IMPACTS OF I4.0 ON SUSTAINABLE MANUFACTURING TO ACHIEVE COMPETITIVE ADVANTAGE

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ABSTRACT

Research studies highlights that Industry 4.0 plays a vital role in different areas of manufacturing industries and requires constant research and improvements due to high demand to meet the global competitive markets in an efficient and economical method. The current industrialisation is facing great challenges in ensuring the sustainability balance of its social, economic and environmental dimensions while they strive to achieve the product demands in competitive market space. As part of achieving these high demands, different studies focus towards developing the understanding of industry 4.0 implementation practices to attain a sustainable manufacturing process that incorporates advanced technological tools for increasing efficiency, financial gains and competitiveness in the market. This paper aims to examine the interrelationship of sustainability practices, the key factors affecting sustainability within manufacturing, and finally the advancements of industry 4.0 and different technologies to achieve sustainable manufacturing that focuses on KPI's of environmental and social dimensions.

Keywords: Industry 4.0; Sustainable Manufacturing; KPI's; Competitive Advantage; Technological Advances; Manufacturing

1. INTRODUCTION

Manufacturing process and performance plays a crucial part for the success of many industries. Manufacturing with a sensitive and competent design process enhancing employee, community and product safety without any detrimental social, economical and environmental effects results in Sustainable Manufacturing [1]. The current industrialisation is facing great challenges in ensuring the sustainability balance of its social, economic and environmental dimensions while they strive to achieve the product demands in competitive market space.

Industry 4.0 (I 4.0) is currently recognised as a collective expression for different technologies [2]. Even though Industry 4.0 is implicit the launch of cyber physical system (CPS), Internet of Things (IoT), cloud computing and big data, these technologies are used with other technologies like Artificial Intelligence, Autonomous Robots, Additive Manufacturing where they are linked by different types of sensors which are physically monitored and create a virtual replica of physical world using cyber physical systems (CPS) to compile decentralised resolutions. CPS links with Internet of things (IoT) to provide

productive entities that communicate and cooperate with each other and even with humans in real time whenever required.

In current situation sustainable manufacturing process has turned out be a critical concern for all the manufacturers. Nowadays all manufacturers curiously want themselves to attain economical, environmental and social sustainability as they realise the significant financial and environmental benefits that will also help them to be competitive in the market. Manufactures use different methods like eco-process designs, lean practice, cleaner productions etc. to attain sustainability.

Developing a profound impact on every organisational elements of real life, sustainability challenges have a mutual rapport with manufacturing as a primary factor of modern lifestyle. Sustainability has been one of the prominent factors in recent researches due to increased manufacturing contaminations, scarcity of natural resources & raw materials, increasing energy and resources expenses, environmental pollutions etc. In this paper researcher aims to examine the interrelationship of sustainability practices, the key factors affecting sustainability within manufacturing, and finally the advancements of industry 4.0 and different technologies to achieve sustainable manufacturing that focuses on KPI's of environmental and social dimensions [3].

2. LITERATURE REVIEW

Since the beginning, many researchers have initiated to incorporate sustainability in the theoretical area of manufacturing concept, where some of them highlighted the benefits of renewable manufacturing consequently integrating either of 3 key pillars of sustainability (social or economical or environmental management) into manufacturing practices [3]. These articles possibly describe the significance of how precisely manufacturing will be influenced while taking care of environment or social or economical aspects. These were primarily conceptual articles as well as literature reviews aiming to add either of 3 key pillars of sustainability new trend to enrich those pre-existing theories of manufacturing.

Second group of articles where typically concentrated on exploring the relation of various key factors of manufacturing with sustainability. The initiatives were incorporating social and environmental sustainability with work place safety as latest concerns for manufacturing [4]. Other researchers had experimented regarding the environmental sustainability as a new efficient consideration to explore the competitive sustainability practices and its effects as a top priority on performance. But, no empirical studies on similar concerns were conducted regarding social sustainability.

The third group of articles reviewed environmental sustainability within manufacturing techniques possibly by including it in strategic determination or by exploring green manufacturing practices. Empirical papers were not available in this category of articles. The final group of articles explored the relationship between a few distinct sustainability practices within performance and manufacturing [5]. When certain articles emphasised the influence of social sustainable practices including human resource management, organisational culture, influence of human resource on social and environmental performance etc other articles studied the effects due to influence of environmental practices such as technology, ISO 14000 regulations, pollution prevention, recycling and waste reduction, efficiency and performance etc.

