An Overview of Smart Manufacturing for Competitive and Digital Global Supply Chains

SARATH MENON[1]
Faculty of Engineering and Science
University of Greenwich
London, UK
S.Menon@greenwich.ac.uk

SATYA SHAH[2]
Off Campus/Institute of Management
University of Bolton
Bolton, UK
s.shah@bolton.ac.uk

ALEC COUTROUBIS[3]
Faculty of Engineering and Science
University of Greenwich
London, UK
A.D.Coutroubis@greenwich.ac.uk

***Abstract*— This research study aims to examine and review the key advantages of smart manufacturing to achieve and improve performance within global supply chain environments. In recent years supply chain has been arisen as one of the major areas to gain a competitive edge in manufacturing industries. The current business methodologies of short product life cycle, increased outsourcing, expanding product variety, improved customer focus and improved technologies has led supply chain to be some challenging and complex tasks. Smart Manufacturing has been considered as a successful advancement in industrial revolution featuring resource efficiency, adaptability, agitability with wide application of internet and other innovative engineering technologies integrating of customers and business value processes creating a better manufacturing environment. The research is at its preliminary stages and will aim to examine and evaluate existing literature within the areas of smart and digital manufacturing and compare examples of best practices and methods towards creating a detailed comprehensive and systematic finding of the key research studies. This paper is a literature review which aims to review the benefits of smart manufacturing and its influence to achieve an improved performance in supply chain.**

Keywords— smart manufacturing, digital Supply Chain, industry 4.0, competitive advantage, digital manufacturing

I. INTRODUCTION

Manufacturing is regarded as one of the crucial resource for today's economic growth in the world. In the current era of Industry 4.0, manufacturing and supply chain management is transforming to be smart. A fully integrated, collaborative system which responds in real time to meet the changing demands and condition in the manufacturing factory, in supply network and in customer needs can be defined as Smart Manufacturing. However, the smart supply chain is far from a fact yet as is supply chain visibility and collaboration. Transformation from manufacturing to smart manufacturing is done in areas of operation, processes and energy footprints of factories and management depending upon how the products are designed, fabricated, used, operated and even how services post-sale are carried out. It will modify the global model of manufacturing competition, potentially reducing the relative advantages of inexpensive regions.

Initiated as a part of Industry 4.0, the smart manufacturing is attracting much interest in recent research. Our physical world is now hyper connected and rapidly being augmented with the level of smartness. Smart in manufacturing is the concept of creating new business models by encompassing new driven technologies with digitalisation of vertical and horizontal value chain, innovation in products and services [1]. Smart manufacturing for a smart supply chain integrate the real and digital world including - the Internet of Things (IoT); Mobile solutions; Cloud computing; Cyber-physical systems (CPS); Big data analytics; Wearable Technology; Additive Manufacturing (AM); Robotics; Driverless Technology.

Recently, manufacturing companies are facing different challenges due to varied customer requirements, short product and technology life cycle, demand for custom and fast delivery products at large scale production. Emerging Industries in developing countries is also creating challenges and competitive pressure globally. Research studies claims that with the evolution and adoption of industry 4.0 in manufacturing applications it will have impacts on the entire supply chain processes. Similarly, the interconnection between suppliers and manufacturers and that of wider specific involvement of customers within the product development process through that of the entire life-cycle of product life. With the widespread use of digitisation and that of smart manufacturing techniques such as 3D printing and automation of the processes, the entire supply chain will be heavily impacted by the adoption of industry 4.0 practices. Hence, the authors of this paper aims to analyse and understand the impacts of industry 4.0 and that of smart manufacturing techniques on global supply chains. Some of the early research studies carried out in this context highlights the importance and benefits of the industry 4.0 implementation on supply chain. For instance, the efficiency and productivity of products and supply chain processes are greatly improved; the quality standards and that of the increasing flexibility of the production and sourcing practices are also improved through the adoption of smart manufacturing and digital fabrication practices within manufacturing. Certainly, through these benefits it further enhances the possibility of mass customisation of products and offerings within the markets, allowing companies to meet the demands of consumers and providing a better value proposition and incentive to the end consumers [2].

As the emerging industries can introduce themselves with latest innovations and getting technologically advanced companies will pave way for low operating costs, less production time etc. that will result in change of focus by the market to them from the previous manufacturers and countries. This research is at a preliminary stage and this paper aims to examine an extensive and systematic review of latest researches within smart and digital manufacturing. Key technologies are identified and their possible applications to smart manufacturing systems are reviewed and discussed in this paper with future perspectives.

