Interface Design in Next Generation Manufacturing

Ralph Baier, Srikanth Nouduri, Luisa Vervier, Philipp Brauner, István Koren, Martina Ziefle, and Verena Nitsch

Abstract With the advent of Next Generation Manufacturing, information and communications technologies have become an essential part of the production process, creating and providing data for all stakeholders. Given the high uncertainty in the likelihood of occurrence and the technical, economic, and societal impacts of associated transformations in production, we conducted a technology foresight study, in the form of a real-time Delphi analysis, to derive reliable future scenarios featuring the next generation of manufacturing systems. This chapter presents the interfaces dimension and describes each projection in detail, offering current case study examples and discussing related research, as well as implications for policy makers and firms. Interfaces play a major role in the provision of information. We discuss the trend of implicit user interfaces and the benefits of working from home. Implicit user interfaces are based on user inputs that are not directly aimed at giving a command, but are nevertheless captured, understood, and used by the computer system to provide a richer user experience. Working from home has many benefits, including reducing costs and dependencies. However, experts disagree on whether plant directors will manage multiple factories centrally via telework due to complete and real-time transparency of all operations in a digital system by 2030. The COVID-19 pandemic has shown that it is important to have such an infrastructure even if working from home may not be considered appropriate in many manufacturing companies. Mobile apps that support production management are one key issue in this context.

R. Baier (✉) · S. Nouduri · V. Nitsch
Institute of Industrial Engineering and Ergonomics, RWTH Aachen University, Aachen, Germany
e-mail: r.baier@iaw.rwth-aachen.de; s.nouduri@iaw.rwth-aachen.de; v.nitsch@iaw.rwth-aachen.de

L. Vervier · P. Brauner · M. Ziefle
Human-Computer Interaction Center, RWTH Aachen University, Aachen, Germany
e-mail: vervier@comm.rwth-aachen.de; brauner@comm.rwth-aachen.de; ziefle@comm.rwth-aachen.de

I. Koren
Chair of Process and Data Science, RWTH Aachen University, Aachen, Germany
e-mail: koren@pads.rwth-aachen.de

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1 Introduction

With the advent of Next Generation Manufacturing, information and communications technologies have become an essential part of production processes, creating and providing data for all stakeholders (Brauner et al., 2022). Interfaces play a major role in the provision of information. Although interfaces have always existed in industry and production, they have changed due to the development of automation technologies (Papcun et al., 2018). Nowadays, there is a distinction between internal and external interfaces. Whereas internal interfaces are usually extensions of a production system controls expanded to include additional process and control functionality, external interfaces serve to connect the production system with the surrounding production facility. Internal interfaces are mainly systems for user interaction, such as human-machine interfaces (HMI), machine and data acquisition, or production management (Weck, 2006). There are various types of HMI, depending on the field of application and the degree of automation or, conversely, human influence (Gorecky et al., 2014). External interfaces are considered the connection between the production system and the environment. Against the background of these two perspectives, manufacturing firms face high uncertainties regarding the management and design of open external interfaces and internal HMI. Dealing with these uncertainties is the topic of this chapter (see Fig. 1).

Using a novel real-time Delphi approach (see chapter "Applying the Real-Time Delphi Method to Next Generation Manufacturing" for a presentation of the method and the sample, as well as chapter "Big Picture of Next Generation Manufacturing" for an overview of the results), we developed propositions for different scenarios within Next Generation Manufacturing in 2030. As suggested by Gawer (2014), we used an integrative framework for platforms, distinguishing four dimensions: governance (e.g., open forms of collaboration; see chapter "Governance Structures in Next Generation Manufacturing"), organization (e.g., boundaries and decision-making; see chapter "Organization Routines in Next Generation Manufacturing"), capabilities (e.g., hybrid intelligence; see chapter "Capability Configuration in Next Generation Manufacturing"), and interfaces (e.g., open APIs and human-machine interfaces; see this chapter). In addition, and influenced by our shared experiences during the COVID-19 pandemic, we added a fifth cluster of propositions addressing the need for resilience in future digital manufacturing (see chapter "Resilience Drivers in Next Generation Manufacturing"). We provide a set of 24 validated projections based on 1930 quantitative estimations and 629 qualitative arguments from 35 industrial and academic experts from Europe, North America, and Asia. In so doing, we deliver a basis on which to substantiate academic discussions and which can support firm decision-making on future technological developments and economic implications that go beyond current speculations and siloed research.