Nevertheless, no review as well as study explored an overall effectiveness of industry 4.0 technologies to achieve an economic, social and environmental sustainability in manufacturing field

2.1 Sustainable Manufacturing

Sustainability is highly critical requirement with sustainable development as key objective in manufacturing industry. Researchers are dedicated on enhancing manufacturing techniques and methods to cut down environmental impacts along with overall economic performance. The study in sustainable manufacturing depends on elementary restructuring of the frameworks within the manufacturing process and systems. Different tools like decision analysis as well as alternative selection techniques have been designed to showcase the idea of sustainability where the most effective solutions are an integrated strategy comprising all three pillars of sustainability (economic, environment and social) [3].

The significance of implementing sustainable manufacturing methods and practices are increasingly recognised by the industries. For instance, scarcity of resources and non-renewability affects the manufacturers which raise the questions about viability and sustainability of existing manufacturing practices that aims for business growth, but industries pay less attention to minimise these impacts beyond the industry [3]. These consequences have increased the seriousness of sustainable manufacturing by stakeholders e.g.: investors, customers, suppliers, regulatory bodies, employees etc. The key factors of sustainable manufacturing are:

1. Optimise current use of fossil fuels
2. Eliminate waste
3. Reduce, or eliminate Pollution**.**
4. Recycle
5. Time saving

Driver KPI of sustainable manufacturing

Table 1. KPI factors for sustainable manufacturing

ENVIRONMNETAL KPI		ECONOMICAL KPI		SOCIAL KPI	
Pollution	Air emission Water emission Land emission	Quality	Product reliability Product durability Conformance to specification Customer complaint Scrap and rework Reject rate	Human	Accident rate Employee involvement Training and education Customer satisfaction Labor relationship Occupational health and safety
Resource consumption	Energy utilisation Water utilisation Fuel utilisation Land utilisation	Cost	Material cost Setup cost Overhead cost Inventory cost Unit cost Labor cost		
Waste	Solid waste Liquid waste Hazardous waste	Delivery	On time delivery Delivery speed Cycle time Delivery lead time Due date adherence Schedule attainment		
		Flexibility	Volume flexibility Product flexibility Process flexibility Technology flexibility Product innovation New product development		

Performance of each process or equipment's is evaluated with certain fundamental defined key performance indicators (KPI) to achieve increased performance and profits. KPI's simply describe what has happened and what will happen as they provide information as per the performance in different areas like material, energy, process, maintenance etc. that helps the decision makers to make decisions which affect the future competitive position of the industry. Based on the literature review, we have developed an initial set of Nine KPI's which has been used most commonly for evaluation by different researches since 2000 to 2108 that has been created by integrating sustainable manufacturing and manufacturing performance indicators by adopting the triple bottom line of sustainability (Economical, Environmental, Social) performance factors and manufacturing performance factors. In addition, from relevant literatures we can sub divide these nine KPI's into 41 sub dimensions.

2.2 INDUSTRY 4.0- Key Technologies

Industry 4.0 uses Cloud storage to store the data (Big Data) that has been created due to communications which will be filtered as per actual required information. It is impossible to physically manage the current volume of information or data that has been saved in relation to various system processes and due to massive data traffic [6]. A detailed assessment of these data will provide us with information regarding the operations that may help to certainly reduce challenges in manufacturing processes via detecting irregular steps or perhaps figure out which process are associated to more complicated operations which will facilitate management by predictions, realising that an operation might further trigger out with a probability. Cloud computing is a paradigm of information technology which allows universal entry to pool of system resources as well as expert services which can swiftly be delivered with marginal manual effort usually over the web [7]. This technology depends on information sharing to gain a consistence and economic dimension in the market.

Additive manufacturing is a technology in industry 4.0 which allows for hyper-customisation of a product to impression of servitisation [8]. It helps to create small set of prototypes and more products with a much cheaper process than usual manufacturing process. Autonomous robots describe the latest development in robots which cooperates more closely with humans, avoiding the typically recommended safety limitations in industrial robotic applications. These robots are distinguished from other normal robots due to its great accessibility, flexibility and programming easiness. Simulation of human intelligence by computer systems and machines which includes learning, reasoning and self-correcting habits of humans is named as Artificial Intelligence (AI). In current data centric industry market, there is an immediate requirement to acquire a value from huge volume of information, for which we use these technology and tools that are able to examine and process from huge volume of data which are obtained from different connected sources including human reactions.

