Abstract

India is the second-most populous country globally, with more than 1.35 billion residents reported in 2020. It is also the fastest-growing major economy in the last decade with an annual average gross domestic product (*GDP*) growth rate of 6-7% and contributed $2.86 trillion to the world's total GDP in 2019. However, contrary to its population and size, its global GDP and international trade contributions are moderately low. Further, the country lacks numerous societal, economic, and environmental issues compared to the developed world. The intensifying unemployment rate and income inequality gap are a few principal societal concerns witnessed in the past few years. Similarly, another concerning factor is environmental degradation, and in a 2018 report, India has been positioned at 168^{th} rank out of 180 countries in the environmental performance index (*EPI*). Even Indian products fail to match the international requirement standards due to low-quality products produced from old or Jugaad technologies/innovations in practices that lead to inferior quality products, import-export deficit, and invites cheaper imports. Therefore, India was ranked in 68^{th} place on the global competitiveness index (*GCI*) out of 141 countries. The manufacturing sector is one of the quintessential components to balance employment generation, economic growth, and environmental sustainability. Due to that, it is admitted as the backbone of the country's economy as it offers a significant contribution to GDP and job creation. Globalization further influences it by the driving forces of outsourcing and distributed manufacturing with technological advances. However, the decreasing share in GDP and shrinking employment from the manufacturing sector has become concerning predicaments. Micro, small, and medium enterprises (*MSMEs*) are the key players in the manufacturing sector because of their abundant production output, export, and employment generation. However, in India, MSMEs are not well equipped with emerging technologies, and they do not follow up the quality and the environmental standards.

This thesis introduces an inclusive manufacturing system (*IMS*) to empower the MSMEs to attain inclusive growth by adopting advanced manufacturing models and emerging technologies to build collaboration among MSMEs. Policies and standards related to the environment, quality, labor, and trade have been coupled to concur manufacturing challenges. This research aims to uncover a novel service-

oriented manufacturing system where various stakeholders (*manufacturers*, *logistics providers*, *suppliers*, *courier service*) can provide their services and enhance market access beyond localization.

In the first stage, comprehensive details have been provided about the inception of the Inclusive Manufacturing System and its requirements by envisioning the manufacturing sector. Inclusive Manufacturing plays a crucial role in connecting the various stakeholders located in scattered places, including manufacturers, logistics providers, designers, experts, and suppliers. Initially, the existing models are elaborated, and then a conceptual model is proposed to give a fair idea behind the Inclusive Manufacturing System. A layer-wise comprehensive framework is illustrated to demonstrate the system's requirements and complexity in support of the model. Furthermore, a flowchart depicts the physical movement and information sharing between various stakeholders and presents an example of crankshaft manufacturing in a distributed environment. One of the sections is devoted to describing the challenges in executing IMS and overcoming them. A brief discussion has been given about the functioning of the envisioned system. Finally, the scope and prospects of the proposed method have been highlighted by exemplifying various sectors.

In the second stage, ontological modeling has been presented to visualize data and network complexity in resource composition-based, digital twin-driven inclusive manufacturing systems. In developing a network of enterprises to enhance the collaboration, there is a need to share immense information among all the stakeholders such that suitable service providers can be offered a task. However, handling such enormous and varying datasets is challenging, especially in realizing machine-to-machine (*M2M*) communication. Several emerging technologies are needed to develop M2M communication, and semantics is one among them. An attempt has been made to capture information from various stakeholders by linking in an ontological model. Further, the ontology data has been extracted using SPARQL Protocol and RDF Query Language (*SPARQL*) to utilize the resource collaboration model. Therefore, a multi-objective problem has been formulated by considering two objective functions: cost and energy consumption. Based on a real-life scenario on movement restrictions and resource capacities, several constraints are established. The problem has been solved by deploying Multi-Objective Binary Particle Swarm

Optimization (*MOBPSO*). A simulation case study to produce Gate Valve has been demonstrated because it consists of different materials, multiple operations, and varying parts.

In the third stage, a multi-level resource composition problem of the entire manufacturing network has been formulated by viewing operational and component-level information in an inclusive manufacturing system. The developed model encapsulates a realistic and complex production system of raw material suppliers, manufacturers, assembly stations, logistics providers, and courier services that compose resource scheduling and vehicle routing problems. The model aims to minimize the cost and emission per product instead of the overall network because it fulfills customers' desires (*cost*) and government policies (*emission*). The formulated optimization problem is nondeterministic Polynomial Hard (*NP-Hard*) and of discrete nature because of the presence of binary and integer decision variables with nonlinear functions. Therefore, evolutionary techniques are employed as solution approaches to handle the problem's complexity and size. Non-dominated Sorting Genetic Algorithm (*NSGA-II*) and improved Multi-objective binary particle swarm optimization (*MOBPSO*) are utilized to get efficient and faster results. A simulation case study has been demonstrated to visualize the concept by constructing a real-life Labeling Conveyor production plot. The study reports that network size influences cost and emission because of competitiveness among service providers. The developed mathematical models are validated using various problem instances generated by simulating a collaborative manufacturing environment study.

In a nutshell, this research mainly focuses on modeling an Inclusive Manufacturing System and envisions practical implications in the manufacturing sector to concur with several triple-bottom-line concerns.

Keywords: advanced manufacturing systems, inclusive manufacturing modeling, evolutionary algorithms, service-oriented manufacturing, sustainable growth, semantic technology