Industry 4.0 And InformalSector: Preliminary Gaps And Scope For Innovation

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1. Introduction

Industry 4.0 (I40) is fuelled by emerging technologies such as Artificial Intelligence (AI), Cloud, Big Data, Block Chain, Cyber Physical Systems (CPS), Industrial Internet of Things (I-IoT), so on, and is driven by the demand for sustainability and personalization expectations from customers [Lasi et al.,2014]. Industrial production under I40 is expected to become flexible and responsive to changing customer expectations and deliver outputs considering sustainability aspects attached to 'growing environmental risks and ecological scarcities' [Beier et al.,2020; UNEP,2011]. It calls for a nexus between technology and organizations that simultaneously facilitates a meaningful and ethical design of work for humans [Dregger et al., 2016; Romero et al., 2016].

Current focus of technological advancements in the direction of I40 is predominantly centered around large manufacturing industries for realizing smart factories of the future [GTAI, 2014]. But relatively less attention is given to realizing features of I40 within organizational forms that integrate small scale and informal enterprises into wider value chains [Ludwig et al.,2018; Zambon et al.,2019]. This is more crucial in developing countries like India where majority of its workforce are engaged in informal sector, either as individual producers/service-providers (e.g., farmers and cab- drivers), or within micro or small-scale informal enterprises [NCEUS, 2009]. Informal economy accounts for over 90% of Indian workforce and contributes to over 50% of the national product [NSC,2012].

In this study we first review literature clarifying important features of I40. Then we look at some of the recent organizational forms attempting to connect informal sector into wider value chains and gaps in realizing expectations of I40. We believe that identifying such gaps can serve as a starting point for product innovations that appropriately combine different technologies and help informal sector reap the benefits of I40.

2. Methodology

In this study, our objective is to arrive at some preliminary gaps in realizing I40 for informal sector by discussing key features of I40 systems vis-à-vis some organizational forms that are currently attempting to connect informal entities into wider value chains. We adopt a socio-technical perspective to clarify key features of I40. Accordingly, we focused on extant literature around technological enablers, organizational features and role of humans in the context of I40. We relied on Google Scholar search to identify most relevant papers based on search strings - 'industry 4.0', 'industry 4.0 + socio-technical', 'industry 4.0 + literature review', 'industry 4.0 + technologies', 'industry 4.0 + organization', 'industry 4.0 + humans'. We selected between 2-3 highly cited papers that came during each of these searches. While carefully reading through these papers, wherever we stumbled upon relevant papers falling into one of these categories, we added them into our list of papers to review. Owing to the absence of literature around I40 and informal sector, we instead look at some of the existing I40 approaches for integrating farmers or Agri-enterprises into wider value-chains as a close equivalent to such literature. This is because agriculture largely falls within informal sector, particularly in the Indian context [NCEUS, 2007]. We searched for relevant literature based on the search-string 'industry 4.0 + agriculture' and here again we relied on 2-3 highly cited papers for our review. To clarify the positives and negatives of existing organizational forms attempting to integrate informal entities into wider value chains, we focused on highly cited literature reviews and articles on platform and sharing economies and informal economy in general [Calo & Rosenblat, 2017; Davis, 2016; Edelman & Geradin, 2015; Frenken, 2017; Gerwe & Silva, 2020; Godfrey, 2011; Joseph, 2008; Schor, 2016]. Since our literature review was structured according to the objectives we set-forth apriori, it is closer to a thematic or framework based review as per the categorization suggested in Paul & Criado [2020]. Following table provides a list of papers that we carefully reviewed for the purpose of our study.