The network of intelligent systems and devices that can gather and share a massive amount of data is knows Internet of Things (IoT). Application of IoT in a greater notion in manufacturing industry is known to be IIoT (Industrial Internet of Things). The data collected by IIoT is delivered to central cloud system where it is clustered with other related data and send to end users for further analysis and actions. IIoT will restructure manufacturing by allowing accessibility and possession of larger amount of information swiftly and more efficiently [8]. CPS (Cyber Physical Systems) can be generally characterised as "physical and engineered systems whose operations are monitored, controlled, coordinated, and integrated by a computing and communicating core". The interaction between the physical and the cyber elements is of key importance: "CPS is about the intersection, not the union, of the physical and the cyber. It is not sufficient to separately understand the physical components and the computational components. We must understand their interaction".

Industry 4.0 will impact product and service profile and even transform the operation of companies where new business framework, innovative technologies, latest products and services can be more innovative [9]. When new smart products and services are developed, new business strategies will follow up. Industries started implementing different technologies of industry 4.0 by understanding the impacts of digital transformation in their business where digitalisation is making it easy for industries to collaborate [10]. The fourth industrial revolution will affect current systems of manufacturing in multiple ways, including:

- Opportunity to develop totally new manufacturing and business strategies.
- Appealing work surroundings with enhanced safety.
- An increase in efficiency and reliability when fully implemented.
- New product design services.
- Mass customisation will helps in reduction of economies of scale.
- Smaller batch sizes can be automated.
- Increase in production flexibility that result in less lead time in production.

2.3 Impacts of INDUSTRY 4.0 on Sustainable manufacturing -

Since 2011, industry 4.0 is evolving, which has opened up a boundless opportunity in the technology and firmly linked the mega trends like connectivity and digitisation. Use of resources efficiently should be considered beyond the competitive technological advantages which results in improved flexibility and efficiency [11]. Economic instability, shrinking resources, environmental pollution etc. are crucial challenges being faced by the manufacturing industries. The manufacturing and production process in industries are nowadays shaped up with industry 4.0 technologies in a holistic and balanced circuit to cope with social and environment regulations, resource cost fluctuations due to scarcity etc. Industry 4.0 provides vast possibilities to develop for a sustainable, resourceful and eco-friendly manufacturing.

Industry 4.0 revolution promises several opportunities environmentally and socially from an ecological perspective. Enabling the technologies of industry 4.0 helps to reduce greenhouse gas emissions by analysing data-centered and carbon footprint traces. In addition, it aims at reducing waste production by proper controlled consumption of resources and energy. Examples include closed value creation networks, reuse of resources and tools, as well as production of machines parts using additive manufacturing technology [12]. Regarding social aspects, Industry 4.0-improved flexibility of management processes and decisions due to transparency that are enabled by real-time data analysis throughout entire manufacturing process and related business strategies. In line with literatures reviewed, implementing innovative technologies from Industry 4.0 have influenced on environment, economics and social factors which benefits the manufacturing industries to achieve sustainability with relations as mentioned in **Table 3** with the key performance indicators.

4. CONCLUSION

The introduction of sustainability into the product and process development, regarding environment, economy, and society, has compelled the manufacturing companies to move instantly toward producing long-life sustainable products. Although many researchers have addressed these prerequisites recently, they have still great need to be enhanced to facilitate the industries' improvement around sustainability with technology. Based on the literature review the researcher had created and opportunity table integrating key performance indicators of sustainable manufacturing and Industry 4.0 technologies.

Table 3. Opportunities of industry 4.0 in sustainable manufacturing KPI's

Effect on SOCIAL KPI with industry 4.0	
Humans	• With increased training efficiency of workers by combining new technologies will help to open new job openings to the public • Implementing the technologies will help to reduce workloads that will results in reduced absenteeism at workplace and increase employee motivation [14]. • Cyber physical systems help to provide more information for audits and help to analyse the working culture. • Improved training to the workers with latest technology will help to increase more opportunities in the industry and improved safety of the workers at the industry [3]. • IoT helps to improve equipment safety though better maintenance solutions. • Better man-machine connectivity with improved technologies like robotics or artificial intelligence systems will improve standard operating conditions. • Improved technologies like safety wearable, for example: Sony glasses used by Virgin for aircraft maintenance will provide users with real-time, local warnings hazards [15].
Effect on Environmental KPI with industry 4.0	
Pollution	• Manufacturing design can be improved through direct data interconnection from product usage back to design, leading to improved product lifecycle management including recycling and hence reduce land, water and greenhouse gas emissions [16].
Consumption of resources	• IoT is an influential concept when considering energy management and operational efficiency in smaller facilities because it is a pathway to cost-effective technology deployment. • The Internet of Things paradigm promises to increase the visibility and awareness of energy consumption [3]. • Smart sensors and smart meters at the machine and production line level help to provide real time data for better improvement. • Real-time resource consumption data from manufacturing processes can be collected easily, and then analysed, to improve energy-aware decision-making [13]. • Load balancing can be optimised by improved process simulation and prediction of energy consumption via smart energy systems that leads to reduced energy consumption
Waste reduction	• Development of the informatics and automation, as well as the increase theirs cohesion enabled the application of the cyber physics systems which can reduce the manufacturing wastes with coupling the manufacturing system's elements. • Process-equipment modification can result in significant waste reduction in industries. • Inventory Management in industry 4.0 reducing both the quantity of hazardous materials used in the process and the amount of excess raw materials in stock, the quantity of waste generated can be reduced
Effect on Economical KPI with industry 4.0	
Quality	• Industry 4.0 applications facilitate the improvement of product and process quality by using real-time problem solving, advanced process control or real-time error corrections to decrease unstable manufacturing processes, rework and consequently extra cost [11]. • Real time monitoring technologies in Industry 4.0 helps to prevent waste by avoiding unnecessary inventory and storage cost, a perfect understanding of customer demand in terms of quantity and product features lead to a much better predictability through new possibilities of reliable and durable product manufacturing. • Innovative services lead to new possibilities of repairing products and to the chance to keep them longer operational. Product manufacturing can be more

