to make their interconnections easily visible. Further, given paper's easy mobility, they put it directly on the tool they are building or on top of other components. We may say that the workers blend the paper-based information into their work environment. With paper documents, workers can place the information directly where they need to consume it: directly where the work is done or where sufficient space is available for large-scale printouts. The amount of dirt on paper (see Figure 2 and Figure 3) may give an impression of usage frequency and usage intensity in this harsh environment.

Figure 2: Paper's Malleability

Workers also alter the content of the presented information by adding their own extensions in the form of markings and notations. As one can see in Figure 3, a worker transformed a bill of material into an assembly checklist and into a progress indicator, simultaneously. This is a recurring practice. The paper-based BOM is especially interesting for its different uses: Besides its traditional use as a components list, ETOC extended information with a rough trajectory through the various machining steps. Thus, the BOM also provides a map on which workers see where these parts could reside if not found in the intended place. However, as this information is not real-time, ETOC only labeled the rough production steps, not the machine performing the operation. Since there are often several machines with equal capabilities, the parts are dynamically scheduled to them. Nonetheless, this augmented BOM provides some hints when workers need to search for parts. Workers also extend the information on paper using their own notations. Sometimes the BOMs are used as a 'script', and workers tick off the parts they have already assembled.

On this shopfloor, paper documents also trigger personal interaction during handoffs. For instance, the machine operators don't retrieve the production orders by themselves.

A machine operator told us: "*Yes, the boss [the production manager] comes in with a list of what will be produced on the machine." (I4).*

This allows the production manager and the machine operators to talk, engage in micro-adjustments of their work, clear up potential misunderstandings, ask questions, and so on. Thus, the information on paper is also accompanied by a brief face-to-face interaction. The machine operators are approached by assembly workers, who want to retrieve updated information when their parts are completed. As shown, the information on the BOM is either too unspecific on paper or is already outdated.

At first sight, this just delays production. But it also sparks social interactions between an assembly worker and machine operators, allowing for further micro-adjustments. While larger deviations from an original production plan (such as reprioritization of the production sequence) would require the production manager to engage in the decision-making process, minor adaptions (such as a quick reworking of a part that doesn't fit) might not be a problem.

In addition to the opportunities for blending with the environment, marking, and personal interactions, paper may also be said to have limitations – there are challenges associated with the medium. Generally speaking, a paper-based organization of the work process runs the risk of not being able to fully provide timely and synchronized information access. A project manager notes: "*Sometimes, I don't have an overview of the whole project. Sometimes, I don't get the full information, or I get it at the wrong time, mostly too late." (I5).*

To address this challenge of working with paper and printouts, at the start of each shift, the project manager manually compares the BOM to the de facto progress on the shopfloor. The information he gets from different paper sources is incomplete and references different points in time: *"[…] we have a [computer program] on which they can solve it. But it is not for all parts, it is not real data. Some workers don't fill it in." (I5).*

The idea is that the workers must enter their paper-based information from the various worksheets and other documents back into the ERP system. However, this is not done consistently by everyone, which causes problems, to a degree where the information in the ERP system cannot be relied on.

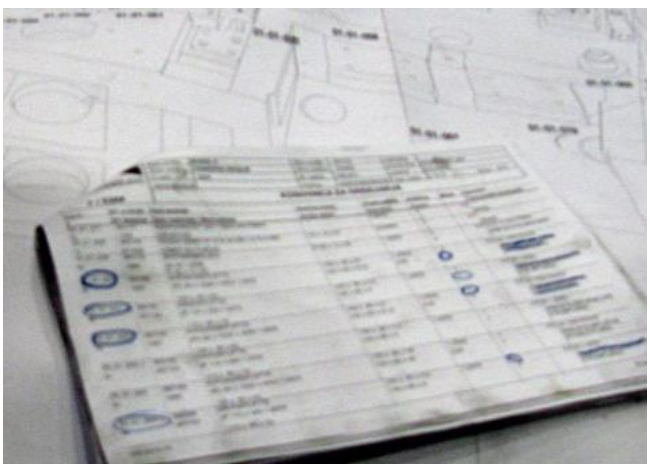

Figure 3: Augmenting a BOM with Custom Information

Further, the shopfloor operations scheduling is done manually, using primarily paper-based documents. Thus, most of the planning-related information remain with certain persons, for instance, the project manager, and are not readily accessible to others, such as other managers or assembly workers. This means that either the person interested in this information must directly approach the corresponding co-worker and must ask him face-to-face, or must search for this information in the physical environment, which is often time-consuming. A typical morning start for the project manager for instance involves getting a picture of the progress made during the last shift. This takes about an hour. To do this, he checks the general workshop status, which pieces are missing, and the status of the finishing process. Once awareness of the overall situation is lost (or perceived to be lost), a complete reassessment of the situation must be done. This reassessment, as done by the project manager, currently involves tracking numerous pieces of information distributed across the shopfloor.