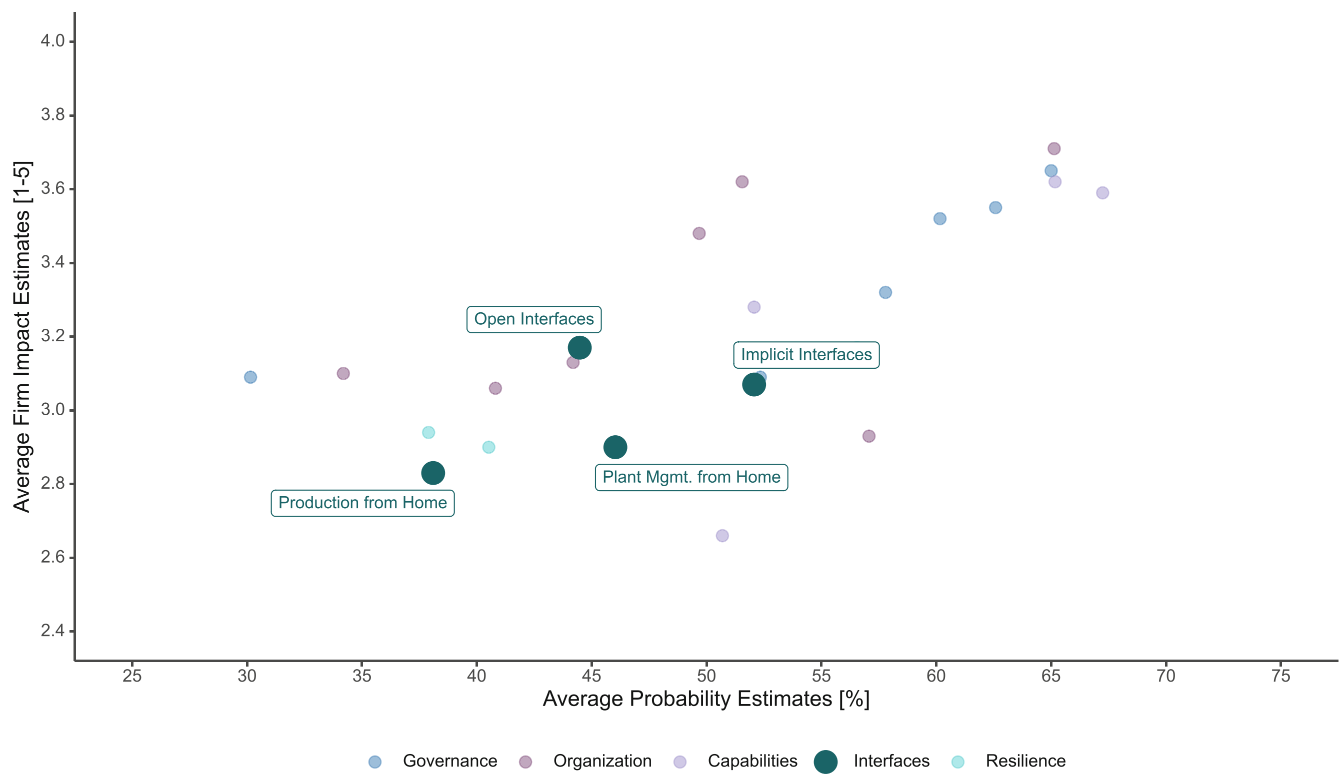

Fig. 1 Expert assessment on interface design in Next Generation Manufacturing (see chapter "Overview of Next Generation Manufacturing for the full results of the Delphi survey")

2 Projection 18: Implicit Interfaces

How we interact with computers and technology evolves constantly. While for decades the primary input devices have been keyboards and mouses (Dix et al., 2003), touch surfaces and voice assistants are now pervasive. In the near future, additional input and output devices, such as proximity or presence sensors and camera systems that can detect one's posture, intentions, fatigue, or mood, will enrich how we interact with technology (Brunner et al., 2021; Garcia-Garcia et al., 2017). Furthermore, while traditionally software systems have offered different users the same functionality and appearance, they have now become increasingly personalized. For example, past search queries, favorite songs, and shopping behaviors are integrated to give a better understanding of what we as users want and to provide search results, playlists, or shopping recommendations that better match our interests.

