Industry 4.0 Visions and Reality- Status in Norway

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Abstract.

The concept and vision of Industry 4.0 has been around for almost a decade and gain a lot of momentum and attraction globally. Central to the vision of Industry 4.0 is the concept of a "Cyber-Physical system", linking the IT elements of an enterprise (Cyber) with the physical system (man and machine) of an enterprise. This vision is well known and promoted as crucial in radically transforming todays manufacturing industry. While there is a plethora of papers and studies of the various "cyber" aspects, the concept, visions, benefits as well as the downsides of Industry 4.0, few papers have much to say about the actual implementation. Based on a digital maturity mapping of ten front line manufacturing enterprises in Norway this paper analyses implementation at shop floor level of both cyber and physical system and their interaction. From the survey data a clear picture emerges of the development of a cyber system, as well as worker usage and benefit of the system. However, the two systems don't interact very well, worker interaction is limited to plain old keyboard usage, instead of employing more mobile, handsfree, voice based or similar interaction methods. Currently there is no cyber-physical system, rather a burgeoning cyber system poorly linked to the physical world. If the cyber-physical system is to be realized there is a need for a rethinking and upgrading of man-machine interaction.

Keywords: Smart Manufacturing & Industry 4.0, Human-Machine Interaction (HMI) & Operator 4.0, Cyber-physical systems, Survey, Norway

1 Introduction

Industry 4.0 (I4.0) as a concept and vision has been around since 2011. If not countless, at least thousands of academic papers have been written on it over the whole world. Most of these papers focus on the technological elements of I4.0, but there are enough papers outlining the concept and its merits. The human aspects of the concept, on the other hand, remain under researched.

While I4.0 is a German concept in its origin, it has become quite popular in Norway and other Nordic countries. Through whitepapers, workshops, networks, industry and government agencies, the idea has been promoted and encouraged in Norway. However, there has been few, if any, attempts to measure implementation rate or benefits for those implementing it. While some case studies exist, no surveys of status of I4.0 in

Norwegian industry exists, and no one knows what the industry is struggling with in its implementation. This paper employs survey data to describe the situation in a group of frontrunning Norwegian manufacturing companies, participating in a national strategic research program called "Sustainable growth of Manufacturing".

2 Visions of Industry 4.0

I4.0 refers to the current trend of digitalization, automation and data exchange in manufacturing. According to the I4.0 Working Group, the German originators of the I4.0 initiative, progress in the field of information technology and concepts such as Internet of Things (IoT) and Cyber-physical systems (CPS) pave the way for a "fourth industrial revolution" [1, 2]. Cyber-physical systems are merging the virtual and physical world through embedded networks which are capable of monitoring and controlling physical processes. These systems detect data from physical objects through sensors and is interacting with physical processes via machinery, actuators and human movements [3, 4].

The current digitalization of manufacturing challenges the traditional role of industrial workers[5]. A shift from physical, repetitive and low skilled work to more complex and cognitive tasks is anticipated [1, 6, 7] Operators at the shop floor will probably need to control more machines simultaneously and thereby know more about the production processes in the future [7]. In order to handle the increasing complexity of production and surged data flows from cyber-physical systems (CPS), the operators need to be supported by well-functioning assistance systems [7].

2.1 Operationalization of Industry 4.0

In a much cited paper by Hermann et al. [2] four design criteria were outlined, these four criteria must be met for a system to be called an I4.0 system:

- Interconnection: This is the systems ability to communicate and collaborate internally and externally (human-human, human-machine and machine-machine). Wireless communication with sensors, IoT and IoE is a critical part of this. It also includes the security aspects of the systems.
- Technical assistance: This is the system's ability to offer assistance to humans in their work, both virtual assistance (information, cognitive support) and physical assistance by various tools.

- Decentralized decisions refer to the system's ability to delegate authority of decision making from managers through operators and ultimately to machines.
- Information transparency refers to the fusion of the physical and virtual world through the linking of sensor data with digitalized plant models, enabling the creation of a virtual copy of the physical world (Digital twin).