This type of challenge of building awareness with paper is one faced not only faced by the project managers; the machine operators and assembly workers also repeatedly try to regain sufficient awareness so as to be able to continue working. For instance, the assembly workers collect the necessary parts for an assembly step before an operation begins. If parts are not yet available, they talk to the machine operators, who are the only ones who can provide predictable short-term information on which parts will be finished next. If rescheduling is required (e.g. to meet deadlines), the production manager is involved, to acknowledge the rescheduling. Although the BOM provides hints about a particular piece's machining sequence, the current stage is not provided on paper, since this would require constant updates. The workers don't have the current machining operation on their list and must search for it themselves.

In sum, this case shows that paper readily affords the creation of personal information spaces via easy bending, placing, marking, and annotating of paper-based resources such as printouts; it also affords a personal touch when it is handed off. However, the case also shows that paper has trouble transferring information in a timely and predictable manner; especially the distribution of key documents (with markings and annotations) across the shopfloor challenges the establishment of a real-time overview or awareness for managers and workers.

CASE STUDY 2: MPC

Case Context

MPC is an automotive supply company. While it operates globally, we conducted fieldwork at a German plant, where (amongst others) different models of high-quality chain-tensioners are manufactured to tight specifications. Since these components are critical to engine reliability, the company's main objective is to deliver components that are 100% fault-free.

Although many production and assembly steps run fully automated and are controlled by sophisticated PLC systems, the human workforce is still needed throughout the shopfloor. Staff members' main task is to operate the machines, handle the pieces produced, and keep the machines clean and in good condition. They also perform regular maintenance, quality control operations, and complex retooling operations whenever they need to produce a batch of different types on the machines.

An outline of the manufacturing process of chain-tensioners on the shopfloor of MPC may look like this: The production is divided into several groups, each of which produces items for the final product and is part of the value stream. One of the main challenges is the just-in-time production, establishing compliance with the quantities and timelines without creating large stocks. The production runs 24 hours in a three-shift operation. The operator, tool-setter, and team leader roles basically describe the task within a shift. Operators work directly on the machines and maintain the production process. Tool-setters monitor the quantities and quality of the multiple machines, set up and retool the machines if necessary, and support the operator when required. Team leaders coordinate the operators and the tool-setters in every production area, and report to the product managers.

A typical day starts with shift handover, which involves operators, setters, and team leaders. During the handover, they – orally and in writing – exchange key information to the next shift. Owing to the large number of documents, information management is a major challenge, especially across multiple shifts or over longer time periods. For instance, several physical and digital shift logs document any occurrences during the shifts. After handover, the setters carry out the necessary maintenance procedures and document them. Also, the machines are calibrated and retooled to meet the current order requirements. The team leader records the product quantities several times a day in a paper template and compares these with the nominal number of production orders. Counting pieces is very time-consuming, and prone to errors owing to media breaks. If the required product quantities are reached, the machines must be retooled for the following order. At the shift's end, handover to the next shift takes place. The exchange of information between employees mostly occurs orally and is not well structured, which means the sharing and traceability of key information over longer periods cannot be guaranteed. Further, it is not possible to access relevant information centrally and efficiently.

Paper Affordances and Practices on MPC's Shopfloor

While MPC is arguably a high-tech and high-profit production company, we found that it deliberately relies on paper in many places on the shopfloor and paper has fixed positions throughout. The documents are fairly short (1 to 2 pages) and are visible under a protective film in close proximity to the workspace. Thus, the information spaces around the machines are designed to match the specific tasks. The documents fulfill different purposes – some are purely informative (e.g. efficiency statistics), while others coordinate recurring actions and have a checklist character (see Figure 5). The document in the middle is a checklist where employees place their signature when they have performed the required maintenance and cleaning operations. Documents that relate to each other are mounted in close proximity so as to ease information interlinking. Also note the different areas, where information is provided in a very structured way, mixed with empty spaces for unstructured information such as simple handwritten logs.

The large document boards (see Figure 4) support management discussions. This configuration allows several persons to have continuous access to all information in parallel, and the presence of paper serves as a reminder to talk about certain issues.

Paper documents facilitate social interactions during handovers. For instance, during handover, shift documentation is passed along and discussed. Further, paper fosters personal responsibility. Employees sign that they have performed certain steps and thereby deeply identify with the task. This activity is also tightly bound to the place of action and is therefore connected to the physical reality. If it were to digitalize these processes, managers would face a dilemma.

