Research on the Application of Internet of Things (IoT) Technology Towards A Green Manufacturing Industry: A Literature Review

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Abstract: The continuing and rapid growth of technology and science will evidently reflect in the demands of the manufacturing industry. Due to this, an increase in the production of waste, gas emissions, and power consumption will occur in manufacturing production. Although, the use of alternative renewable energy sources is becoming popular due to the effects of climate change caused by pollution and the use of fossil fuels is slowly decreasing. This paper aims to present the current environmental problems contributed by of the manufacturing industry, identify the main causes brought by unmanaged waste and industrial practices, and the solutions of manufacturers to address these, based on available literature. Available technologies will be presented as a solution to these problems particularly the use of Internet of Things (IoT) in the industry, or Industrial Internet of Things (IIoT). Existing technologies and possible areas of implementation discussing the advantages will be discussed.

Key Words: internet of things (IoT); industrial internet of things (IIoT); green manufacturing; sustainability; energy consumption

1. INTRODUCTION

Even though factories were already present in the 18th century, the replacement of wind, water, and wood with fossil fuel as the main source of energy indicated the start of the Industrial Revolution in the mid-1700s. It helped increase production capacity and greatly improved human condition as it affected all basic human needs (Greenberg, 2014; McLamb, 2011). Furthermore, the Industrial Revolution marked the use of machines as a substitute to human labor. Since then, fossil fuel has been the number one source of energy and electricity (McLamb, 2013). In 2016, the International Energy Agency reported that coal is still the top source of electricity in the Organization for Economic Cooperation and Development (OECD) region with 59.5%. Among the three (3) regions – Europe, the Americas, Asia/Oceania – with Asia/Oceania countries having the highest percentage of 88% for the total electricity produced came from fossil fuel (*Key Electricity Trends 2016*, 2017).

Industrial revolution, with the use of fossil fuels, paves the way for manufacturers to have bigger and efficient factories; however, as the industry's production increase, so will the environmental damage it causes (Greenberg, 2014). Ever since industrialization, greenhouse gas concentration greatly increased. This was caused by the discrepancy between production (i.e. gas emissions) and elimination (i.e. removal from atmosphere) ("What are the greenhouse gas changes since the Industrial Revolution?," n.d.). Data from Eurostat shows that the manufacturing industry contributed to 11% of acidifying gas emissions from countries in the European Union (EU) (*Air pollution by industries and households*, 2016).

With the continuing growth of the manufacturing industry and the advancement both in technology and in science, Industrial Pollution is the unfortunate effect of these. Today, many companies are finding ways to reduce, or even prevent, their degrading impact on the environment through technology.

2. EXISTING INDUSTRIAL ENVIRONMENTAL ISSUES

Industrial pollution is one of the main contributors to environmental degradation in developing countries. High energy consumption, and waste from production are the main causes of industrial pollution. The increasing growth in of manufactured products to meet society's demands result to the simultaneous growth of industrial waste and energy consumption (Yuan, Zhai, & Dornfeld, 2012). The large amount of industrial wastes affects all forms of environments by contaminating the air and nearby bodies of water with hazardous emissions or discharges (Despeisse, Oates, & Ball, 2013). Along with this, it is crucial to monitor the use of energy resources in manufacturing as it has a great impact to the consumption of available fossil fuels given the energy-intensive processes used in the industry (Garetti & Taisch, 2012).

However, the source of manufacturing pollutants and environmental issues do not originate mainly from the output or waste of the process. Causes relating to manufacturing practices are as follows:

- Lack of sustainability projects and policy implementation
- Reliance on outdated production waste and quality monitoring technology
- Lack of waste disposal planning and management
- Dependency to non-renewable power sources and raw materials

In recent years, the impacts of these issues have grown more significant that it has encouraged the initiative in performing comprehensive studies to increase awareness of the society's responsibility to the environment. Governments and specialized organizations enforced strict laws and delivered initiatives to impose a standard on the amount of waste and emissions each company can produce (Haapala, Camelio, Sutherland, Skerlos, & Dornfeld, 2013). The persistent movement and awareness towards green manufacturing influenced businesses to see sustainability as a competitive advantage. The goal towards sustainability pushes innovation to increase effectiveness leading to developing alternate energy supplies and reducing the amount energy, resources, and space for production (Bunse, Vodicka, Schönsleben, Brülhart, & Ernst, 2011; Chiou, Kai, Lettice, & Ho, 2011; Dornfeld, 2014; Garetti & Taisch, 2012).

