Ethical stakes of Industry 4.0

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Abstract: Industry 4.0 provokes a shift in the way production systems are designed and used that raises ethical questions. This shift stems from several features relevant to Industry 4.0, specifically the increase of the importance of the digital world and the fostering of the development of more autonomous and intelligent systems that will interact and interoperate with humans in more open production environments. The first aim of this paper is to study to what extent Industry 4.0 impacts ethics. The second one is to raise the awareness of researchers regarding potential ethical risks when designing and evaluating future Industry 4.0 compliant production systems. For that purpose, the ethical stakes of industry 4.0 are first presented. Then, an overview of related work is done to evaluate the different scientific fields potentially contributing to the study of the ethical dimension in Industry 4.0. A discussion is finally proposed from this overview. The main conclusion of this discussion concerns the urgent need to address the ethical dimension of scientific contributions relevant to Industry 4.0, given the lack of work in that field.

Keywords: Industry 4.0, ethics, production systems, human-machine systems, complex systems, autonomous systems.

1. INTRODUCTION

Industry 4.0 (I40) provokes a shift in the way production systems are designed and used that raises ethical questions. This shift stems from several features relevant to I40, specifically the increase of the importance of the digital world and the fostering of the development of more autonomous and intelligent systems (A/IS) that will interact and interoperate with humans in more open production environments. The first aim of this paper is to study to what extent I40 impacts ethics. The second one is to raise the awareness of researchers regarding potential ethical risks when designing and evaluating future I40 compliant production systems.

The outlines are the following: first, a short description of the concept of ethics is proposed. Ethics in I40 is then studied. From this, an overview of related works is done to evaluate the different scientific fields potentially contributing to studying ethics in I40. A discussion is proposed to point out some key points identified from our review.

1. ETHICS: DEFINITION, PARADIGMS, TYPOLOGY

Defining ethics, initially a field of study in philosophy, has been a subject of discussion (in science, philosophy, law, etc.) for centuries with many paradoxes at the heart of it (Kant, 1785). An ethical behavior is in accordance with the cultural expectations of a society in relation to morality and equity (Morahan, 2015). The authors adopt the following definition for ethics : *the strive for the good life, with oneself and others, in just/fair institutions* (in French: « Une vie bonne, avec et pour autrui, dans des institutions justes ») (Ricoeur, 1990).

Several philosophical currents consider ethics from different angles and lead to the construction of different paradigms. Two maim paradigms emerge: *deontology* (decisions are made using immutable ethical rules) and *consequentialism* including *utilitarianism* (decisions are made using rules evaluated in terms of possible ethical consequences) (Kant, 1785), (Karnouskos, 2018), (Bergmann et al., 2018).

Inspired from (Bird and Spier, 1995) and (Trentesaux and Rault, 2017a), an ethical behaviour can concern two types of actors: the *humans* and the *A/IS*. The second type refers to the concept of machine ethics, moral machines, social future robots, moral robots, virtuous robots, etc. (Allen et al., 2005), (Allen et al., 2006), (Arkin et al., 2012).

A growing set of application fields are concerned with ethics, mainly because of the conjunction of the digital and physical worlds where humans interact with complex artificial systems. We hereinafter discuss about one of them, the I40.

2. ETHICS IN INDUSTRY 4.0

I40 is based on nine technological pillars: big data and analytics, autonomous robots, simulation, horizontal and vertical system integration, the industrial Internet of Things, cybersecurity, the cloud, additive manufacturing, and augmented reality (Rüßmann et al., 2015). Two issues are identified inducing the need to study ethics in I40.

