

Industry5.0 and Sociotechnical Theory: Theoretical Underpinnings

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Abstract

As the European manufacturing sector has increasingly embraced the Industry4.0 (I4.0) paradigm of near-total automation based on connectivity, data, robotics and machine learning algorithms, there has been a tendency to overlook the role of the humans in the loop. In this regard, I4.0 can be seen as technologically deterministic, with humans acting as an organic part of the overall machine. However, the latest moves within the sector – Industry5.0 (I5.0) – has seen an increasing re-emphasis of the wider social value of manufacturing where the knowledge and skills of humans add value to industrial processes. It also foregrounds the role of manufacturing in the wider context of a society and the need to reflect and promote societal goals, such as prosperity, resilience, environmental sustainability, inclusivity, equality, and mental and physical health & wellbeing. These ideas are conceptually underpinned by Sociotechnical Theory, which highlights the interdependencies between people and technologies. This paper explores the origins of sociotechnical theory, what it means for I5.0, and how the European Commission has applied it to I5.0 drives towards human-centric, resilient and sustainable manufacturing. It argues for a mindset change with the introduction of I5.0 from profit-above-all to prosperity-for-all.

Keywords

Sociotechnical theory, Industry5.0, prosperity, resilience, sustainability, human-centric

1. Introduction

The European manufacturing sector has, for the past decade, been characterized by the ever-increasing move towards near-total automation based on connecting machines, data and activity flows in areas such as quality, predictive maintenance, energy use, and waste management among others. The backbone of this interconnectedness has been the deployment of AI and ML (machine learning) algorithms through platforms, services, sensors and robots, both locally on-premises and remotely in the cloud, across multiple manufacturing domains. Collectively, these connected automation technologies, and this overall trend in manufacturing, has been referred to as Industry4.0 (I4.0) after Seimen's original coining of the phrase the Fourth Industrial Revolution. Initially, in addition to the primary aims of increasing growth through improving efficiency, reducing defects and minimizing factory line downtime, I4.0 also had the worthy goal of reducing or eliminating “the ‘three D’s’ – dull, dangerous or dirty jobs” [1]. Subsequently it also became apparent that I4.0 connected technologies could enable mass customization of products and/or lot-size-one manufacturing. These all remain important aims for manufacturers today.

However, in the last five years it has also become increasingly apparent that I4.0 developments were overly technologically deterministic, whereby the value and needs of humans, both the makers and the consumers, took second place to the value and needs of the technologies and technological goals. Technological Determinism, especially a ‘hard’ determinism, suggests that social and technological change autonomously and automatically results from the existence of prior

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technologies, according to certain laws, and independently of other factors [2]. In other words, the existence of sensors, robots and AI inevitably leads to Industry4.0 automation, within which employees are primarily intended to behave like organic machines within this technological system. This view of the primacy of technologies over humans remains commonly embedded in popular culture in many settings today, as can be seen, for example, by the way we refer to periods of history or civilizations by their technological level, such as the Iron Age, the Steam Age, the Jet Age, the Computer Age and so on [3]. Another important part of this technologically deterministic view is that the current level of technological advance defines the present and inevitably determines future change - in other words, the power, or agency, to affect change is ascribed to the technological artefact itself [4]. This also remains a common meme in the popular psyche today, as can be seen in headlines such as ‘Robots could take 4m UK private sector jobs within 10 years’ [5]. This view suggests that it is the technological artefacts (the robots) who are the agents of change, ignoring the many humans who design, produce, purchase, install and maintain those technological artefacts.