Table 1: List of papers reviewed for this study

Search Categories	List of Journal Papers and research articles
Industry 4.0 Industry 4.0 + technologies Industry 4.0 + organization	(Boos et al., 2013; Cassandras, 2016; Da Xu, 2011; GTAI, 2014; Han et al., 2018; Izza, 2009; Keutzer et al., 2000; Kirkpatrick, 2013; Krugh & Mears, 2018; Lee et al., 2016; Lei & Ming-Lun, 2017; Yongkui Liu & Xu, 2017; Monostori, 2014; Petrasch & Hentschke, 2016; Shrouf et al., 2014; Sisinni et al., 2018; Sztipanovits et al., 2011; Van Der Aalst, 2012; Van der Aalst, 2013; Verma et al., 2017; Vicaire et al., 2010; Vogel-Heuser & Hess, 2016; F.-Y. Wang, 2010; L. Wang et al., 2015; H. Xu et al., 2018; Zeng et al., 2020; Zhang et al., 2018; Zhong et al., 2017)
Industry 4.0 + Humans	(Fantini et al., 2020; Frazzon et al., 2013; Frey & Osborne, 2017; Gorecky et al., 2014; Romero et al., 2016; Waschull et al., 2020; Zhang et al., 2018; Zolotová et al., 2020)
Industry 4.0 + literature review Industry 4.0 + socio-technical	(Beier et al., 2020; Dregger et al., 2016; Lasi et al., 2014; Ludwig et al., 2018; H. Xu et al., 2018)
Industry 4.0 + Agriculture	(Ahmed et al., 2018; Chen et al., 2019; De Clercq et al., 2018; Deichmann et al., 2016; Ge et al., 2015; Ye Liu et al., 2020; Ozdogan et al., 2017; Weersink et al., 2018; Weiss et al., 2020; Wolfert et al., 2017; Zambon et al., 2019)

3. Industry 4 0: Technology Enablers And Key Features

Components within industrial production as envisaged in I40 can be analytically evaluated through intersections of technologies, organizations, and humans [Dregger et al., 2016]. Emerging technologies facilitate organizations to achieve desired performance in production along parameters such as flexibility and sustainability apart from efficiency [GTAI, 2014]. Organizations here are constituted by structures comprising their technical and business processes, location in relevant product value chains, and relation with suppliers and consumers [Beier et al., 2020]. I40 is also touted to transform the nature of work performed by humans, where decision making and social interaction skills are expected to assume greater prominence over manual works and routine cognitive works [Waschull et al., 2020]. Below, we discuss some of the technology enablers, organizational features, and prospective role of humans expected within I40 systems.

3.1. Technologies enablers and organizational features of I40

CPS, I-IoT, Business Process Management (BPM), Cloud computing, Big Data, AI, Blockchain are some important technologies driving I40 [L. D. Xu et al., 2018]. Together, these technologies facilitate seamless interconnection between physical devices, software systems and humans at different levels of production hierarchy and enable intelligent fusion of both technical and business processes within organizations [Monostori, 2014]. Here we discuss how some of these technologies act together and provide platforms for realizing expectations of I40.

3.1.1. Cyber Physical Systems and Industrial IoT

CPS and I-IoT can provide a base for realizing interconnected and modular components facilitating effective deployment of process aware information systems linking technical and business processes within a production system [L. D. Xu et al., 2018]. Providing distinct identities and communication capabilities to sensors, actuators, and other components, I-IoT interconnects almost anything, anywhere and at any time within the production process [Sisinni et al., 2018]. CPS are driven by control, network and computing technologies that reduce differentiation between physical and digital representation of components within an I40 system [H. Xu et al., 2018]. Control technologies facilitate centralized, decentralized or hierarchical control over the production components. Networking technologies facilitate dynamically reconfigurable and interoperable network infrastructure which can interconnect components differently for different industrial applications [Kirkpatrick, 2013]. Computing technologies enabled by cloud, fog and edge computing infrastructure facilitate real time data analytics, ensuring timely transmission of decision or control signals between various components [Verma et al., 2017].

AI and Big Data, along with CPS and I-IoT, can enable production components to learn their surrounding contexts, self-organize themselves for different production scenarios and function autonomously [Lee et al., 2016; H. Xu et al., 2018]. These autonomous and self-organizing components trigger a shift from centralized control to decentralized control, ensuring a decentralized way of functioning in I40 systems [Monostori, 2014]. Analysis of data generated from all the production components help to detect and overcome performance problems and manage overall system complexity [Lasi et al., 2014]. Blockchain can enhance security and resiliency in operation of such decentralized production systems [L. D. Xu et al., 2018].

Acting together, technologies can further provide platforms over which domain specific industry applications can be built facilitating design and development of customized and innovative products or services [Verma et al., 2017]. Such applications can be built following a layer based framework where design flows are vertically abstracted shielding underlying details at each abstraction layer [Zeng et al., 2020]. Within such a framework, the configurability of cyber and physical components and of their interconnections give way for industrial applications to make dynamic adjustments replacing or expanding component modules contributing to the flexibility of I40 systems [Beier et al., 2020].