	cost effective, when machines get a longer operational time which is possible through remote maintenance or virtually guided self-service. In this case it is possible to carry out error diagnosis and repair without the necessity of a technician visiting the site [3]. • The avoidance and early correction of defects can therefore save costs and drive production throughout, which consequently increase product durability and conformance to specification that results in customer satisfaction and decreased rejection rate.
Cost	• It is possible to decrease material costs by less defective goods and optimise processes (in speed or yield) via the use of cyber-physical systems. • It helps industrial concerns make better decisions faster to reduce operational costs and increase efficiency and productivity In other words; it's about making factories smarter. • Industry 4.0 solutions improve the efficiency, quality, and utilisation of factory operations which helps to improve on labor cost, overhead cost, unit cost [11]. • The optimal use of a companies' machinery park is supported by Industry 4.0 based technologies, for example predictive maintenance. • A proper management system of data helps in control of inventories which leads to saving great capital costs. • Improvement of manufacturing processes including the optimisation of material consumption will drive value and will make it possible to increase productivity.
Delivery	• Through the permanent, remote monitoring of machinery conditions it becomes possible to reduce machine downtimes or changeover times by an early detection of possible problems and continuous maintenance [15]. • New emerging technologies like drone delivery system, automated guided vehicle systems (AGV) enables faster and cheaper delivery system in the supply chain to achieve on time delivery with increased delivery speed and decreased lead times [17]. • Demand and process transparency allows intelligent scheduling of tasks and processes which helps to attain the schedule with due date adherence [18].
Flexibility	• The improvement of labor productivity can be realised by using the new technologies of Industry 4.0. • Industry 4.0 technologies enables mass customisation, allowing companies to meet customers' demands, creating value through constantly introducing new products and services to the market with technology flexibility that results in product innovation that helps to gain process and product flexibility [24]. • New technologies emerging with Industry 4.0 enabling faster and cheaper R&D processes, e.g. concurrent engineering or rapid prototyping by using 3D-printing can significantly reduce the time to market [25]. • By applying real-time supply chain optimisation, drivers of excess inventories can be targeted by addressing problems like unreliable demand planning and overproduction.

Information flow, advanced technologies, and materials—in other words, the Information Technology (IT) and Operation Technology (OT) that comprise Industry 4.0—make it possible to manufacture entirely new things in entirely new ways and revolutionise supply chains, production, and business models. Further to the literature review the KPI approach introduced in this paper is completely new. Initial set of KPI's for sustainable manufacturing was identified using literature review which has been incorporated and defined with the technology and its performance. The performance indicators referred to in this paper serve as a good starting point for companies that are launching a KPI-system for the first time within a service organisation but should by no means be considered to be complete or universally valid. These findings are consistent with previous literatures and researches.

Future research focus on incorporating KPI's and Industry 4.0 technologies to achieve a sustainable manufacturing process with a new level of optimisation and productivity. The concept will push global manufacturers to a new level of sustainably manufacturing processes. Also, customers will enjoy a new level of personally customised and even smart products that may have never been available before. As mentioned above, the economic rewards are immense. However, this study offers suggestive evidence where there are still many challenges that need to be tackled systematically to ensure a smooth transition of manufacturing processes by incorporating of industry 4.0 technologies and sustainability. To be able to do this, the determining factors such as control variables and disturbance variables have to be identified. Their impact on important performance indicators should be qualitatively and quantitatively examined to develop a decision-support-system for managing the service delivery organisation.

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