2.2 The human aspect of Industry 4.0

I4.0 is criticized for being just another "tech-concept". However the I4.0 literature, actually accentuate the human factor and consider the vision of a completely automated factory as neither desirable nor realistic [9]. The proponents of I4.0 expect digital assistance systems and a new generation of collaborative industrial robots to make work more exciting and rewarding across all hierarchical levels [1, 2]. Hence, in order to create an optimal cyber-physical system, the human workers should be able to interact and use the cyber system as much as possible. As I4.0 is introduced to enterprises, this becomes even more prominent. With the advancement in technology "*the number of computing devices that a person uses is increasing and there is a need of faster and non-intrusive methods of communicating with these devices"* [11].

3 Survey method, questionnaire and sample

3.1 Design of survey

Sustainable growth of Manufacturing is a cross-disciplinary center for competitive high value manufacturing in Norway, established in 2015. Its vision is that with the right products, technologies and humans involved, sustainable and advanced manufacturing is possible in high cost countries such as Norway. I4.0 is a key element in this vision of preserving Norwegian manufacturing and keeping it competitive. In the spring of 2017, it was decided to carry out a survey for mapping the digital maturity of the participants. The participating companies were concerned about their ability to implement I4.0 and wanted an analysis of their performance.

It should be noted that the enterprises in question clearly belongs to the more advanced group of Norwegian manufacturers. While they vary in product, ownership, geographic region in Norway, they are all exporters with decades of operation at the location investigated. They are also strategically thinking regarding development, and they have all earlier experiences working with research milieus and use considerable internal efforts on this.

3.2 Designing and implementing the survey

A cross-sectional study was carried out in ten Norwegian manufacturing companies, covering all organizational levels and roles (N = 3188) in spring/summer 2017. The survey was constructed in dialogue with the enterprises building on the I4.0 design criteria. However, "interconnection" and "information transparency" were dropped from the survey, because the respondents (especially at shop floor level) were not expected to have knowledge of these issues.

The study was mostly conducted via email, but some paper copies were also distributed. After repeated follow-ups, the total sample consists of 1023 male and 160 females. With a total response rate of 37% the sample can be said to be representative of the participating enterprises, but as outlined the participating companies are not representative of the Norwegian industry. Within the enterprises not all respondents were relevant in the sample, given our focus on production and production workers. The sub sample (n = 305) of interest in this study are operators working in the production hall. When looking at the whole sample together, the most frequently age range are 41 to 60 years (59,67 %), and 9,8 % were women.

4 Results

4.1 Existing digital tools and systems at shop floor level

We surveyed a set of digital tools and systems at shop floor level. Figure 2 reports the usage of each digital tool. Note that this finding supports the prediction of Fatima et. al [11] on number of devices, numbers of devices per user are now clearly above 2 on average. A total of 98% of the respondents are using computers in their work. Computers are both a traditionally digital tool, but also an extremely powerful and versatile tool. It can be integrated with all kinds of systems and for almost all kinds of digital tasks, including of course all administrative tasks. However, as can be seen from Figure 2 the PC is not the only tool used. The typical operator uses several tools, new tools are added to the old, not supplanting them. As we can see, 61% are also using portable smartphones to carry out their work. Only 7% are using tablets or smart watch, and less than 3% voice control from portable equipment or smart glasses. In addition to PCs, Smartphones and Photo/video, we can see a fair use of "cybersystems". 58% use MES,