While these developments are mainly driven by consumer products and services, we assume they will continue and that there will be more implicit user interfaces in the future, including in production. Explicit user interfaces are ones where users interact with computers through direct commands – by either command line, speech, or a graphical user interface. In contrast, implicit interfaces are based on user inputs that are not intended to give a direct command, but are nevertheless captured, understood, and used by the computer system to provide a richer user experience (Schmidt, 2000).

Possible application areas of implicit user interfaces include human-robot collaboration (HRC) or decision support systems at the administrative level of manufacturing companies. For example, a robot at a hybrid workstation could detect the current workload of its human colleague utilizing a camera system and adjust its speed accordingly (Prewett et al., 2010). In the case of a decision support system for administrative tasks, the interface, the presentation of information, and the level of automation could be implicitly customized to best fit the human decision-maker's capabilities and current state and thereby reduce errors and workload (Kaber & Endsley, 2004).

AI-based approaches to both the recognition of human intent and selecting appropriate responses are being worked on to enable smooth and implicit interactions between people and technology. Despite much progress in the field of implicit interactions in production, many questions remain unresolved. For example, it is still a fundamental challenge for machines to reliably recognize human intent and to respond appropriately. Furthermore, transparency, traceability, security, reliability, trust, and social acceptance are unresolved issues.

Projection 18 states that in 2030, human-machine interaction will have evolved away from explicit interaction, where the human operator has full control of the actions of the production system's entities, toward implicit interaction, where the system automatically adapts to the human operator's behavior by detecting and predicting their actions and modifying these actions accordingly.

On average, the members of our expert panel assessed this trend as having a medium probability of occurrence by 2030 ($M = 52.07\%$, $SD = 17.93\%$) and a medium projected impact on companies ($M = 3.07$). However, there is disagreement among the experts on the likelihood of occurrence of implicit HMI by the year 2030. Consequently, there are both strong supporters and rejecters of this projection. According to the experts from our panel, the challenge lies in the complete development of implicit HMI, and 2030 is seen as most certainly too soon for this. Another problem is long machine lifecycles in manufacturing and thus slower adoption of new production machines that would explore the potential of future implicit interfaces. In addition, numerous unresolved issues regarding the social acceptance of implicit interfaces must be addressed by academia and industry. From the development of explicit interfaces for Next Generation Manufacturing, we already know that interface design, privacy perception, and trust in technology play essential roles in successful interaction and that human factors must be considered from the beginning of the technology's development (Hoff & Bashir, 2015; Valdeza et al., 2015; Brauner et al., 2022). Implicit interfaces for Next Generation Manufacturing must be designed to support employees in their work while being aligned with their expectations, norms, and values. Approaches to this include new implicit and explicit interfaces in Next Generation Manufacturing being developed in a stakeholder-orientated way together with employees (user-centered and participatory design) to identify and mitigate possible acceptance and interaction barriers at an early stage. Otherwise, companies risk losing the motivation of their employees through a lack of perceived utility, autonomy, and self-determination (Deci & Ryan, 2008), all of which are urgently needed for the upcoming digital transformation of production.

3 Projection 19: Open Interfaces

To enable data-driven services across organizational boundaries within Next Generation Manufacturing, the IT systems of two companies must communicate with each other to exchange data. Interfaces act as points of contact between involved stakeholders and are thus technically the foundation of distributed computing. Service-oriented architectures allow enterprises to encapsulate business functions in well-defined components. A look back at history reveals the role of open interfaces as a catalyst for the internet and computers in general. A computer with all its many different components from different manufacturers would not work without commonly defined and used interfaces. The internet makes this clear at the level of communication. It was only by means of standardized protocols that it became possible for all kinds of devices to communicate with each other via a local or worldwide network. Open interfaces are considered vital in Next Generation Manufacturing (cf. https://openindustry4.com/), as they make data exchange between manufacturers, customers, and service providers possible. The German

Standardization Roadmap Industrie 4.0 mentions that harmonized interfaces presuppose that these are based on standards and coordinated specifications.