II. LITERATURE REVIEW

As defined by researchers [3], smart manufacturing comprises of innovative techniques in different mode as shown in Fig 1 that provides flexible and adaptive production processes that will solve different challenges that are arising in a production facility rapidly with a dynamic boundary conditions in globally increasing complexity. As it defines, it comprises automation with different hardware and software which optimize the process of manufacturing that result to reduce the time, labor and resource wastes. This optimization also results in associating with a variety of industrial and non-industrial partners, forming a strong organization with smartness. In various countries smart manufacturing is known as smart industries, advanced manufacturing, digital manufacturing etc.

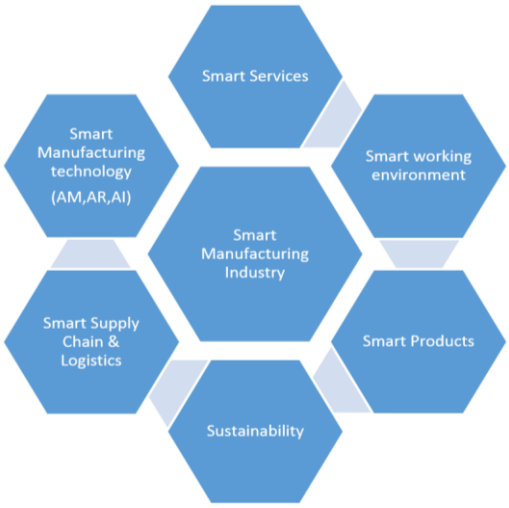

Fig. 1. Smart Manufacturing Network

A reliable infrastructure foundation introduced by a manufacturer that transfers from manufacturing to smart manufacturing (Smart-M), improves the efficiency and productivity with the current performance results delivered within the intelligent plant data. It is apparent that once transferred, smart manufacturing provides many advantages from flexibility to meeting customer demands by increased productivity with minimum downtime and efficient scheduling [4]. The resultant data can be used for different analysis from the production team to the maintenance team to perform preventive maintenance to avoid downtime which will result in greater profitability for the industry.

Emerging smart manufacturing techniques is identified in part by the innovation of new technologies which are promptly wide spread flow of information within the manufacturing systems and its surrounding controls. These systems are delivering unrivalled awareness, productivity, resilience and agility within the production system by capitalizing the ever-increasing availability of real-time production data. Optimized collection and analysis of these data and following distribution of information for decision making throughout the enterprise necessitate, however a complex and dynamic process.

Smart manufacturing is a collaboration of human creativity and information technology that brings out a rapid revolutionary change in the application and development of technology in every aspect of manufacturing and its business [5]. It is changing the mode of product design, manufacturing, supply chain and even the way the products are sold. Smart manufacturing will improve the workers safety with zero incidents and open the opportunities for skilled jobs by keeping the industries competitive globally with zero environment emission as their achievement target.

A. *Smart Manufacturing vs traditional Manufacturing*

Traditional Manufacturer generally consists of an open conveyor belt with several machines deployed along the production lines. Even though several machines are deployed, each machine performs its predetermined tasks when an unfinished product flow through the line from input to output. This process results in single type of product production in traditional manufacturing industry. Generally, no redundant machines exist, and the conveyor belt is carefully tailored [6]. In traditional manufacturing, the machines has its own independent controller, but the communication in between the machines is seldom, where in smart manufacturing unit the production system aims to process multiple types of products [6]. The fundamental differences between traditional and smart manufacturing is described in Table I:

TABLE I. TRADITIONAL VS SMART MANUFACUTRING [7]

Description	**Traditional Manufacturing**	**Smart Manufacturing**
Resources	Limited and Predetermined Resources	Diverse Resources
Routing	Fixed routing	Dynamic Routing
Network Connections	Shop Flow control network	Comprehensive Connection
Layers	Separated Layer	Deep Convergence
Organisation	Independent Control	Self Organisation
Data	Isolated performance	Big Data

B. *Smart Manufacturing with 6 Design Principle*

Today's technology innovation impact is pervasive and creating massive change. Smart manufacturing, the ongoing evolution in the revolutionary processes that will change and shape the manufacturing world with greater sharing of information in real time and partnership brings together physical and digital world. As the industry 4.0 design principles, Industries can use the below given 6 design principles to identify and implement Smart manufacturing:

1) Interoperability: Internet of things and Services enables to connect, communicate and share data between partner industries and humans with Cyber physcial system (CPS) comrpising work piece carriers,assembly stations and products

2) Virtualization: A virtual copy of the industry is created using sensor data, virtual plant models and simulation models.

3) Decenteralization: The technologies like cyber physical systems enables self decisions

4) Real Time Capability: Provides real time insights with the capability to collect and analyze data.