In essence, CPS, I-IoT along with technologies such as AI, Big Data and Cloud, form the foundation for making I40 systems decentralized and flexible, exploiting components which now become interconnected, autonomous, reconfigurable, and self-organizing [Vogel-Heuser & Hess, 2016]. The resulting systems provide diverse set of 'automated services', and can collectively react to the specific needs and requirements of customers [Lasi et al., 2014].

3.1.2. Process Aware information systems

Process aware information systems (PAIS) such as BPM systems play crucial role in the context of I40 as they can streamline business processes taking into account entire product value chain. PAIS built over the platforms enabled by CPS and I-IoT ensure horizontal integration of different stages of a product life cycle or value stream, and vertical integration from physical component level up to production management and corporate planning levels [L.D. Xu et al., 2018]. Facilitating end-to-end integration of technical and business processes in a product's entire value chain, together with the modularity and reconfigurability of production components, makes the production system flexible. This allows it to not only cater to varying customer demand, but also provide value added services to customers beyond their products enhancing service-orientation of I40 systems [GTAI, 2014; Lasi et al., 2014]. Services developed at one place can be made available in other geographically dispersed locations and dynamic orchestration of smaller services into larger end-to-end services can enrich industrial applications furthering the flexibility and responsiveness of such systems [Beier et al., 2020; Da Xu, 2011].

3.1.3. Organizational features

Technologies driving I40 are expected to span innovations at different levels –

product, enterprise and society. At product level one recent example is the application of CPS in smart vehicles where 'parallel smart vehicles', can help simulate safety issues in self-driving vehicles [Han et al., 2018]. Mass-customized production models and enterprise management systems, are enabling innovation and flexibility within organizations [Lei & Ming-Lun, 2017]. At societal level, applications like intelligent transportation, smart energy systems, environment monitoring and several others, are facilitating the realization of smart cities [Cassandras, 2016].

From the above discussion it is clear that production systems or organizations of I40 are expected to become flexible to customer demand, decentralized in their production hierarchies, and more service-oriented. Interconnected, autonomous, re-configurable and self- organizing production components realized with help of aforementioned technologies are expected to transform organizations into 'smart factories' of the future [Lasi et al., 2014].

3.2. Integrating humans within I40 systems

In addition to being flexible to customer demands, organizational forms of I40 also expected to facilitate meaningful role for its employees [Romero et al., 2016]. Studies show that emerging technologies are expected to have 'skill-biased' effect on jobs where routine and medium skilled jobs that do not require 'manual dexterity or social interaction' are susceptible to automation [Frey & Osborne, 2017]. While technologies equip production components with communication and computational capabilities, studies urge that I40 objectives must take into account meaningful integration of humans within production process [Fantini et al., 2020].

Technologies are required to support workers as decision-makers and flexible problem solvers within I40 systems [Gorecky et al., 2014]. Technologies such as CPS and I-IoT complemented by AI are expected to foster human decision making by supplying individualized information to workers about their surroundings, and to conduct activities that are difficult to evolve in the cyber world [Krugh & Mears, 2018]. Human-machine interaction technologies such as 'dialogue systems', 'adaptive interfaces', and virtual/augmented reality devices, are expected to extend physical and cognitive capabilities of humans [Zolotová et al., 2020], and transform cyber physical systems into cyber physical social systems [Zeng et al., 2020]. Services built over platforms enabled by CPS and I-IoT systems can process data from industrial components to detect critical events and timely alert operators in necessary situations. Such services can model or predict behaviour of industrial systems and provide context-aware prescriptions, augmenting humans in their decision-making [Fantini et al., 2020]. These augmented technologies and support services can also bridge context specific differences, in terms of geographic location and culture from which employees operate [Frazzon et al., 2013].
Technology augmentation is required to support humans perform tasks of higher complexity, skill variety and function with greater autonomy within organizations of I40 [Waschull et al., 2020]. Organizational designs are required to provide humans

with greater operational freedom and possibilities to 'learn on the job', enabling 'polyvalent utilization' of human actors [Dregger et al., 2016]. Human machine interfaces supported by intelligence assistance systems are expected to help workers retain appropriate 'control over the production process' [Boos et al., 2013]. Expectation from I40 is that automation enabled by various technologies shall enhance 'physical, sensorial and cognitive capabilities' of humans, making them smart operators or 'operators of the future' [Romero et al., 2016]. As industry 4.0 systems comprise interconnected, modular, autonomous, and self-regulating components, tasks are expected to be dynamically allocated between humans and machines, necessitating organizations to 'turn towards far-reaching decentralization and delayering of hierarchies' [Dregger et al., 2016].