Hence I4.0 can be seen as being conceptually underpinned by Technological Determinism, yet as near-total automation has yet to be achieved in the manufacturing domain, it has become increasingly clear that humans retain a vital role in the process far beyond that of an ‘organic machine’. In response to the determinism implied in I4.0 automation, a reconceptualization of automated manufacturing has occurred - Industry5.0 (I5.0). Initially, I5.0 was seen as a system in which human experts would work collaboratively with robotic and automated systems to produce personalized, customized or lot-size-one products that have a sense of human craftsmanship - the “human touch” [1]. More recently this has developed into a conceptualization in which I5.0 “is value-driven” [6]. This means that I5.0 recognizes wider goals for manufacturing than just the production of an item and economic growth. It values the knowledge and skills of the humans in the system, while also recognizing that manufacturing processes and companies are embedded in the wider context of a society and therefore need to reflect and promote societal goals, such as prosperity, resilience, environmental sustainability, inclusivity, equality, and mental and physical health & wellbeing [7]. The purpose of manufacturing as an industry is not just to produce ever-larger quantities of product ever-more efficiently, but to also have a value and meaning for employees, customers and society.

It is worth noting here that the efficiency gains from I4.0, especially in terms of zero-defect manufacturing, zero waste and energy savings, do have a social value in terms of environmental sustainability in particular. Equally, efforts to reduce the ‘three D’s’ also display a human-centric consideration. However, the point is that I4.0 does not foreground these aspects, rather these wider social benefits are more a by-product of near-total automation, growth and efficiency drivers.

2. Sociotechnical theory – origins and application to Industry5.0

Consequently, this latest understanding of Industry5.0 (I5.0) marks a fundamental shift away from the Technological Determinism which underpins I4.0 to a theoretical underpinning for I5.0 drawn from Sociotechnical Theory. Developing from the field of Science & Technology Studies, Sociotechnical Theory, e. g. [8-13], marked the endpoint of an academic reaction to Technological Determinism which includes the Social Construction of Technology (SCOT) (e.g. [14-18]), and Actor Network Theory (e.g. [19-28]).

The Social Construction of Technology (SCOT) argues that technological change evolves as a result of the interplay of social groups, forces and contexts [14]. It suggests that “science and technology are themselves socially produced in a variety of social circumstances” ([14] p.403). Technologies do not exist in a vacuum, divorced from the people who design and use them nor from the societies which they effect. Technological change is not a linear progression from one improvement/innovation inevitably to the next, but rather a multi-directional process in which many developments fail and fall by the wayside, until, through ‘closure mechanisms’ a ‘stabilization’ is reached and a technological change takes hold.

In proposing their theory, academics emphasize the need to identify all the “relevant social groups [and] describe them in more detail” [14] (p.415) paying particular “interest in the problems each group has with respect to the artefact” ([14] p.415). In relation to I4.0 this would mean identifying the stakeholders affected by near-total automation and mapping the problems they may have – for

example, employees (who may find themselves unemployed or acting as simple organic machines), owners (who may find themselves requiring ever-more complex computer and digital literacies in order to achieve more growth and efficiency), communities (who are dependent on manufacturing jobs), supply chains (who are required to automate their systems as well)...and so on.

This approach however was criticised as SCOT, in an attempt to rebalance Technological Determinism, had swung too far in the opposite direction and become overly socially deterministic by raising the social to primacy over the technological and failing to fully consider the interconnectedness of people, societies and technologies. In other words, in the example above it is all about the people and there is no mention of technologies. It is also the case that SCOT was developed in a pre-Internet, pre-Big Data, pre-ubiquitous mobile computing era. Consequently, Actor Network Theory (ANT) came to the fore as a widely-applied descriptive tool for the analysis of the complex relationships between the human and the technological. ANT has been described as: “an instance of a wider sensibility in the contemporary human sciences for the intertwining of ‘the human,’ ‘culture,’ ‘language,’ ‘mind’ or ‘society,’ with ‘the nonhuman,’ ‘nature,’ and the physical world of things, artifacts and technology” [29] (p.420).