5) Service Oriented: The technologies like Internet of services offers different services to cyber physical systems,humans etc.

6) Modularity: Flexibel adaption for the changing requirements of individual modules.

C. Key technologies in smart manufacturing for competitive global digital supply chain

Entirely automating the system try to eliminate the manual data which, results in reducing the human random error. Smart manufacturing is integrated into company's value chain: innovation and development of products, engineering, manufacturing, digital sales channels and customer relationship management. It is an implementation of a broad variety of digital technologies — Sensors and GPS, Robotics, big data, the cloud, the Internet of Things (IoT), 3D printing, augmented reality. The following are the key technologies in smart manufacturing [8]:

- Smart Modeling and simulation
- Cloud computing and connection
- Online monitoring and control
- Modular machine and material handling tools
- Secure Communication processor system
- Additive manufacturing/3D printing (AM)
- Artificial intelligence (AI)
- Augmented reality (AR)
- Cognitive bots and autonomous robots
- Digital twin
- Inventory tracking/management software
- Real time equipment monitoring
- Health and safety sensors and automatic identification

D. Smart manufacturing for global digital supply chain

The key aspects of smart manufacturing consist of the following:

1) Smart design: It consist of a combination of tools and techniques like virtual reality and augmented reality which supports to transfer from traditional design to a smart product design era including design automation, computation intelligence etc. that assist for rapid testing and development of innovative designs which results in better product and profitable revenues. The engineering change from physical realizations to achieve a smart design paradigm where the design software such as CAD/CAM and other are able to interact with smart prototype devices in real time enabled 3D printings that are integrated with Augmented Reality and Cyber physical Systems [9].

2) Smart machining: It is a technology that combines intelligence with high speed machining process that results in optimized machining performance for an improved process reliability, even to achieve an unmanned operations level. Robots, Automated Guided Vehicles (AGV) and other related computing systems that are designed to work without human interactions can be categorized under this technology. Smart Machining is achieved with help of robots and other smart objects that performs with real time sensors and interacting each other [10]. Smart machining tools empower the industry to automate their processes where they can absorb the insights from past experiences to improve their future planning processes.

3) Smart monitoring: The key technologies that configures smart monitoring in Smart-M are IoT and CPS. Various types of sensors deployed in the smart manufacturing systems enables to monitor different key aspects in a manufacturing industry from scheduling to operations, logistics and reaching to maintenance level of manufacturing. Smart monitoring are updated to level where it can provide warnings or alerts if there is any variance in the process, machines or tools [11].

4) Smart control: Smart Control is executed to physically manage variety of smart tools and machines using cloud platforms. A high resolution, adaptive output control is achieved with smart control system using CPS. End users in a manufacturing plant are able to control their machines or tools with the help of smart phones or other devices with cloud enables smart control systems. A timely decision using smart control system reflects in frontline manufacturing where smart machines or robots or robots based assembly lines are enabled [12].

5) Smart scheduling/planning: Smart manufacturing integrates with digital supply chain platforms that enables the industry to meet the variance in customer or product demand with the smart scheduling and planning. From sourcing to transport, tracking and warehouse management system are integrated with advanced models and algorithms using IOT, sensors, cloud systems that use data driven techniques for advance analysis and decision making under smart planning. Design and production procedures will be alternated automatically and efficiently with the data input mechanisms and the output are feedback the respective parties for future analysis and improvements [13].

E. Key features of Smart Manufacturing (SMART-M)

The key features of smart manufacturing are discussed as below.

1) Specific: Smart manufacturing enables each procedures to be specific to achieve the targets. Primarily determining the goal to be accomplished is an important aspect in manufacturing. Determining the goal will help to use smart manufacturing accurately to integrate with the respective dimensions and decide on changes and time requirements and process to meet the goals. Goals can be specific which can vary between the industries or between the respective teams [14].

2) Measurable: Unexpected delay of resources or influx of orders to supply chain delays to equipment downtime can happen at any time. In addition to deciding the required changes for a specific goal we may require to track data

over the course of operations for an effective analysis to decision making to be in line with the schedules [14]. Smart Manufacturing makes the systems and procedures measureable and allows industry to make adjustments as per requirements based on actual results that enables them to determine the effectiveness in strategy during the implementation.

3) Attainable: Attaining the customer demands is one of the primary goal in a manufacturing industry. This is an "action-oriented" step where both target the same strategy – to ensure the target is one that can be achieved. Smart manufacturing enables to create a clear action plan from the current end analysis results of procedures. Attainable goals are set with by analysing the end result after production process which are improved after achieving the current attainable goals which result for a continuous improvement in the manufacturing system [14].