Following Figure-1 summarizes essence of above discussion.

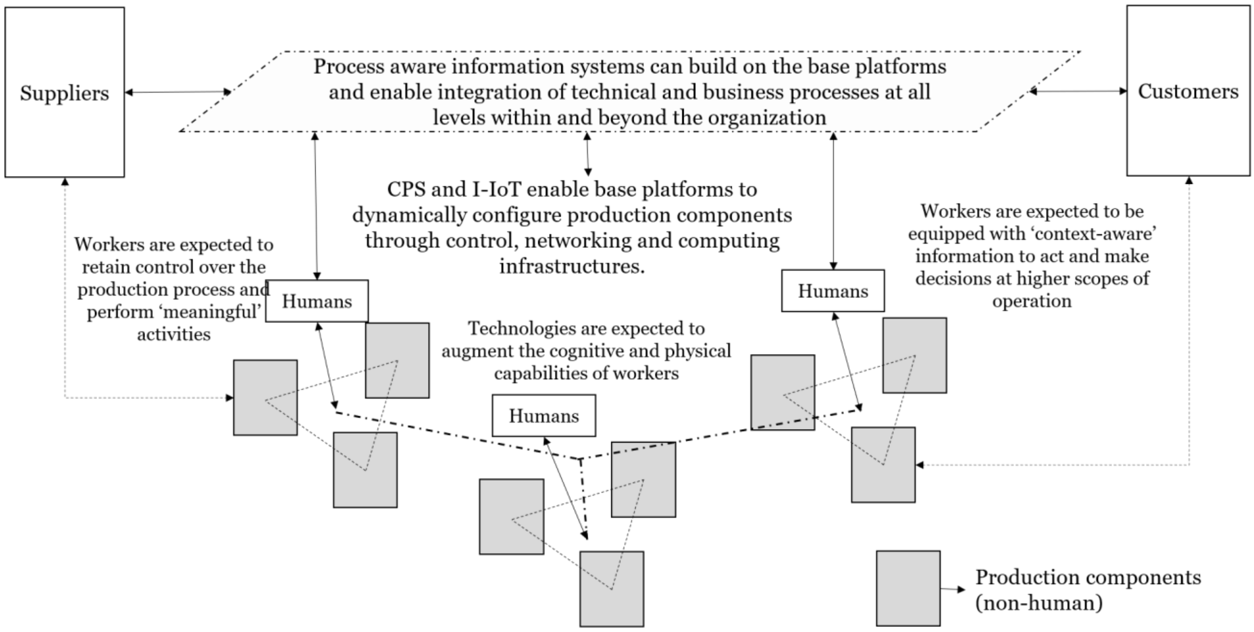

Figure 1: Technologies, organization and humans in I40 systems

4. Industry 4.0 And Informal Sector

Informal enterprises are socially embedded in their local environments, operate at small scale with low capital intensity, and function flexibly in uncertain and turbulent environments [Godfrey, 2011]. Given their small scale of operations, majority of such organizations rely on worker's expertise and are characterized by lower levels of automation making it difficult for them to transition to expectations of I40. In order for informal sector to transition to I40, their effective integration into overarching organizational structures that can retain their autonomy and their reliance on human agents for local innovations is crucial [Ludwig et al., 2018].

4.1 Existing structures integrating informal sector

Existing organizational forms integrating informal producers/service-providers - like aggregator models within sharing economy - are common today. They range from local cooperatives limited by geographical reach to global venture capital backed firms like Uber and Airbnb [Gerwe & Silva, 2020]. The latter firms having global reach do not own assets of individuals whom they integrate as service-providers into overarching platforms, but make technological investments to reduce transaction costs and barriers to entry (Davis, 2016). Overarching software platforms allow them to exploit data from different stakeholders for effectively match demand with supply [Calo & Rosenblat, 2017]. Resonating with I40 systems these overarching platform-based structures while integrating service-providers into wider value chains, they are also believed to provide latter with some form of autonomy and flexibility in terms of how they operate [Sundararajan, 2017]. The freedom to work part-time, allows service-providers to reduce their income volatility by working on need-basis, while the overarching platforms play the role of maximizing utilization of idle assets and improving overall system productivity and sustainability [Frenken, 2017].