ANT suggests that material factors, as well as human/social factors, act together equally to shape both social and technological change. [26] points out that ANT dissolves certain dualisms, such as the big and the small, the social and the technical, the human and the non-human, in other words, “the distinction between human and non-human is of little initial...importance” [26] (p.147). Rather, these apparent opposites are in fact interlinked and inseparable parts of a whole. This means that neither the human/social nor the non-human/technological has primacy over the other, as both are co-dependent on the other. For the purposes of I5.0 this is formalized by the concept of Generalized Symmetry [20, 21, 30]. Generalized Symmetry makes explicit the equal nature of the relationships between human and non-human actors in a system. One can not fully be understood, nor function to maximum effectiveness, without understanding the relationship it has to the other. In other words, the I4.0 near-automation agenda based on technological determinism is unlikely to actually be the most effective approach to future manufacturing due to its failure to recognize the equal importance and value of the human and social relationships in which I4.0 technologies are situated.

To this understanding of the interconnectedness of technologies and people, Sociotechnical Theory suggests that development to and changes within manufacturing are also co-dependent on the social and technological. Hence, any new ‘industrial revolution’, such as I5.0, must focus “on the interdependencies between and among people, technology and the environment” [8] (p.625). Sociotechnical systems recognize the ‘interlinkages’ [13] that lead to ‘co-evolution’ effects [12] when it comes to system change. In an I5.0 manufacturing context such relationships are to be found between all of the following [13, 31]:

- technologies and their use (function, usability, complexity, aims),
- techniques & knowledge (development, learning and transferral of),
- networks of people (including employers, employees, suppliers, customers, developers, designers...etc),
- institutions (including companies, trade bodies, governments)
- socio-cultural norms and societal goals (including behaviors, prosperity, environmental sustainability, resilience, inclusivity, equality, health & wellbeing)
- capital (such as financial, social, cultural...etc)
- standards, regulations, rules, requirements, and laws

Furthermore, Sociotechnical Theory also suggests that sociotechnical systems exist at differing, nested scales of analysis, which have been defined as [9, 12, 32]:

1. The Macro: Landscapes / socio-economic / physical and external context
2. The Meso: Regimes / techno-cultural / semi-coherent ‘rules’ within a community
3. The Micro: Niches / networked-individual / individual networks of radical innovation

Although connected with each other, analysis of these three levels has indicated that technological change frequently occurs at different speeds at different scales. Technological change at the macro level tends to be a slow process, at the mezo level only slightly more dynamic, but at the micro level it can be radical and rapid [12]. Consequently, for I5.0 this means that at the individual manufacturer level it is possible to implement I5.0 developments quite quickly. However, similar changes across

the supply and customer chains may be considerably slower to implement, while those at regional, national or international scales will be slower still.

In short, in relation to I5.0, Sociotechnical Theory states that the development of and/or changes to societies, communities and individual companies is co-dependent on the technologies available to those societies, communities and individual companies, and will occur at different speeds at different scales. Similarly, the development of technologies is co-dependent on the societies, communities, companies and people that design and use those technologies. Or as [26] (p.147) simply states, “the social and the technical are embedded in each other”.

3. Industry5.0 and the European Commission

In relation to the network of interconnected factors outlined above, the European Commission (EC) has applied Sociotechnical Theory to I5.0 through a specific focus on ‘sustainable, human-centric and resilient’ industry [6] – see Figure 1.



Figure 1: The EC focus for Industry 5.0

However, despite the theoretical underpinnings provided by Sociotechnical Theory, the EC has also identified six enabling technologies, including among others, Digital Twins, data interoperability and AI [33]. This appears somewhat at odds with sociotechnical principles, and with the [6] report, as it again foregrounds the technologies without being clear on how those technologies will be shaped by and result in human-centric, resilient and sustainable systems. On the other hand, Muller’s [33] Independent Expert Report does list human-machine interaction as another area of enabling technologies, identifying things such as speech & gesture recognition, health tracking, collaborative robots, AR/VR/XR, exoskeletons, and AI-brain interfaces as having the potential of “supporting humans in physical tasks” ([33] p.8). As many of these are currently at a low TRL (technology-readiness level) then the involvement of human stakeholders (i.e. the employees themselves) at the earliest possible design stage becomes critical – otherwise they become yet more technology-driven tools. In other words, for a truly effective I5.0 sociotechnical system to evolve, the interconnectedness of humans and technologies must be recognised through a process of co-design and co-creation with stakeholders, rather than a ‘pre-selection’ of technologies deemed to be suitable for meeting a human-centric agenda.