4) Real time visibility: Enabling the industry with latest technologies and becoming smart manufacturing could vastly improve efficiency and reduce waste. Implementing smart manufacturing will provide a dynamic, secure and interactive visibility across the entire process from sourcing to end customer will improve the management of industry [14].

5) Time: Time play an important role from achieving customer demands to specific targets within the industry and even in global market. Smart Manufacturing technology enables the system to work efficiently and provides periodic reviews over the process to measure and analyse the data to ensure the targets are achieved within scheduled plan [14].

F. Advantages of smart manufacturing for digital Supply Chain

Smart Manufacturing aims towards a fully integrated sequence of planning and production solutions that work in tandem to create a more visible manufacturing process and supply chain stream across each touch point of the value chain which result in a more responsive, agile, and transparent supply chain network that can readily adapt to a host of industry-wide unknown variables such as inventory shortages or overages, modifications to orders, and availability of resources. Through this digital transformation, companies can experience lower production and operational costs, downtime accelerated efficiency and quality and lead times, with enhanced reporting and data analysis capabilities which can fuel better planning and production programs.

Smart manufacturing creates more skilled job opportunities and it also creates more opportunities which will require the manufacturers to conduct more training for skill development of the unskilled employees in best possible ways which will create a healthy atmosphere in the industry. The performance measurements in smart manufacturing is carried out by examining the ability of resource availability, meeting the customer demands, filling of orders till due day, delivery time, supplier reliability, chain cost or delays, among many others. The wide spread adoption of smart manufacturing is realized due to the critical advantages as described in TABLE II.

TABLE II. ADVANTAGES OF SMART MANUFACUTRING [15][16][17]

Advantages	**Description**
Increased Efficiency	Smart manufacturing implements technologies which generates different types of data through continuous analysis that may optimize the procedure for improvements. This self-correction is what distinguishes the smart manufacturing from traditional automation, which yield greater overall efficiency with seamless integration of people, processes and technology.
Increased Quality	Smart manufacturing can predict and detect quality defect trends sooner and can help to identify discrete human, machine, or environmental causes of poor quality that can optimize the future quality process that that could lead to a better-quality product with increase fill rates and yield and decreased defects, recalls, scrap rates and lead times.
Significant Cost Reduction	Advanced automation, analytic tools, shared information and flexible systems helps industry to decrease waste and increase forecast accuracy. Smart manufacturing helps to reduce costs related to excessive inventory or unexpected production volume with better insight into supply chain system such as demand, inventory and delivery cycles.
Shared information	Smart manufacturing allows easier information sharing from resource availability, sales forecast to production data and supply chain that helps to work according to demand. Capabilities are harmonized within and beyond physical boundaries to increase collaboration between involved actors of the industry including the supply chain.
Adopting advanced analytics and analytics tools	Advanced data analysis improves decision making. Gaining better understanding and forecasting of the demand and solve previously unsolvable and even unknown problems along the manufacturing process and supply chain. (e.g., Big Data and Data Analytics, etc.).
Flexibility	Digital plug-and play capabilities make it easier to configure and re-configure based on demands. Product and service functions can be altered easily to meet customers' changing demands.
Personalized experiences, Customer-centric	Channel-centric manufacturing and supply networks support customized products and services.
Enhanced responsiveness	Better information and sophisticated analytics can help accelerate responses to competitors' moves, technology shifts, and changing demand and supply signals.
Predictive Maintenance	Decision support systems driven by predictive analytics can strengthen adaptability and reliability. With better visibility, manufacturers can predict and resolve maintenance issues before the downtime that may affect product quality and customer feedback.
Improved Productivity	Real-time data outlines the demands which makes the manufactures swiftly optimize the organizational assets assisting on ensuring the process are aligned with evolving demands only which reduce waste and associated downtime to meet the supply demands.
Safety and Sustainability	Smart Manufacturing impart around benefits of labor wellness and environmental sustainability. Automation increase operational efficiency decreasing the human-machine interaction and environmental footprints.