2.1. Issue 1: Industry 4.0 is a source of complexity

From (Stevens, 2008), it is possible to identify main complexity factors in the context of I40: the use of artificial intelligence (AI) to implement the learning ability of A/IS allowing their behaviour to evolve; the environment in which they evolve becoming more and more open and unpredictable; the consideration of the diversity and the growing influence of stakeholders involved (users, operators, maintainers, constructors, agencies, …); the consideration of the entire network of companies involved in the lifecycle of A/IS (especially from a product-service-system point of view); the diversity of specificities relevant to humans involved (age, gender, disabilities, etc.); and last, the growing requirements in terms of sustainable development in a world now characterized by strong resource limitations and societal expectations. To these, one can add the impact of the concept of "Machine to machine" massively applied among A/IS.

The inherent complexity of I40 naturally leads to a lack of exhaustive views about possible future behaviours of a set of interacting A/IS and possible evolutions of their environments (the proofs of properties being usually done under strong assumptions). In I40, A/IS are cyber-physical production systems, intelligent products, cobots, intelligent AGV, etc. It is now no more possible to evaluate all the possible impacts of these A/IS (they become "autonomous" systems, they are no more "automatic" systems) and to affirm that expectations expressed by the different stakeholders are met. Consequently, one can face a shift in the way A/IS such as products and production systems are designed, operated, maintained and recycled in I40. The explicability issue of AI will generate risks that people may not accept. For example, soon, the responsibility of a researcher may be at stake because an AI he designed and published has been used to develop a robot that killed someone. Consequently, moral, legal and societal responsibilities of the stakeholders involved in the lifecycle of products and systems are much blurrier.

2.2 Issue 2: Industry 4.0 is a source of risks for humans involved

The nine pillars have in common to increase the interaction between humans and several A/IS at different stages of their lifecycle (from design to end-of life). Through digitalization processes, and compared to Industry 3.0, I40 reduces the physical, informational and cognitive "distances" among A/IS as artificial entities, and humans. And this may be amplified in the context of the Industry 5.0, where researchers point out the future increasing role of humans (Nahavandi, 2019).

Such a reduction generates a first risk for the humans involved, especially operators. For example, cobotic systems are intended to operate jointly with the human in the same 3D sphere (Sandoval et al., 2019). Even if they may be designed with force sensors to limit potential user harm, it is hard to ensure their total reliability and benignity for any possible situations involving the human, as an unpredictable element of the system.

Second, it is hard to forbid the possible twists by others of research contributions involving humans in a direction initially unforeseen during researches and designs. For example, the wellbeing of operators is often dealt with using sensors in I40. How to ensure this cannot be diverted to maximize financial benefits or to justify political or religious positions? Operator tracking for safety reasons can also be diverted out of praiseworthy design intentions.

Third, the possible loss of skills and the replacement of humans by A/IS are at stake. Indeed, some of the production and logistics tasks, usually allocated to humans up to now mainly because of their complexity, will be done by A/IS in a safer, faster, or cheaper way than humans. Consequently, a risk holds at a societal level: the replacement of humans by A/IS and the disappearance of jobs. Jobs done by robots in the near future is one of the most discussed subjects about ethics in future industrial systems (Karacay, 2018). This is not new: since the early years of automation, societies are concerned with the replacement of workers by robots and artificial systems. What is changing in the context of I40 concerns the increasing set of tasks potentially manageable by robots previously in charge of simple repetitive tasks in a fully controlled environment (Dregger et al., 2016). The use of A/IS in logistics 4.0 is also under studies (AGV, drones…), which may make disappear as well as jobs in logistics (and more globally, in transportation).