With these, studies and research on sustainable manufacturing, management concepts and technological advancements to improve manufacturing practices such as the application of lean manufacturing and environmental management practices. These have been positively associated with environmental and market performance (Yang, Hong, & Modi, 2011). A study on an approach towards sustainable manufacturing is what they call the three-dimensional approach which aims to improve overall sustainability with a pollution prevention perspective. This study presents an adaptable framework on implementing this perspective to three main components which are the technology, energy, and material (Yuan et al., 2012).

3.1 Waste Reduction

The production of solid waste byproducts from excess materials and rejects are inevitable in any manufacturing process (Haapala et al., 2013). Chemical waste discharge that may come from manufacturing pharmaceutical, electronics, household products, and the like can dangerously impact the health of the people and environment exposed to it if improperly managed or treated upon disposal. Chemicals are hazardous waste which may be toxic, ignitable, reactive, or corrosive while certain compounds and nutrients can affect the eutrophication of freshwater (Canada. Environment Canada. & Canada. Health and Welfare Canada., 1991).

Due to these, a trend in the industry emerged aiming towards zero-waste facilities. This means recycling excesses products or waste or converting them into energy (Garetti & Taisch, 2012; Haapala et al., 2013). Waste reduction processes usually start with prevention strategies then, data of waste patterns are collected to identify the needed action for waste reduction. Next, is the reduction of the materials or energy used as a solution followed by the reuse of the produced waste. This study on sustainability tactics stresses the need for the application of new technology to increase efficiency (Despeisse et al., 2013).

3.2 Energy Consumption

According to the Energy Information Administration in a study conducted in 2010, manufacturing industries in the United States consume 21.1 quadrillion Btu energy, which is about 21% of the entire country's energy consumption (Yuan et al., 2012). Majority of the total industrial energy consumption in a country comes from energy-intensive bulk manufacturing processes (Haapala et al., 2013). Certain procedures consume more due to the lack of technological advancements that can regulate its use. Inefficient process flow structure and poor planning of machine designs in underdeveloped factories not only waste more time and energy in production but also the cost of labor (Herrmann, Thiede, Kara, & Hesselbach, 2011). Training of operators and proper education on the factors that contribute to productivity also directly affect energy consumption and is rooted mainly to manufacturing practices. In line with this, the scarcity of non-renewable energy sources caused the prices of oil and gas to rise immensely making sustainability more important to massive manufacturing companies (Bunse et al., 2011).

Power consumption in the industry are included in the study for process effectiveness which classifies use on whether it is part production consumption or a consequence of idle machine time. These are traced by analyzing and planning the process flow and route of materials to determine inefficient workloads and wasting of energy (Bribián, Capilla, & Usón, 2011; Dornfeld, 2014).

3.3 Emissions

A study conducted from 2009 to 2010 show that the manufacturing industry in the United States produced 3.37 billion pounds of toxic chemicals and 1.4 billion metric tons of carbon dioxide emissions to the environment (Yuan et al., 2012). Strict regulations on airborne pollutants set limits to factories due to the immense consequences on the health of the workers and the nearby residents. Regulations such as the Kyoto Protocol from 1998 and the Copenhagen Accord from 2009 aim to reduce greenhouse gas emissions based on studies that prove the presence of global warming and its causes(UN, 1998; UNCCC, 2009).

Particulate matter and hazardous emissions mainly come from the effect of manufacturing procedures especially the ones involving the use of chemicals and products of combustion. "Greenhouse gas emissions are associated with energy use, coke combustion, semiconductor etching, and acquisition of input materials, among other sources. Airborne emissions also come from the fugitive release of ozone-depleting chemicals," (Haapala et al., 2013). Sulfur and nitrogen oxides, lead, mercury, and persistent organic pollutants are some of the most released types of emissions from manufacturing industries (US EPA, n.d.).

The amount of emissions in manufacturing companies are part of the metrics in analyzing resource effectiveness or labor productivity. Labor productivity is the amount of output produced per unit of resource expended, such as gas emissions, pollution impact, and percentage of reuse of materials (Dornfeld, 2014).