III. Research gaps and Future Studies

It is evident from the literature that smart manufacturing offers unlimited possibilities of exploration as the market dynamics widely vary in economies, regions, climate zones, time zones, political systems, countries, population demographics, and so on. The field of smart manufacturing continues to enhance as the world is integrated into one great global marketplace, and the researchers are faced with new scenarios from time to time. Some of the limitation in smart manufacturing paves way for future research scope of development as highlighted below [18]:

- Wearable Technology
- Manufacturing Execution Systems (MES)
- High Initial Cost
- Data Security
- More Versatility
- Zero Emission
- Social Sustainability
- Continuous Maintenance Support and Training
- Driverless technology

Modern manufacturing and logistics practices focus on the circular concept, involving the use of previously used products as raw materials. The reuse of products and materials is known as reverse processing, and it is a novel, innovative approach. It helps companies reduce administrative and transportation costs, achieve higher sustainability, better customer service and loyalty, create value and conserve resources [19]. Used products can be kept in circulation through good cooperation between companies and their suppliers and customers. Manufacturers should enable the use of wearable technology for fast, accurate collection of product data, keeping track of production, inventory and distributed data with cloud technology, wearable devices by real time input data by employees. Wearables can also monitor vital signs so health problems (exhaustion, heart attacks) among the warehouse workers can be prevented [20]. Through proper data collection and analysis, wearable technology allows manufacturers to maintain control of their inventories. They can also stay up-to-date with product demand. Smart Manufacturing technology provides opportunities to better support the supply chain with proactive tracking of resources, demands, production, location and delivery information. They also give better insight into the performance of supply chain. Digital platform used in smart manufacturing should be able to merge global transportation data combining it with relevant weather data and news feeds from traditional sources as well as social media. This much more comprehensive picture enables the logistics and customer service teams to collaborate on events impacting the manufacturing and supply chain each other, resulting in more timely and accurate information for suppliers and customers [21].

Conventional Manufacturing Execution Systems (MES) don't really support environmental sustainable goals but are actually the most suitable background for an extension towards sustainability monitoring, control and assessment [22]. MES is a very critical component of Industry 4.0 that has been evolving day by day with more advanced intelligence. It enables to achieve end to end digitization objective by acting as a bridge between various plant floor systems and providing an integrated ecosystem for real time information exchange and better and faster decisions between the manufacturing and supply chain. Internet of Things (IoT) has been envisioned as the integral part of industry that will impact all the areas from planning till delivery [23]. An amalgamation of MES and to reconfigure production, quality, maintenance, and inventory systems management is defined as MES 4.0. MES 4.0 is the concept of developing a smart factory by integrating PQIM pillars through smart objects for providing smart processes [7]. "The factory of the future" known as smart manufacturer or smart factory is one of the mile stone of the fourth industrial revolution. It is often represented as the aggregate of all the Industry revolutions till date with latest technologies: cyber-physical systems—physical assets connected to digital twins—the Industrial Internet of Things (IIoT), data analytics, additive manufacturing, driverless technology, delivery drone systems and artificial intelligence [24]. Beyond the way we commute, driverless technology is set to disrupt the smart manufacturing. The surge of interest from tech giants like Google, Apple and Tesla in creating driverless vehicles is changing the way vehicle works, the market landscape and challenging traditional companies like Ford, BMW and Mercedes. The entire transportation chain which plays another major role integrating smart manufacturing and digital supply chain depends on technological progress and market shifts. The logistics industry is poised to be the fastest adopter of driverless vehicles compared to other industries [25].

IV. Conclusion and Future Research

It is evident from the literatures that researches, and industries have yet to succeed in transforming conventional manufacturing system to a true SMART Manufacturing system due to its extremely complex organism even yet many of the required applications are not widely used. The latest technological advancements discussed in this paper makes the manufacturing more efficient, effective and flexible than conventional system. Different companies are integrating to be Smart at varying speed which will results in a radical change over the next five years. First row of companies to be smart will absolutely achieve a difficult-to-challenge advantage in the race to Industry 4.0, and will influence or be able to set, their particular industrial technical standards that may results in greater efficiencies with no means of any limitations. This advanced technology opens up for many new business design models and generate revenue streams [26]. Smart factory describes an environment where machinery and equipment are able to improve processes through automation and self-optimization. The benefits also extend beyond just the physical production of goods and into functions like planning, supply chain logistics, and even product development [27]. Smart manufacturing is a manifestation of what's being called the Fourth Industrial Revolution — a concept that's been in the conceptual-buzz phase for years. A major challenge of smart manufacturing, the development has been an issue for technologies in all sectors: big data. Smart technologies need to store, process, analyze and transfer massive amounts of information [28]. Volume isn't the only issue, though. With so many different components

from diverse industries and manufacturers being implemented in unique manufacturing environments, connecting them is a challenge.

As seen through earlier research studies the key design factor in smart manufacturing is innovation. Companies could find themselves in losses and face bankruptcy if they don't embrace now for innovations and implement themselves with technological advancements [29]. In some respects, becoming smart protects established market leaders from highly innovative upstarts because the art of designing, creating and shipping products around the world requires a degree of "old world" processes with advanced technology.

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