2.3 Ethics in Industry 4.0: concept, examples and dilemma

These two issues lead from our point of view to important ethical stakes yet to be stated in the context of I40. The introduced definition for ethics is particularized as follows in the context of I40: the extended enterprises (including governmental agencies) are the *institutions* while *oneself and the others* are all the humans involved thoroughly the lifecycle of A/IS used in I40 production systems, that is: the supplier of these A/IS (designer, manufacturer…) and the people involved during production using these A/IS (operators, maintainers, supervisors...). Defining in a precise manner what is a "*good life*" is a complicated thing to do, it is clearly beyond the scope of this paper. In the context of I40, one can translate "good" at least in terms of technical, social (personal, familial or professional networks), societal, political, environmental and economic expectations. It is suggested to state the stakes of ethics in I40 as follows: "*the ethical design and use of ethical Industry 4.0 production and* *logistics A/IS*". The word ethics appears twice to show that I40 must deal with the two types of actors concerned. We provide in table 1 various examples to illustrate the diversity and the richness of these stakes. The seek for the ethical behavior of an A/IS requires that some of the stakeholders involved in the realization of the A/IS are *de facto* concerned by ethics as well (e.g., researchers…).

Each of the examples can be associated to possible real situations implying ethical and moral dilemma <u>*that cannot be avoided*</u>. For illustration purpose, in the example #9, let consider that the basic Industry 3.0 behaviour would be simply to trigger an alarm. In I40, the intelligent supervision system could test different escape strategies for localized (instrumented) workers and advise them the best escape strategy to adopt, considering an estimation of the global number of casualties. Helping them would be useful: it would help reduce the total number of casualties, but it may imply to associate a cost or a value to each major injury or worker! Here is thus the dilemma*: if the alarm is just triggered (nothing is done to help workers while I40 technologies enable it), would it be ethical? And if, on the contrary, all is done to help them escape using I40 technologies, forcing the monitoring system to quantify who could be saved, would it be ethical too?*

Table 1. Ethical-related stakes in Industry 4.0: examples
(D: Deontology, C: Consequentialism, H: Human, A: Autonomous Intelligent System)

#	*Ethical-related stake in Industry 4.0*	*Actor*	*Paradigm*
1	An intelligent production monitoring system will never disclose the performances of operators.	A	D
2	An intelligent production monitoring system considers the risks for the human to lose his skills or for him to become too much reliant on the monitoring system with time.	A	D, C
2	A maintainer will never spy on company's data memorized by an intelligent sensor of an equipment under his maintenance.	H	D
3	An intelligent AGV will always stop in front of operators to avoid harms.	A	D
4	A defective AGV that cannot stop in front of an operator will do its best to avoid him.	A	D, C
5	An intelligent production resource will learn and act to limit as much as possible the fatigue and the stress of its augmented operator.	A	D, C
6	An intelligent production monitoring system will never over-solicitate a supervisor and will never ask him to react to a perturbation without ensuring his correct awareness of the situation.	A	D
7	An intelligent product that detects an operator laying on the floor must trigger an alarm.	A	D
8	A cobot must anticipate possible human errors and act consequently if risks are too important.	A	D, C
9	In case of emergency (eg., fire alarm, cyber/terrorist attack…), an intelligent supervision system must guide operators towards exits while minimizing the total number of injured people.	A	D, C
10	Each intelligent production resource owns a shutdown system it may trigger by itself if it evaluates that a decision to be applied leads to a harmful situation for humans.	A	C
11	A researcher applies an ethics-aware design method to design and test I40 systems.	H	D, C
12	A production system must monitor the risks of internal sabotage or physical and cyber-attack.	A	D, C

3. RELATED WORK

Even if the authors state that ethics in I40 is a new field of research that cannot stay unaddressed, a certain state-of-the-art thus exists at a scientific and technical levels that can be considered as possible starting steps towards ethical studies in I40. We present thus hereinafter some various contributions as an illustration of what is done currently, according to different scientific fields.

3.1. System engineering and safety studies

To have a global overview of the different systems interacting and their interlaced lifecycles requires a systemic approach as defined in systems engineering. If the principles are clearly stated, the difficulty of using them for complex learning A/IS in open environments remains a challenge. But considering ethics is not a common practice in systems engineering and for systems engineers. Meanwhile, ethics have been identified for several years as a key element in the design of complex products (van Gorp, 2007). The question of ethics in design of future products and systems is becoming of great importance and accompanied with stakes and risks not completely identified at the early stage of the life of these systems. These stakes and risks are amplified in the context of big data (van der Aalst et al., 2017). Typically, the signature of charters by designers and researchers (a kind of “Hippocratic oath”) is often proposed (Baura, 2006). This relates to the ethical behavior of humans. For example, (van der Aalst et al., 2017) studies the conditions of Fairness, Accuracy, Confidentiality, and Transparency (FACT) during design. The IEEE proposes the IEEE code of ethics (IEEE, 2019).