They recognize the benefits of vertical information integration, yet fear that digitization would reduce this coupling to the physical reality. Employees could take actions more light-handedly on digital artifacts than signing off at the work location immediately after a task has been performed: *"Who ensures that the workers don't tick the checkboxes later on their mobile phones in the cafeteria?" (I9)*

While workers enter certain information directly into the ERP system so as to speed up processes, they still need to enter the same values on their paper forms by hand. Using barcodes, workers tag the documents so that they can be referenced from within the ERP system once archived (digitally scanned). Some of these paper-based documentation processes and archiving activities are also required by their customers.

Some workers don't trust the systems: *"[…] some dispatchers [...]don't feel comfortable if they haven't manually sorted all this again according to their own rules. That is my concern here, to also have this effect when giving rigid instructions from the system" (I11).*

Figure 4: A Management Meeting Board on the Shopfloor with All Relevant Aggregated Shopfloor Data Displayed

Especially the quality assurance (QA) setting has proven insightful, since we observed very different stakeholders with different information-sharing needs. Already, QA workers act as problem-solvers and autonomous decision-makers, supporting the machine operators and tool-setters whenever quality-related problems arise.

However, it is hard to plan these operations, since (1) errors arise unpredictably and (2) it is hard to exactly time regular QA activities. These regular activities include for instance assistance from QA personnel when a machine is retooled to produce a different part. While the retooling is a planned process, given the complexity of such a process, it is hard to exactly time events, which simply emerges as a result.

From the perspective of a QA employee, this relates to the problem of insufficient information availability to make accurate predictions. As a result, the loads on these employees vary significantly. What the QA employees would need is a coherent picture of the current state of the shopfloor and a projection of future QA-relevant events. But the environment is spatially too distributed to be easily recognizable to them, and the available feedback information transport based on paper and direct face-to-fact communication is either too slow or too unpredictable.

In addition, providing spontaneous assistance to tool-setters and machine operators is difficult in terms of providing awareness. The quality assurer may visit the machine with close to zero awareness of what the progress status is. *"[...], he simply needs a better perception of the process, to be better integrated and to be able to better accompany, control, and influence it" (I3).*

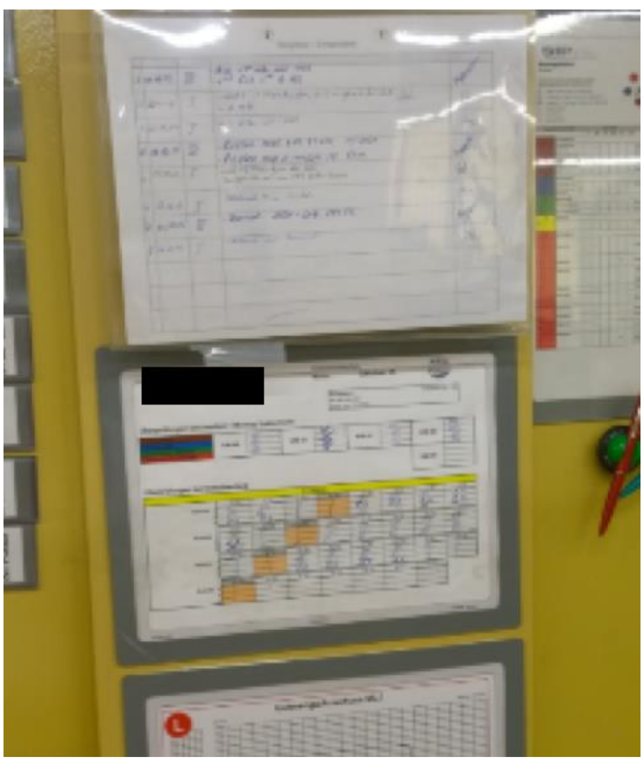

Figure 5: On an Assembly Line, Documents for Shift Entries, Quality Control, and Performance Data

The information this quality assurer received beforehand per telephone is often insufficient. Thus, as a first and time-consuming step, he needs to build a picture of the situation by talking to the staff at the machine to find out how the problem surfaced and what they have already tried. At the time of the interviews (2015), the quality assurer planned to start using a paper document to transport this information in the form of a ticket on which it would be mandatory to fill a description of the problem and the steps performed to resolve it – in other words, using the paper to convey situation awareness information. Here, the quality assurers actively try to manage the problem of perceived unpredictable feedback information quality by standardizing the format in which this information must be submitted.

