

Convergent Systems of Systems Manufacturing (Convergent SoS Manufacturing)

Historically, each industrial evolution was triggered by an invention that was a game changer. The first industrial revolution (Industry 1.0) was marked by discovery of the water- and steam-powered machines, which increased efficiency and capability. Discovery of electricity brought the second industrial revolution, Industry 2.0, by replacing water and steam as primary power sources. This period also introduced mass production via assembly lines, which became common in integrated manufacturing systems. The third industrial revolution (Industry 3.0) was marked by invention of transistors and integrated circuit chips enabling machines automation, which combined with computers (programmable logic controllers) enabled the replacement of human operators with automation. Advanced wireless communications triggered the fourth industry revolution (Industry 4.0) by incorporating smart devices to provide the desired intelligence, implementing and

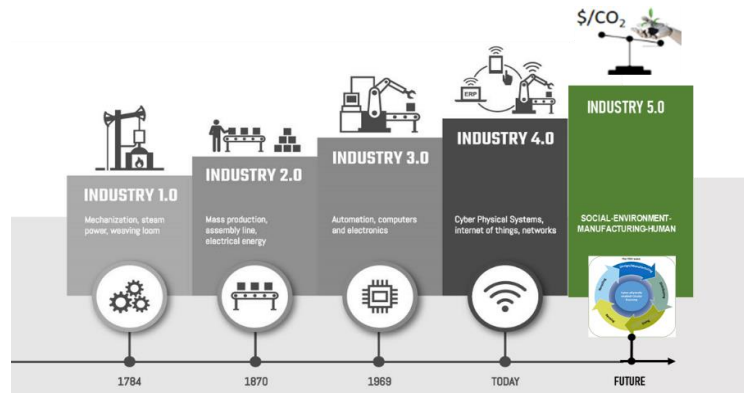


Figure 1- A forecast of the future of manufacturing¹

maintaining appropriate network capabilities leading to cyber-physical systems, interconnected networks of sensors that make up the Internet of Things, where cloud computing, and cognitive computing are key factors. Shortly after Industry 4.0, the nucleation of the next revolution has started with a focus on human-machine interaction, where human workers and machines are connected into a global highly interconnected network enabled by tools such as virtual reality, gaming devices, and wearable sensors. In this context, this presentation focuses on a vision for the next revolution (Figure 1). However, this next revolution must also address the most important societal challenges we face today. Climate change, production and supply chains disruptions, segregation of wealth, and social justice are challenges that can be addressed only by a convergent approach that interconnects four key elements as a system of systems (SoS): manufacturing, climate change, social justice/equity, human behavior. Metrics and interdependencies of these elements include: (1) for manufacturing: autonomy, cost efficiency, productivity, quality; (2) for climate change: carbon footprint, recyclability, natural resources; (2) for social justice/equity: level of industrialization/agriculture, government stability, human development index, gender inequality index; (4) for human behavior: cognitive workload, creativity, diversity, topology of social networks. Scientific silos around each of these elements have hindered the understanding of their interdependencies. For example, advancements in manufacturing without considering environmental aspects leads to catastrophic climate changes; advancement of manufacturing without considering social justice creates poverty and segregation in society; advancements in human-machine interaction without understanding of human behavior results in societal rejection of novel technologies. Thus, the next industrial revolution must include a convergent SoS manufacturing vision, where individual component systems – such as enterprises, micro-climates, cities/regions, and communities – exhibit operational independence, managerial independence and geographical distribution, as well as emergent behavior and evolutionary development processes. Component systems and their dynamic interdependencies are characterized by nonlinearities that can result in regime shifts from stable to unstable dynamics. These systems are exceedingly complex to completely model with high fidelity. Aggregation methods and novel compartmental models must be developed together with techniques for data-driven forecasting of their dynamics and their tipping points. Examples of forecasting methods based on big-data will be presented along with novel compartmental models that address the intelligent adaptation of manufacturing processes in response to disruptions such as those caused by social events and public health emergencies.