Aside this idea of charters to be signed, researchers also work to design safe systems, that is to ensure the integration of safety-related rules into complex products and A/IS. This translates a deontological approach where “good” of the definition of ethics is here reduced to “safe” (referring to the ethical behavior of the A/IS), which militates to consider ethics as a more global and inclusive concept than safety. For example, (Case, 2015) suggests designing non-intrusive products, that is products asking for the user attention only when required, paying attention to his needs, and limiting as much as possible the number of solicitations. This approach seems to be promising in the context of I40 where highly connected artefacts are intended to interact with humans through the Internet of Things for example, potentially increasing solicitations, stress and fatigue. As other examples, the concepts of “safety bubble” and “safety bag” enables to consider some aspects relevant to the ethical production by ensuring that A/IS will put priority to the well-being and the security of operators (Sallez and Berger, 2018). Finally, cyber-secure A/IS is also an important aspect relevant to the design of ethical A/IS (Hurlburt, 2018).

Methodological aspects relevant to system engineering are also concerned. The idea is to propose design methods that promote as much as possible considering ethics during the design. Such a methodological approach, dealing with the two types of actors concerned by ethics, is suggested in (Trentesaux and Rault, 2017a). The concept of safe design (Michalos et al., 2015) also promotes a methodological approach to design products in a safe way through risks assessment and hazard identifications. These methods can be adapted in the context of I40.

3.2. Human-machine systems

Human-machine systems (HMS) are logically concerned with ethics, even if their industrial applications scarcely address ethics. Deontological rules and charters (human actor) are meanwhile developed and promoted when experiments are made with the human. In HMS, the idea is to adopt a human-centered approach. Typically, design of HMS is done according to different levels of cooperation (Pacaux-Lemoine et al., 2011). Studies in HMS also pays attention to psychological aspects such as trust and confidence. For example, (Rajaonah and Sarraipa, 2018) suggested a function allocation process based on trustworthiness.

In the context of I40, main potential contributions of HMS to ethics essentially hold at the level of definition and support of human tasks considering his limits and his capabilities, (Trentesaux and Millot, 2016). The concept of “operator 4.0” is gaining interest in that context (Romero et al., 2016), (Pacaux-Lemoine and Trentesaux, 2019). Instrumenting (using Internet-of-Things sensors, etc.) or augmenting (using augmented reality tools, exoskeleton, etc.) the operator enables to ease operator’s job, maximize his well-being and limit his stress and his fatigue. The development of human-system symbioses during production (Gill, 1996) is also regaining interest. Optimizing his situation awareness is finally a challenging historical topic when designing HMS (Endsley, 1995). In this context, the “psychological acceptance” needs to be dealt with when one tries to design “ethical” A/IS. For example, it is the responsibility for a supervisor to decide to let or not an autonomous cobot work with a young or novice operator.

3.3 Robotics, embedded systems and cyber-physical systems

Robotics, cyber-physical systems (CPS) and embedded systems (Nagenborg et al., 2007), (Thekkilakattil and Dodig-Crnkovic, 2015) are A/IS concerned by ethics : for these systems, the digital world is tightly merged with the physical one, generating ethical risks for humans, especially in the healthcare and transportation sectors. For example, ethics of autonomous cars is one of the most studied aspect, since cars are nearly the first type of autonomous CPS evolving in open environments and interacting with humans (Gerdes and Thornton, 2015). (Mackworth, 2011) suggested the use of constraint satisfaction as a unitary design framework and (Vanderelst and Winfield, 2018) adopted the consequentialist paradigm to design ethical robots using simulation.