On a wider sociotechnical level, I5.0 is, in part, in response by the EC to key social, economic and geopolitical drivers, in particular environmental concerns. It also implies a concept of prosperity that

is not dependent on, nor measured by, continuous economic growth alone. This novel notion of prosperity was first expounded by Tim Jackson in his influential 2011 work ‘Prosperity without Growth’ [34]. The pervasive current mindset in manufacturing (and indeed all business) is, necessarily, driven first and foremost by questions of return-on-investment (ROI). A lack of clear ROI is often cited as the main barrier limiting I5.0 innovation – from everything from Digital Twins to exoskeletons to ‘green’ technologies. Typically, senior management teams will ask: ‘Will an expensive exoskeleton that will need maintenance and upgrades be worth the investment if it only manages to ensure one of my workers has three fewer days off with injuries or back strains per year?’. However, the concept of prosperity within I5.0 demands a different sort of calculation and a different mindset. When considering ROI, I5.0 demands an accounting of the true ‘cost’ and ‘value’ of business activity and change. For example, a collaborative robot that requires large amounts of metal and chemical resources to build, is very energy-intensive to use, and is dependent on replacement parts being shipped from overseas with a large carbon footprint would be neither sustainable nor resilient. In other words, its cost is high, but its value (to sustainability and resilience) is low. On the other hand, the same collaborative robot might allow employee empowerment, creativity and job satisfaction. In this case, the cost remains high, but the value (to humans) is also high. Equally, the same robot may help to improve productivity by 3% (as modelled in a Digital Twin), also meaning that its value (to profit) is high. Sociotechnical Theory suggests that the social and the technical are equally important and should not be separated from each other for the purposes of analysis. Therefore, a sociotechnical understanding of I5.0 and prosperity, means that before investing in that collaborative robot the ROI must be calculated according to all these factors equally (humans, resilience, sustainability, profit, society...etc). The key point here is *equally* – no single factor is more important in that ROI calculation than any other. At its heart, it can be argued that I5.0 recognizes that people, communities, businesses, societies, technologies and the planet can no longer afford a technology-first, profit-above-all mindset.

4. Conclusion

Unlike Industry4.0 which has foundations in Technological Determinism, Industry5.0 is underpinned by Sociotechnical Theory. This theory highlights the interconnectedness of the ‘social’ – factors such as people, behavioral norms, societal goals, knowledge, regulations; with the ‘technological’ – factors such as function, complexity, performance, usability. It requires us to consider all the aspects of the social and the technical equally when designing, developing or changing systems, processes and practices, and when calculating ROI. Through the application of Sociotechnical Theory, I5.0 positions manufacturing within a wider paradigm, whereby it is a value-led domain with a role in providing societal, personal and environmental value as well as economic value. Manufacturing, indeed any business, is not separate from the societies which support and enable them, just as societies are dependent on the manufacturers (and other businesses) to support its needs and structures. As a result, I5.0 importantly foregrounds this co-dependency in shaping future change within the domain. However, much remains to be understood concerning these reciprocal relationships and therefore I5.0 design and development processes must be centered around co-design and co-creation with all stakeholders. Furthermore, it must factor in all social and technical aspects *equally* if I5.0 is to foster the effective development of manufacturing, a more accurate calculation of ROI, and a general mindset shift from profit to prosperity over the remainder of the decade.

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