Among the experts surveyed as part of the Delphi study, there is clear disagreement on the regulatory requirements for introducing open interfaces by the year 2030. The probability of this projection is estimated to be 44.48%, with a comparatively low standard deviation ($SD = 21.77\%$). The experts predicted that it would have a medium impact on firms ($M = 3.17$). The experts see two ways in which open interfaces can be established: through regulations or through (proprietary) standards from companies that become established on the market. The feasibility of implementation in the next 10 years is considered unrealistic, not least because resistance is expected from companies that want to protect their know-how. Nevertheless, the experts see open interfaces as a game-changer and a way to reduce costs and dependencies.

In the future, this certainly means that individual manufacturers will have to keep their products at least compatible with open interfaces to remain competitive. Companies will not risk running into a dead-end of incompatibility with their machines or robot fleets. An example of an open interface with standardized communication is the OPC Unified Architecture (OPC UA), a machine-to-machine communication protocol for industrial automation. It is freely available and implementable under the GPL 2.0 license and focuses on communication between industrial equipment and data collection and control systems.

Benefits of standardized interfaces in Next Generation Manufacturing include easier integration of products into production networks, coherent documentation, information about interaction possibilities, and streamlined modularity between components of various manufacturers. Some general concerns regarding interfaces include security-related aspects like possible entry gates for hackers and exploiters. Overly complex standards or overlooking configuration basics can also be potential problems. A prime example of this is keeping the default settings for access control (Dahlmanns et al., 2020).

Secure and sovereign data exchange among industrial partners is of overall strategic importance. The International Data Spaces Consortium is working on standardized processes, metamodels, and a technical reference architecture to enable data exchange. These go beyond pure (technical) descriptions of data exchange and enable new deployment scenarios, such as the inclusion of an independent third party to monitor and regulate policy-based data sharing between two organizations (see chapter “Governance Structures in Next Generation Manufacturing”).

4 Projection 20: Production from Home

Rapid advancements in digital technologies for industrial applications are promoting the transformation of conventional production facilities into cyber-physical systems (CPS; Schumacher et al., 2020). Although these modern technologies have great application potential and have shown promising results in the research phase, their development as of today is not yet sufficient to meet real-world challenges. Therefore, it is farfetched to expect that all the operations at a production facility will be compatible with employees working from remote locations by 2030. The expert survey resulted in disagreement as to whether production employees will operate their workstations from home ($IQR = 3.00$), and the experts in this field do not expect that employees will predominantly work remotely by the year 2030 ($M = 38.10\%$, $SD = 24.93\%$). As well as this low probability rating, the experts do not believe that remote work will have a significant impact on the future of production ($M = 2.83$). While experts from the industry estimated this probability to be 37%, experts from academia estimated it to be 40%. Additionally, the experts from Germany gave lower estimations for this projection (probability: 33.10%; firm impact: 2.62) compared to those coming from other parts of the world (probability: 51.25%; firm impact: 3.38).

The COVID-19 pandemic has shown that there are situations for the industries where working from home can still help maintain production. Siemens, for example, has used this experience as the basis for its "New Normal Working Model" policy (Siemens, 2020). This agreement allows employees to work from home 2–3 days a week. Remote working can be beneficial for those who can utilize flexibility in their schedules to improve work productivity. While tasks, like modeling, simulations, documentation, etc., can be completed on a workstation from a remote location, the physical presence of a substantial portion of the workforce is required for shop floor operations. Although industries currently employ advanced robotic solutions for ongoing operations, remotely controlling artificial intelligence-based agents (cognitive robots, cobots) and having them perform comparably well to natural ones (human workers) still pose difficult challenges (see also (P7) to (P9) in chapter "Organization Routines in Next Generation Manufacturing").