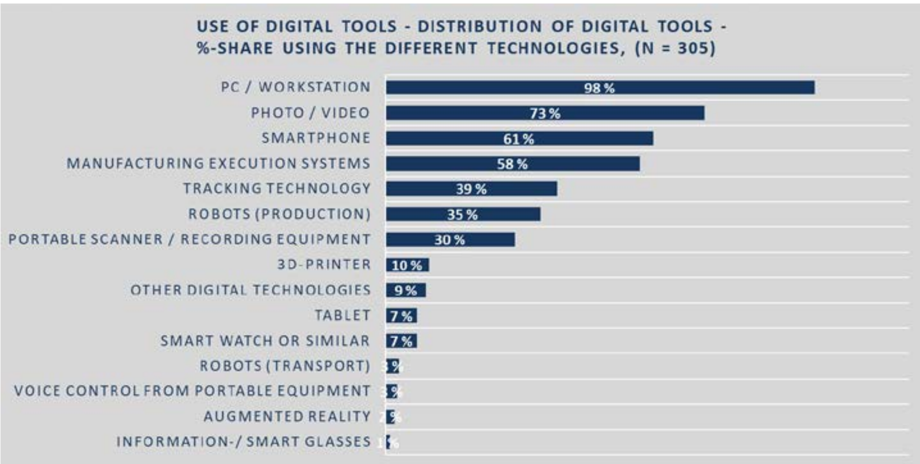

Figure 1 Digital tools employed at shop floor level. Percentage using this tool in their work.

all ten companies employ MES. Tracking systems (RFID and similar), robots and portable scanners are used by 39, 35 and 30% respectively.

For those workers that have administrative tasks such as record- and documentation of quality, ordering components and planning own production in their work description, a total of 67-77% have digital systems to perform these tasks. More specifically, 77% of the respondents uses digital systems for documenting product quality, compared to 20% that only have paper or oral documentation systems. Also, about 70% of the respondent group uses digital systems for orders, production planning and maintenance. Thus, it seems like I4.0 has gained some position on the shop-floor, as digital tools and systems is available, a least to some extent, at the shop floor level.

As outlined in the design principles of I4.0, supporting companies in identifying and implementing I4.0 scenarios, decentralized decisions is the ability of cyber-physical systems (machines) to make decisions on their own and to perform their tasks as autonomously as possible. Only in the case of interventions, exceptions or conflicting goals, are tasks delegated to a higher level (humans). However, only 9% of the respondents in the study report that ICT systems suggests or take decisions in normal operation, 29% report that people and ICT-systems cooperate to some degree in proposing and evaluating solutions, while 47% reports that all decisions are made by people in production. 16% reports they do not know. Thus, the I4.0 transformation towards decentralized decisions has started, as digital decision tools are to some degree available at the shop-floor level, but there is a lot of remaining work before reaching an I4.0-level.

For those respondents having access to digital systems in own production planning (N=156), only 6% have access to portable information (information available on the body through smart phones, tablets, smart watches etc.), and only 40% experiences that the information is updated instantly if any changes. Most workers have the information for use in production planning available at the workstation (82%), thus limiting their ability to move around at the shop-floor and at the same time have full control over production to continuously being able to optimize their production planning.

4.2 User, perceived usefulness and quality of digital technology

85% of the total sample size of N=305 uses digital tools to get information about the production in their work. However, only about half of the respondents that receive this type of information digitally, believe that the information they receive is sufficient (54%), updated (47%) and understandable (51%). Thus, the perceived quality of digital information about the production at the shop-floor level has room for improvement.

Still the operators see digitalization as useful for carrying out work tasks. More than 70% of the respondents believe that the quality of work gets better, and they get the work done faster, using digital tools. Also, about 60% believe that they get the work done safer, and by using digital tools gets work done which could not be carried out without such tools.

5 Analysis

5.1 State of the Cyber-systems

The survey clearly identifies the beginning of a cyber-system. We can see that the investigated companies have implemented manufacturing execution systems (MES), they use robotics and production planning systems, and have started to delegate authority to machines. The changes have reached the shop floor level, operators find the information useful albeit incomplete and rely on it in their work. Coordination, information, maintenance and order planning is being done digitally for two thirds of the operators. We have not discussed issues of interconnection (connectivity and security), but we know that the system is at least functioning in a daily work setting. While we clearly can see the beginning of a cyber-system, it is also clear that there is much potential for further development. Information is not perceived as trustworthy for half of the users, it is real-time for only 40%, and a third of the workers are not using digital coordination and order planning.