3. INDUSTRIAL INTERNET OF THINGS

Internet of Things (IoT), introduced by Kevin Ashton in 2009, is the interconnectivity between humans, machines, and infrastructures through the cloud. It makes use of network of sensors and smart objects to improve efficiency, intelligence, and innovation. This includes day-to-day objects like appliances and home devices to industrial objects (Breivold & Sandström, 2015; Casini, 2014; Li & Li, 2017; Rong, Vanan, & Phillips, 2016; Weber, 2016; Witkowski, 2017). Since then, the application of IoT has become broader where some are using the technology to create Smart Homes, Smart Transport, and Smart Factories. Furthermore, companies are now applying the technology in healthcare, buildings, environment, and energy to name a few (Civerchia et al., 2017; Ting, Shee, Choong, & Jonathan, 2017;

Witkowski, 2017).

The next industrial revolution will be called Industry 4.0 and IoT plays a big part on this. Witkowski (2017) describes that the Industry 4.0 will make use of an improved low-touch approach model like digital product models together. These products will then be produced in Smart factories. Smart factories and/or smart manufacturing are considered sustainable through the use of the technology (Hoske, 2016; "Industrial Internet of Things, Industry 4.0," 2015; Rong et al., 2016; F. Shrouf, Ordieres, & Miragliotta, 2014; Waibel, Steenkamp, Moloko, & Oosthuizen, 2017; Witkowski, 2017). Industrial Internet of Things or IIoT is the term for the application of IoT in the manufacturing industry but has since expanded to other industries like smart agriculture, smart cities, and smart grid (Rong et al., 2016). Moreover, it is used for motion control, machine-to-machine interaction, predictive maintenance, big data analytics, and interconnected medical systems (Mumtaz et al., 2017; Ting et al., 2017). Like IoT, it makes use of wireless monitoring systems and predictive maintenance applications to achieve efficiency in production and in energy consumption as well as increase productivity; promote safety; and predict outputs, maintenance, and failure rates (Breivold & Sandström, 2015; Casini, 2014; Civerchia et al., 2017; Fuertes et al., 2016; Li & Li, 2017; Xu & Chen, 2016). This reduces maintenance costs, avoids dangerous situations and delays, and removes human interaction or intervention (Civerchia et al., 2017). Additionally, IIoT is not only utilized to improve efficiency in production but also to lessen the impacts of industries to the environment and enhance energy management. Shrouf and Miragliotta (2015) detailed some of the benefits of IoT adoption in energy management practices. These benefits are (Fadi Shrouf & Miragliotta, 2015):

- Finding and reducing energy waste sources,
- Improving energy-aware production scheduling,
- Reducing energy bill,
- Efficient maintenance management,
- Improving environmental reputation, and
- Supporting decentralization in decision-making at production level to increase energy efficiency

However, Breivold and Sandstrom (2015) described the challenges with employing IIoT solutions to a system. These are:

- Mixed criticality – The transition from single core to multicore to be more flexible and adaptable for future improvements.
- Latency – Achieve optimal performance especially in real-time services without compromising the reliability and timeliness of the system since the hundreds to thousands of sensors, actuators, and programmable logic controllers are used
- Fault tolerance – Know how much one can tolerate and recover from "accidental and malicious failures"
- Scalability with respect to data update cycles – How to manage huge amounts of data from thousands of control loops and applications while maintaining the performance of the system
- Scalable collaboration – The communication and collaboration of horizontal and vertical systems, products, and devices
- Functional safety – Compliance to safety standards especially when systems make use of general purpose technologies that lack proper documentation
- Industry-specific security challenge – Security of the data collected from IoT-based industrial devices and systems for smooth upgrades with no interference and risk in functional safety
- Legacy long-lived industrial systems – Adapting legacy systems with end-to-end IoT solutions

4. SOLUTIONS THROUGH THE APPLICATION OF IOT

Upon reviewing the technological trends in IoT and the existing environmental issues, there is a way to automate and integrate this technology to develop currently implemented manufacturing concepts for sustainability. Considering that the causes of increased production of waste and unmanaged consumption originate from industrial practices, the application of Internet of Things will focus on developing this area. Developing human interaction and concentrating on integration to practices and elements in the manufacturing process are one of the main objectives in IIoT (F. Shrouf et al., 2014). This approach can be applied in other manufacturing concepts such as lean and green manufacturing.