For instance, in an automotive manufacturing facility, industrial-grade robots handle tedious tasks like material handling (transferring, stacking), processing operations (welding, painting, assembly), and final inspections. At the same time, a worker on the shop floor takes care of the tasks that require human intervention (system maintenance, machine tools setup, equipment repair). The ability of such experienced technicians to work remotely mainly depends on the need to use specialized equipment and make machine-assisted decisions. Closely related to the question of the systematic acquisition of expert knowledge (P14), it will be necessary to determine the nature of the information (visual or audiovisual) a worker needs to interpret so that this information can be incorporated into the decision-making process. Therefore, fundamental research that focuses on remote interactions between humans and production systems is needed to enable the execution of production tasks from workspaces at home in the future (Lund et al., 2020). A better understanding of human cognition is a primary requirement for passing these milestones, and this can be based on work in the fields of human-robot interaction, information visualization, and interface design.

As research in these fields is still embryonic, it is not fundamentally excluded that remote work will take place from beyond the shop floor, but it is only occasionally assumed that this can happen via working from home. At the same time, some see working from home as an option for tasks in more strategic areas, and industries are currently progressing in the direction of so-called hybrid offices, a mixture of telework and presence work. Looking at the reasons given for moving toward hybrid offices reveals a wide range of arguments, such as that human beings are social animals that rely on day-to-day interactions to survive and thrive. However, as part of the changes associated with Next Generation Manufacturing, Schwab (2017) points out that combining different technologies like robotics, mixed reality, and artificial intelligence could blur the lines between the physical and digital worlds, which would have a substantial influence on the workplaces of the future.

5 Projection 21: Plant Management from Home

In this projection, the perspective has changed from shop floor operations to that of the higher-level management. Here, the addressed question is whether, by 2030, plant directors will manage multiple factories centrally via telework due to complete and real-time transparency of all operations in a digital system. The experts from the Delphi study rated the probability of occurrence as medium ($M = 46.03\%$, $SD = 25.61\%$) and the firm impact as low ($M = 2.90$). Experts from both industry and academia gave similar estimations. While the German experts estimated the probability for this projection to be only 39%, experts from the rest of the world estimated it to be over 64%. Additionally, the firm impact was as low as 2.67 in Germany and higher in the rest of the world, at 3.50. There is strong disagreement among the experts on this topic ($IQR = 4.00$).

The differing opinions of the domain experts elicited several competing arguments. On the one hand, experts who estimate a lower probability of this projection emphasized two reasons: the timeline requirement for this implementation and the importance of human-to-human interactions among the top management. On the other hand, those experts who foresee a higher probability of occurrence stated that many aspects of this hypothesis already exist today and the implementation of remote plant management is more likely than remote production. Among the many infrastructural and technological hindrances mentioned, security risks associated with remote desktop connectivity and installing communication channels in residential buildings are prominent. Also, studies have long shown that frequent in-person interactions can lead to commitment, support, and cooperation among people on teams (Fayard et al., 2021). For some experts, this approach is incorrect as they believe that factory management is all about addressing problems directly on-site, and therefore handling such issues from home could be ineffective. Although it is also argued that the feasibility of remote management depends on the size of the factory, simpler tasks such as machine status queries can be handled remotely by the factory management, and facilitating such provisions would increase technological progress in this area.

The recent COVID-19 pandemic has shown that it makes sense to have such an infrastructure even if working from home may not be considered appropriate in many manufacturing companies. Mobile apps that support production management are one key issue in this context. Monitoring machine statuses in a digital twin of the factory via apps that support virtual execution of shop floor operations is a promising application prospect. Here, the key question that arises is which tasks can be carried out via telework, and it turns out, from the investigation of Lund et al. (2020), that it is not easy to answer this question. It is no surprise that working from home can affect highly qualified, well-educated employees and an increase or decrease in their productivity depends on the type of the task (Wu & Chen, 2020). However, Lund et al. (2020) also found that more than 20% of employees can work from remote locations for more than 2 days a week while being just as productive as if they were working from their offices.