5.2 State of the Human computer interaction

"The ultimate aim is to bring HCI to a regime where interactions with computers will be as natural as an interaction between humans" [12]. We can see that this is not the case in these companies. The most frequent form is still computer interaction, taking place via a keyboard and a mouse. Historically we interacted with computers as "key strokers" working on a keyboard. Over the years several new features and possibilities have been introduced. The first major update was the introduction of touch-screens, providing lightweight mobile and easy to use interfaces relying on wireless communication. From now on we had evolved into "screen pawers", and as can be seen from Fig 2 at total of 61 percent use their smartphone and 7 percent their tablet in work. The second upgrade is a set of technologies including virtual reality, augmented reality, various voice control and voice command systems, gestures/hand movements and eye movements. Even brain waves are now possible [13]. We can call that third generation "data whisperers", since several of these systems allow for speech commands. However, use is limited still and interaction between man and machine is happening through computers using keyboards or through smartphones/tablets.

To what degree are those various tools suitable at shop floor level? We will analyze this along two dimensions, mobility and the need to for the operator to employ his/her hands in interaction with computers. Starting with the latter we can see that an operator at shop floor level moves around and uses his/her hands a lot in the operation, it would seem obvious that an easy interaction should be mobile and allowing for hand-usage in work. PCs are not a good choice, relying on keyboards and hand usage. Neither are smartphones, because information must be retrieved by key-stroking or touching screens, and thus limits other hand-usage and ties the operator up in the task of commanding the smartphone instead of doing his physical work. Voice commands would be very appropriate if the noise level allows it, and eye movement would also be a good option for a worker.

Regarding mobility, PCs are not a good choice because they are stationary, which significantly reduces the operator's ability to move freely and still getting access to updated and important information when he needs it in his work. Smartphones are a powerful portable device that is easy to carry along and deploy, often has a very simple user interface and is user-friendly as most workers utilize this digital tool more or less all day outside of work. It can provide necessary real-time information and is very flexible in use as one can gain almost any information through the internet. Of course, as the smartphone is very flexible it can support voice-control or hands-free usage though customs applications delivering important information through speaker or headset. Digital tools such as smart glasses or voice control, though often not as flexible as smart phones, are completely hands-free, and thus support the operator in doing his/her tasks while at the same time receiving information.

However, so far it seems like operators' interaction towards digital systems in production planning is limited to plain old stationary keyboard usage, instead of using more mobile, handsfree, voice-based or eye-moving interaction systems. If I4.0-goals are to be achieved, operators at the shop floor will need to control more machines simultaneously, and therefore cannot be placed stationary in front of a workstation. As they most likely will need to know more about the production processes in the future to become strategic decision-makers rather than pure operators of machines, the operators will thus need to be supported by well-functioning portable assistance systems that provide the necessary real-time information which will contribute to letting them continuously optimize their own production planning.

6 Conclusion

Comparing the ideals of I4.0 to the reality of a group of frontrunning Norwegian Manufacturing enterprises we can clearly see the start of a cyber-physical system. There are digital tools and information in use at shop floor level, and decentralization of decisions have started. While we can see a start there is also a lot of room for improvement. This is especially true regarding the human parts of the system. Our findings indicate that the employees on the shop floor lack the necessary digital tools and assistance systems to form a truly interconnected cyber-physical system. Old (digitally speaking) human computer interactions like computers dominate.

Some respondents use mobile digital tools, such as tablets and smartphones, but they are not nearly as common in manufacturing as in people's private lives (this is the case in Norway at least). Technologies like smart glasses, virtual reality and augmented reality are almost completely absent in the investigated companies. Human employees in all levels and departments of the organization need such tools to be part of the CPS and to improve their performance, and especially at the shop floor. For instance, smart glasses and voice-control could make it easier for operators to receive information and guidance while having their hands free and ready to handle their actual job. Mobile solutions, such as tablets or smartphones, could make operators more flexible and capable of controlling more machines simultaneously. In order to utilize these tools, the interfaces should be designed in a way which satisfies the demands of the operators.

Both hardware and software must be developed with respect to the workers at the shop floor. In order to improve the implementation of the cyber-physical systems we need to improve the collaboration between man and machine through better interfaces.

We consider this finding applicable also outside of Norway. As far as we know, no survey based studies outlining the situation in other countries in implementing I4.0 have been carried out. However, while the exact level of I 4.0 implementation is likely to vary, the challenges facing the operator at shop floor level is similar across nations, there is a need for mobile and hands free HCI in other countries as well. Therefore, we expect the general problem of poor human-machine interfaces to be relevant in settings outside of Norway.

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