4.1 Predictive Maintenance

Predictive manufacturing is having a system predict or detect beforehand errors, production status, and product output for identifying operation and process problems root causes. "To achieve transparency, the manufacturing industry has to transform itself into predictive manufacturing. Such evolution requires the utilization of advanced prediction tools so that data can be systematically processed into information that can explain the uncertainties and thereby enable personnel to make more informed decisions" (Lee, Lapira, Bagheri, & Kao, 2013).

Smart sensors can be used for this application to gather data towards developing a self-learning algorithm or an artificial intelligence program to predictive manufacturing capabilities (Lee et al., 2013). This data gathering process is not only applicable for quality accuracy but also for developing product design and material through a life cycle assessment to reduce the amount of waste produced and develop the company's reuse capabilities (Kaebernick, Kara, & Sun, 2003). This technology will allow more accurate and efficient ways to predict unscheduled machine downtime to reduce energy consumption (Lade, Ghosh, & Srinivasan, 2017).

4.2 Overall Management System

Management of the system involves being able to monitor and regulate manufacturing operations. This may be directly applied to the manufacturing practices and has been performed and developed through the application of concepts and disciplines practices of lean manufacturing. Lean manufacturing deals with the systematic elimination of waste in operations using synergistic organizational practices such as quality management, productive and preventive maintenance, and the like (Fullerton, McWatters, & Fawson, 2003; Shah & Ward, 2007; Simpson & Power, 2005; Yang et al., 2011).

Energy management in production require monitoring of energy efficiency throughout the process by measuring key performance indicators to present the relationship between the activity and the required energy. A study on integrating energy efficiency performance to production management also focuses on the importance of information and communication technologies (Bunse et al., 2011). Applying a means of connection increases the sources of information to the flow of the overall manufacturing operation.

This will mean being able to easily monitor and analyze the loss factor and efficiency of production with direct connection and possible application of data connection to sensors and controlled procedures in a plant. This can develop the focus on the planning and implementation for sustainability and logistics. This is the application of sensor nodes and smart devices with RFID or wireless internet connection. Plant devices, sensors, and real-time records can be wirelessly connected and accessed through a cloud server, which can allow devices to be accessed using an interface or virtual display (Bandyopadhyay & Sen, 2011; Wang, Wang, Sun, Guo, & Wu, 2016).

4.3 Enhanced Process Control

Sustainability in manufacturing operations entails evaluating and improving performance based on quantitative and qualitative metrics (Haapala et al., 2013). Proper planning of manufacturing system with implementation of real-time monitoring and enhanced wireless control mechanisms will allow better auditing and adjusting procedures for energy consumption. There is a need to develop advanced automation and control systems for process industries with fluctuating input streams (Garetti & Taisch, 2012). The key is stability and this can be attained by increasing the accuracy and control in quality (Bandyopadhyay & Sen, 2011). The use of sensors and collective data from monitoring can be used to develop the process of product recovery optimization (Ondemir & Gupta, 2014).

A concept of IoT involves capacity to control or override devices and machines through established connections to improve production flow (Sun, 2012). RFID technology is used to implement IoT as the easiest way to integrate connection to various devices. This can be applied in certain procedures to better assist workers and machines in implementing waste management techniques. This can improve the accuracy and speed of implementing changes in set up of production which usually contribute to the amount of rejects thus, waste and cost (Waibel et al., 2017).

Table 1. Summary of related references that applies Internet of Things technology