Mobile applications for production management promise more flexibility and up-to-dateness, irrespective of the use case (telework or presence work). An optimized yet simplified decision-making process can be expected if users are presented with the right information at the right time and in the right way via a mobile application. Decision support systems in production can add real value to the process if they succeed in handling data from analysis using artificial intelligence-based agents to provide meaningful presentations for people in real time. Similarly, other aspects, like automated support, questions of liability, etc., will also become more relevant in this context.

6 Summary

In this chapter, insights about different types of human-machine interfaces were discussed, based on the results of the expert panel.

In projection 18, the question was raised of whether implicit interfaces will become established in the industry and whether they promise added value. Our expert panel could not provide a clear answer to the question. The typically long service lives of machines are seen as a particular obstacle, which noticeably slows down innovations in this area. This projection will depend on other factors, such as the retrofittability of the implicit interfaces. Retrofittability has worked before, for example, with numerical displays on production machines such as milling machines and lathes. Another aspect may be the attractiveness of the workplace with respect to the impending shortage of skilled workers. If implicit interfaces make work easier, then higher motivation, lower downtimes, and a lower error rate can also be expected. These inevitably lead to increased productivity, which is why retrofitting or even renewing the machines can pay off.

The question of whether, in 2030, regulatory requirements will demand open and standardized interfaces for data exchange for all kinds of manufacturing equipment was expressed in projection 19. There is disagreement among the experts regarding this projection, although they agree that open interfaces can only be introduced through legal regulations or if a manufacturer prevails on the market. However, it should not be underestimated what is happening in universities and other organizations in the field of open-source projects. A good example of this is the Robot Operating System (ROS), an open-source robotics middleware that originated at the Stanford Artificial Intelligence Laboratory as part of the Stanford AI Robot Project (STAIR) and is now widely used and making its way into the industry.

Projection 20 dealt with the question of whether, in 2030, production employees will operate their workstations from their homes, using remotely operated robots. The general question about working from home at the shop floor level cannot be answered conclusively: it is necessary to look in much more detail to identify which activities could be carried out remotely from home. For some of the interviewed experts, this will simply not be possible. For the rest of the experts, it is then necessary to clarify the extent to which teleworking makes work easier for the employee. Telework is not in itself a reason for enterprises to introduce it. It is rather a question of the workplace's attractiveness, flexible working hours, or prevention of infections or injuries. Many researchers believe there will be a hybrid form in the future, and research is currently being conducted in this field.

Finally, projection 21 focused on the scenario in which plant directors would be able to manage multiple factories centrally from their home office due to the complete and real-time transparency of all the operations in a digital system. In contrast to the shop floor level, management is more abstract. The processes that occur are not necessarily linked to and therefore dependent on physical objects. Management is therefore inherently more suited to teleworking, at least superficially. However, here too, the question must be asked as to what benefits and advantages the employee receives from teleworking. For example, a disadvantage is that personnel management, in particular, requires personal interaction. In this field, researchers agree that we will also end up with a hybrid solution. The experts interviewed did not consider the issue very relevant, as the group of people affected is small. They pointed out that some functions – especially in monitoring – are already possible. They also stated that personal contact and human-to-human interaction are important, especially as a manager.

It must be highlighted that several of the projections in this study have the potential to be used in the future: projections 18, 20, and (in parts) 21 show that it is possible to facilitate work and increase productivity at the same time. Furthermore, the attractiveness of workplaces can be increased with more flexible working hours and protection against infection or other dangers due to teleoperation.

Considering all the projections in this dimension, it becomes apparent that the HMI projections evoke various challenges at first glance. For a long time now, HMI has no longer consisted of buttons and switches only, but rather of incorporated digital displays, dashboards, and touch screens in modern control systems. It is possible to divide the challenges into general potential and barriers on a meta-level. As in all transformation processes, where interactions between humans and machines take place, it is essential to consider the humans' needs, at least initially, to increase acceptance (Hartson & Pyla, 2018). Acceptance is understood as the willingness to use or work with a specific type of interface. In essence, acceptance is largely determined by the ergonomics and usability of a technology. Thus, the mentioned aspects regarding the results of the Delphi study should be understood as indications for the successful implementation of a roadmap to the transformation into Next Generation Manufacturing.

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