Nevertheless, there are also negative sides to these platform-based organizational forms. There is growing evidence that platform owners have become immensely powerful and are having significant information advantage over service-providers, unleashing a new form of ‘platform capitalism’ [Srnicek, 2017]. Exploiting data gathered in real-time about participants give platform owners an undue leverage to reap maximum value out of their participants [Calo & Rosenblat, 2017]. Growing power of platform owners is expected to erode traditional employment relationships, increase labour market uncertainties, replace traditional economies and eventually lead service-providers into working in poor work conditions [Hill, 2015]. Therefore, questions still remain as to whether individual service-providers are autonomous or tacitly manipulated by platforms through ratings or incentives. As a response to power imbalances caused by capital backed firms owning platforms, there is a recent trend towards platform cooperativism where the individual participants are expected to collectively own and manage platforms [Gerwe & Silva, 2020; Slee, 2017].

While a majority of large-scale platforms we are witnessing today are privately owned, there are also active government interventions enabling integration of informal entities into larger value chains. For example, Farmer Producer Companies in India are one example of legislated organizational forms that aim to integrate small holder farmers or their collectives into larger supply networks minimizing transaction and coordination costs and enable them benefits from economies of scale [Trebbin & Hassler, 2012]. There are also several joint public-private collabo- rations intended for integrating small holder farmers through technological platforms that aggregate data from government databases and farmers and help the latter make informed decisions [GoM, 2020; Microsoft, 2017; Vijay, 2020]. As we saw earlier, privately owned platforms are questionable in terms of facilitating the set expectations of I40, mainly in terms of the extent of overall flexibility and autonomy they give to informal entities – the individual service-providers. In this aspect, active government interventions can help mitigate such problems. However, unlike privately owned platforms that build over advanced technological base underneath, techno-centric initiatives driven by government are often top-down and fail to sufficiently account for technological milieu that is essential for organically integrating informal entities. For example, given the lack of technology advancements suited for small farms, techno-centric top-down approaches often fail to secure the expected benefits of I40 to small holder farmers [Wolfert et al., 2017; Zambon et al., 2019].

5. Conclusion And Future Work

Review of industry 4.0 systems through a socio-technical perspective reveals that – technologies are key to enabling organizational forms of I40 to become flexible and responsive to variety of customer expectations, while at the same time, attempting to achieve sustainability and meaningful integration of humans. Among existing organizational forms integrating informal entities into wider value chains, we note that there is a noticeable advantage to large capital-backed firms in adopting technologies underpinning I40. These overarching organizational forms however, also pose disadvantages by casting excessive centralized control and power over informal entities. On the other hand, organizational forms legislated by the government are top-down but envisage integration of informal entities into wider value- chains while retaining their autonomy and reliance on socially embedded human agents. The technological interventions helmed by government in partnership with private entities are also still largely top down, and there is still a long way to go for the technological basis to reach levels that are currently achieved by large capital-backed platform owners. We believe that, for informal sector to realize the potential of I40, the intent of government driven top-down organizational forms complemented with technological milieu underpinning private platforms could be a way out. However, in order to achieve this, bottom-up efforts are required in terms of devising appropriate technological solutions for organically interconnecting and integrating informal entities into overarching platforms that are not overwhelmed by centralized authority and control. We surmise the following two propositions which may lay ground for future research to drive appropriate technological innovations – particularly platform-based product innovations – within industry 4.0 that can effectively integrate informal economy into wider value-chains.

Proposition 1: For informal economy to reap benefits of industry 4.0, efforts must start with identifying and developing technologies that organically interconnect informal entities into overarching platforms characterized by decentralized authority and control.

Proposition 2: Policy interventions can be directed towards enabling product innovations (both hardware and software) that minimize cost of such technologies while ensuring their variety - in terms of catering to a wide range of sectoral, geographical and other con- textual diversities that characterize enterprises and workforce in any informal economy.

Characteristics of informal economy are closer to the expectations such as flexibility and sustainability set by industry 4.0. As we covered in this study, entities within informal economy are socially-embedded and therefore are flexible and responsive to local needs. Their continued reliance on expertise and innovation potential of human agents can ensure sustainability in terms of providing meaningful employment to humans. Incorporation of appropriate low-cost technologies can also set-in motion sustainability in terms of resource utilization while helping such informal entities reap benefits of economies of scale. Through this preliminary study, we call for a more structured research agenda that looks at analysing industry 4.0 technologies for benefitting informal economy – an agenda that is urgently required for developing countries, where informal economies are at the danger of being captured within large capital-backed and centrally controlled platform economies.

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