In sum, our study of the MPC shopfloor shows that, also in a mass production environment, paper has a place and that its properties allow for effective designs of large information spaces, facilitates the integration of different documents, and explicates liability, thereby creating high information quality.

However, looking into the practices of QA employees, the task is so demanding from an information-sharing perspective that a paper-based approach doesn't seem feasible. Thus, employees use other media (such as telephone or direct face-to-face communication) to perform their tasks. Hence, digital technology must not only match the performance of paper but must significantly outperform it in order to yield the expected benefits.

DISCUSSION

We have studied the use of paper as a key information source and transport medium in two automotive supplier shopfloors.

These two companies differ in their manufacturing strategy (engineer-to-order vs. make-to-stock/build-to-order), are located in different countries (Slovenia and Germany), and have fundamentally different personnel costs and different shopfloor organization schemes (dynamic self-organization and hierarchical control). Still, paper's roles on both shopfloors are similar. Thus, we argue that paper's use in factory environments is neither a question of how advanced and innovative a company is, which basic organizational model it applies, or if it is in a high-wedge or low-wedge country. Rather, as shown, the value of paper derives from its interactional affordances for the cooperative actors on these shopfloors.

Notably, this argument runs parallel to the findings of MacKay [21] and of Ghosh et al. [7], who similarly underscore the key value and importance of paper's affordances in shaping practice, albeit in difference circumstances and settings. The specific practices of for instance air traffic control, microfinance, and – in our case – smart factories are inextricable connected to paper's affordances. We may assume that ending the use of paper in shopfloor settings would fundamentally change the practices applied there, too. This is because paper fundamentally shapes each of these practices. Further, we may observe that paper's affordances seem to be valuable in both the technology-rich settings of smart factories and for instance in the comparably technology-poor setting of microfinance in a developing region [7]. Arguably, the value of paper persists across diverse settings because its value derives from general interactional affordances, which may lend themselves to practices as diverse as smart factories in Europe and microfinance in Africa. This says something about paper's flexibility and how it may be fundamental to many types of contemporary practices. Having said this, we may also note differences across settings. That is, where paper's uses in smart factories and air traffic control [cf. 21] is mainly a question of efficiency and practicality, paper's uses in microfinance [cf. 7] is also encouraged by low cost, which is especially important in a development context.

We summarize our findings concerning the smart factory context as follows: we found four paper practice categories in both shopfloor settings: (1) creating and adapting individual information spaces, (2) reinterpreting information, (3) combining information handover with social interaction, and (4) visual cuing. In all these aspects, current digital alternatives are no match. We will now elaborate on this.

Creating and Adapting Individual Information Spaces

In both industrial cases, we have observed that individuals or teams deliberately design their information spaces to match their requirements by distributing the different documents in their physical environment. Many of these documents have a low page count and their entire content displays at once. This is notable, since it reflects the flat nature of the information hierarchy used to provide the information. In contrast to that, digital alternatives either feature visualizations such as *wizards* or *zoom and filter* [cf. 28] metaphors that deliberately hide information so that the entire content is never visible at once. The difference between the observed cases is the responsibility of the creation and arrangement of elements in the information spaces. While at MPC, the arrangement is largely predetermined by management and supervisors, at ETOC, the creation of information spaces happens dynamic. Another common observation is the *always-on* arrangement in the field of vision that also provides visual cues and reminders of unfinished documents and open tasks. Especially paper's flexible nature and robustness allows one to embed documents directly into the manufacturing process. This flexibility is hard to recreate in current digital systems, since this would require massive screen space. Augmented reality human-machine interfaces (HMIs) could be helpful here, but it should be noted that these entirely lack paper's haptics [30]. Further, a common cognitive task is to relate to and integrate different documents into the work environment dominated by machinery and physical objects. This is currently enabled by paper's malleability, which is wholly unmatched in today's digital alternatives.

Reinterpreting Information

As illustrated above shopfloor workers face the challenge of how to integrate many different information sources. We also observed how the workers update these many documents. Some of the documents are simple forms, and workers just fill them out as required. But first, several documents can be managed in parallel. Second, and more importantly, paper documents can be re-purposed by annotations. This differs from the known practices in the office world where annotation aids text comprehension [cf. 25] and shifts the meaning of a document (e.g. a bill of material) from something map-like to something script-like [cf. 27] and use as a checklist by simply marking what has already been processed. There were some differences in the observed cases. While MPC supplied its workers with much more predetermined checklist-style documents, ETOC provided more map-like documents. The interesting observation here is that paper provides easy transitioning from maps to checklists via annotation and from checklists to maps via complete representation that is always visible. Thus, questions like *What is the current state and progress of the construction process?* or *Which activities and tasks do we need to perform during machine retooling?* are easy to answer with paper documents, even if their initial character did not target this interaction. Since digital alternatives are much less malleable, the initially intended use is 'enforced' much stronger, and even the simplest interaction such as extending documents with arbitrary content becomes impossible if not initially accounted for in software.