Article	Summary	Category
Distributed System as Internet of Things for a new low-cost, Air Pollution Wireless Monitoring on Real Time (Fuertes et al., 2016)	Developed a low-cost, real-time wireless monitoring system for air pollution which has three (3) sensors to examine and record carbon dioxide (CO_2), carbon monoxide (CO), and powder density levels in the area. Results were compared with the acceptable threshold set by the US EPA and WHO.	Air Pollution
Internet of things for Energy efficiency of buildings (Casini, 2014)	Discussed the use of Internet of Things to manage and control different features in buildings to achieve energy efficiency as well as in the various equipment inside it (i.e. mechanical, electrical, plumbing, etc.).	Energy
Industrial Internet of Things Monitoring Solution for Advanced Predictive Maintenance Applications (Civerchia et al., 2017)	Developed *NGS-PlantOne* system that "*supports advanced predictive maintenance applications. The system was tested and evaluated with a real testbed based on real IoT devices installed in an electricity power plant.*"	Predictive Maintenance
Internet of Things for Real-time Waste Monitoring and Benchmarking: Waste Reduction in Manufacturing Shop Floor (Ting et al., 2017)	Proposed a methodology to have an IoT-enabled real-time waste monitoring, and to analyze the data which can be used to determine areas in the shop floor where waste reduction techniques can be applied. Data Envelopment Analysis (DEA) was used to perform benchmarking analysis where the result was considered as relative efficiency.	Waste Reduction
Internet-of-Things Enabled Real-time Monitoring of Energy Efficiency on Manufacturing Shop Floors (Tan, Ng, & Low, 2017)	Created a software program for real-time monitoring of the energy efficiency on manufacturing shop floors with the use of IoT. DEA was also utilized to "*detect abnormal energy consumption patterns and quantify energy efficiency gaps.*"	Energy
Methodology for Monitoring Manufacturing Environment by Using Wireless Sensor Networks (WSN) and the Internet of Things (IoT) (W. Li & Kara, 2017)	Developed a methodology to monitor manufacturing environment using Wireless Sensor Networks (WSN). Furthermore, the system being proposed can be easily integrated with IoT. To demonstrate and prove the concept, temperature monitoring in an office environment was conducted.	Wireless Monitoring
Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm (F. Shrouf et al., 2014)	Presented a "*reference architecture for IoT-based smart factories, defines the main characteristics of such factories with a focus on the sustainability perspectives.*" Moreover, the paper proposed a methodology for energy management in smart factories.	Energy
Application of RFID Technology for Logistics on Internet of Things (Sun, 2012)	IoT-based RFID technology application in logistics to monitor products in the supply chain for accurate inventory knowledge system	Logistics
Energy management based on	Discusses IoT-enabled energy-efficient production	Energy

Article	Summary	Category
Internet of Things: practices and framework for adoption in production management(Fadi Shrouf & Miragliotta, 2015)	management practices. Benefits of adopting these practices are explained.	
Investigating the Effects of Smart Production Systems on Sustainability Elements (Waibel et al., 2017)	Identified current trends and evaluated technical, economic, social, and environmental aspects in utilizing smart production systems.	Manufacturing
Quality management in product recovery using the Internet of Things: An optimization approach (Ondemir & Gupta, 2014)	Proposed a system integrated with IoT to "*reach the optimum remanufacturing, disassembly, recycling, disposal, and storage plans in a demand- driven environment.*" The paper also proposed an end-of-life recovery approach named ARTODTO or advanced remanufacturing-to-order and disassembly-to-order system.	Quality
IoT-based solid waste management system: A conceptual approach with an architectural solution as a smart city application (Bharadwaj, Rego, & Chowdhury, 2016)	Developed and created a prototype of an IoT-based solid waste management system using open-source technologies. The system was able to track, collect, and manage solid waste with the use of sensors.	Solid Waste Management
Internet of Things-Enabled Supply Chain Performance Measurement Model (Dweekat & Park, 2016)	A research on the use of IoT for optimal supply chain performance measurement and proposed a new model to enable efficient SCPM in real time	Supply Chain Performance
IoT-based manufacturing system with a focus on energy efficiency (Cao, Chung, Xiong, Chu, & Gadh, 2016)	Proposed an IoT-based manufacturing system architecture focusing on energy efficiency improvement through quantitative analysis and production planning. The system was tested and proved to have great saving potentials	Energy
Real-time data driven monitoring and optimization method for IoT-based sensible production process (Yingfeng Zhang & Shudong Sun, 2013)	Extended IoT techniques in the manufacturing field by presenting an IoT-enabled manufacturing execution system architecture where operators, machines, pallets, materials are embedded with sensors.	Manufacturing
Internet of Things: Applications and Challenges in Technology and Standardization (Bandyopadhyay & Sen, 2011)	Presented different applications of IoT and its challenges in Retail, Logistics, and Supply Chain Management as well as other industries	IoT Applications

5. CONCLUSIONS

Approaching the next industrial revolution, this paper was able to present how utilizing Industrial Internet of Things can be a solution to the current environmental issues in the industry specifically in manufacturing. Furthermore, this does not only help in minimizing the manufacturing industry's effects to the environment but also provides a solution to increase efficiency and improve production, maintenance, management, and quality. On the other hand, the Internet of Things technology can still be further developed towards in other industries and applications.

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