In the context of I40, the study of the impact of robots, embedded systems and CPS on ethics remains a scarcely studied topic with limited scientific contributions. Some of the technical, social and economic expectations have been expressed in terms of trustworthiness (including explicability of AI), safety, security, altruism, accountability and equitability for cyber-physical industrial systems (Trentesaux and Rault, 2017b).

3.4 Computer science and AI

Computer science (and AI) is also concerned with ethics (Kumar et al., 2016). Contributions are mainly focusing on the ethical behavior of A/IS dealing with ethics of artificial entities. Using methods and tools developed in AI (machine learning, case-based reasoning, etc.), simulation and optimization, researchers have developed both deontological and consequentialist ethical models and architectures. For example, (Bonnemains et al., 2018) and (Dennis et al., 2016) used formal approaches to embed ethical rules in autonomous machines.

In the context of I40, these algorithms and architectures could gain from being embedded into production resources and intelligent products. For example, an intelligent product or resource may embed formal ethical rules (to ensure that it will always apply moral and legal decisions) or a digital-twin to evaluate the consequences of these decisions on the humans concerned. Meanwhile, to the best of our knowledge, and despite their potential, there is still no direct or even indirect application of such developments in this context.

4. DISCUSSION

Ethics in I40 is an urgent need to be addressed but one can face a critical lack of contributions in that field. To start working on it, researchers would gain from considering the different studied scientific fields. Meanwhile, working on ethics is not an easy task for researcher and engineers. Five reluctances have been identified and discussed (Trentesaux and Karnouskos, 2020). Among them, the idea that safety studies are sufficient, and that ethics is not the problem of engineers. Because of a lack of hindsight, or the will to remain in their trusted zone or to avoid taking risk, researchers tend to focus on other aspects that are more easily affordable from an operational technical point of view. In (Trentesaux and Karnouskos, 2020), an example clearly shows that it is not possible to avoid ethical studies when working with A/IS. This holds also true for I40 where various and numerous A/IS are intended to communicate, decide, evolve, interact and work with humans.

Obviously, formalization, control and evaluation of ethics (engineering ethics) (Baura, 2006) is not done yet and this is a true challenge to address. The authors suggest that existing contributions should be analysed at least using an "ethical filter": researchers do not systematically ask themselves if their work leads to ethical stakes or not (eg., the concept of symbiosis may lead to ethical issues). Ethical models should also be developed considering safety constraints to preserve legal aspects.

On the other side, paying too much attention to ethical aspects may generate paradoxically ethical issues as well. For example, recent development in AI could let a more limited, even highly reduced place to human designers and users. If a decision support system is more and more intelligent, what is the role left for humans? Can we let a system make the final decision when the life of humans is at stake? Can we admit that human will lose skills and knowledge? If we go a step further, should we let humans develop empathy, fondness and emotional relationships with A/IS (Pacaux-Lemoine and Trentesaux, 2019)?

Ethics will also have to be part of the I40 engineer curriculums. Future engineers and scientist must be taught according to a more pluri-disciplinary approach, including soft skills and social sciences (Rahwan et al., 2019). Science and engineering are application fields for philosophers. Why engineers rarely study philosophy and ethics?

5. CONCLUSIONS

The concept of I40 raises different ethical questions. We proposed here a first study. In the form of a synthesis, in our review of the scientific literature and in the construction of our thinking, we realized the obvious lack of scientific, technical, operational and mature contributions in the field of ethics when designing or imagining future industrial systems. I40 will provoke a shift in paradigms used to design future industrial system. This shift consequently impacts the priorities in the activity researchers should set. From our perspective, future high-stake scientific issues will concern the way researchers integrate ethically humans and ethical artificial beings when designing I40 systems.

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