Combining Information Handover with Social Interaction

Besides these personal practices, paper also facilitates social processes. In both case studies, we found support for Sellen and Harper's [29] assertion that document handover can initiate and support face-to-face discussion between a sender and a receiver. In the context of manufacturing, this exchange of additional information fills the gaps in the incomplete information on paper and also bonds people to the according processes. Knowing and meeting the person who is waiting for a part (see ETOC) differs from merely reading information on a digital device. Thus, care should be taken to retain these established social protocols when digitalizing such processes. Both at ETOC, when the production orders are distributed by the production manager, and at MPC, when teams hand over shifts, documents support social interaction.

Visual Cuing

So far, we have already carved out that taking paper away from people must be a well-considered decision. However, depending on the specific shopfloor, there are already problems when the information distribution speeds hits its limit via paper-based processes. Besides negatively affecting overall shopfloor performance, it primarily affects decision-making by impairing a decision-maker's capability to effectively gain sufficient situation awareness.

The unpredictable feedback issue also affects awareness in terms of perceptions of the environment [13,14]. When the information provided to a practitioner is incomplete or doesn't reflect the environment's state at a point in time, it cannot be utilized to generate a consistent overview of the current state of a shopfloor. The challenge is that, although shopfloor environments can be designed to supply a large stream of information simultaneously from several sources (e.g. by combining information sources with large information spaces), it hits limits with paper-based processes in terms of latency.

Once lost, situational awareness must be rebuilt. Given the size of typical shopfloors and the diversity and focus of an employee's work situational awareness, breakdowns happen at every major shift in activity (e.g. the service technician approaching a faulty machine or the assembly worker switching between two projects they are working on). If situational awareness is not efficiently conveyed, it must be obtained from interaction with the environment. But even if the information is available at the right time, synchronized, and well accessible, we may see breakdowns in terms of the prediction of future events. As the information updating speed of a paper-based process is low, it makes no sense to include data into the documents that immediately become invalid or inconsistent. Especially with paper, having this strict document co-notation, only information is provided in the first place that is correct and remains correct – facts from the past or information that is time-invariant altogether. In combination with the low latency, paper fails to deliver the real-time information required for predicting upcoming events on a shopfloor.

Nonetheless, there is still more room for purposeful uses of digital technology in manufacturing workplaces. Especially at some ETOC cases, workers fell back to paper use although their software offers the required capabilities. This may well be owing to a lack of organizational support and training on new procedures, resulting in outdated and missing pieces of information in systems. But, again, paper can be advantageous here, since one can work even with partial information only, while a software solution would need to explicitly account for it to function.

In sum, digitalization is a two-sided coin. On the one hand, focusing just on efficiency aspects [10,19] neglects all the positive aspects of working with paper that are deeply embedded in our society and workplaces. On the other hand, one cannot overlook the emerging problems of the slow paper-based processes. For the proclaimed new role of the human worker as a problem-solver and decision-maker, real-time information is vital.

CONCLUSION

By studying paper practices at two automotive supplier shopfloors, we were able to illustrate paper's roles as an information source and communication medium. Using the theoretical lens of affordances, we have discussed these roles from a material and a social perspective and have also elaborated on workers' need for situation awareness, which may increase in the years to come and may make the reliance on paper a growing problem.

This research has focused on the general problem of using paper in decentralized control environments. While we have been able to empirically ground our findings in only two case studies here, we know from other cases in the FACTS4WORKERS project the problem is more widespread and poses a risk to digitalization efforts in every manufacturing company. We do not claim that our results are representative. We are aware that our arguments' significance is limited owing to qualitative research's – well-known – restrictions. To assess the rigor of our research, we sought to meet quality demands such as multiple data collection methods, controlled deductions, and analytical generalizability [8].

We have identified several valuable paper practices that are at risk if the transformation process in a company is not human-centered, although we are only at the start of transitioning to smart factories. Further research is needed into how to retain the benefits of traditional paper-based systems while providing the real-time support, which only a digital system can offer.

Based on the results from these case studies, we currently work on developing exemplar shopfloor solutions, trying to retain a maximum of the established practices while supporting the workers with real-time information. Further, we plan to expand our study scope so as to get deeper insights into the phenomenon of companies staying with paper from other perspectives, such as from different firms or industries.

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