

Potential Impact of Industry 4.0 in Sustainable Food Supply Chain Environment

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Abstract— Integration of suitable supply chain system with the industry 4.0 in the face of the evolving sustainability consciousness is of paramount importance to engineering and manufacturing industry at large; this is gradually becoming an irresistible option to manage production effectively and with high efficiency in engineering and manufacturing sector. Industry 4.0 also referred to as “smart factory” enables to address issues such as food safety, security, control, perishability, competitive pressure, demand predictions etc. within the food manufacturing aspects. The paper examines the challenges and opportunities towards the advancement of technology and that of industry 4.0 implications towards sustainability and more closely on sustainable food supply chain environments.

Keywords— Supply Chain Management, Industry 4.0, Supply Chain Environment, Sustainability, Sustainable Practice, Food Supply Chain

I. INTRODUCTION

Technological advancement could be linked to one of the main causes of the sustainability challenges the world is facing today. The more advanced the technology becomes, the more needs arise which results in more greenhouse gas emission to the environment. This is believed to be responsible for global warming which the main cause of climate change. Meanwhile, this same technological advancement and digitisation if well utilised could be used in solving these sustainability problems that seems to be a menace to the society. Integration of the new industrial revolution (Industry 4.0) in the industrial supply chain management and logistics could go a long way to support the Sustainable Development Goal (SDG) that is being preached and worked on every day [1].

The supply chain can say to be a network of organisations responsible for production and distribution of goods and service from conception to the final consumer while supply chain management is simply an improved coordination within and between various supply chain members [2]; [3]. Meanwhile, Industry 4.0 can say to be the information-intensive transformation of industries with the environmental connection

of data, people, processes, services, systems through information technology as means of getting smart industry and ecosystems [4]. Implementation of industry 4.0 within engineering supply chains can lead to a reduction in lead time and cost, alignment of interdependent decision-making process and improvement in the overall performance of each member of the supply chain as well as the production process working towards achieving the great sustainable goal. Achieving sustainability within any manufacturing company starts with the supply chain management; if the supply chain is well managed from the point of material sourcing till it gets to the final consumer, then sustainability is achievable. Managing sustainable production through supply change is important in food manufacturing due to the complexity of food production that is associated with food safety, food wastage, food security etc. However, the introduction of certain features and components of industry 4.0 could ensure successful sustainable supply chain management within the food industry. The evolution of industry 4.0 components will go a long way to positively impact and improve sustainability in food processing supply chain management.

This paper intends to review, discuss and analyse the sustainable food supply chain management, evolution and basic components of Industry 4.0 and its adoption within the sustainable food supply chain management environment. Literature had been silent over the important role Industry 4.0 could play in sustainable food supply chain management. Therefore, this paper will further look into a case study of a food supply chain system that has incorporated Industry 4.0 into its operations to show how important the integration of Industry 4.0 could be and its entire potential impact within food supply chain environment. The case will be analysed and critically reviewed with the core findings to identify both the present and future challenges and opportunities associated with the integration of Industry 4.0 in the food supply chain for sustainability. The paper further goes into discussion and conclusion looking into the future research and development.

II. LITERATURE REVIEW

A. Sustainable Food Supply Chain Management

Food processing and manufacturing starts from the farm where the needed raw materials are produced and ends on the consumers' table. This supply chain needs to be monitored from the start till the end to ensure the safety of the products. Food safety is paramount in the food industry because of human life that is involved. The food supply chain is complex and complicated considering food perishability factor and food safety in agricultural product, a better plan is therefore needed within every part of the supply chain during food processing and manufacturing [2]. The food supply chain can be described as the key activities carried out on agricultural products from production state till its distribution for consumption [2], this chain, therefore, needs to be controlled and monitored to prevent wastage and ensure good quality end products.

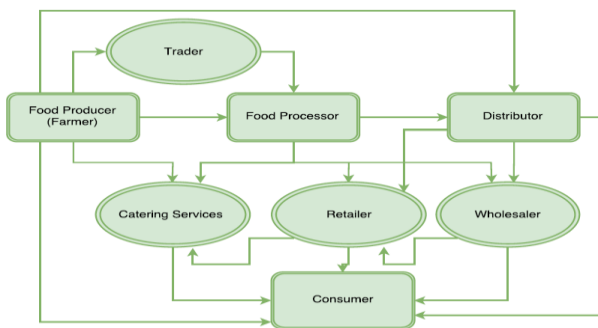


Fig. 1: A Typical Food Supply Chain [2]; [5].

To ensure good quality and quantity of their products within a food supply chain, a well-planned and structured supply chain strategy is needed [6]. The Fig. 1 is a typical food supply chain showing every player within the chain, it is essential to have a good plan in place to coordinate and manage the chain appropriately to ensure good food quality getting to the final consumer. Meanwhile, the battle for environmental protection has made sustainability i.e. the social, environmental and economic factors as one of the major criteria in the evaluation of supplier selection [7]. The storage and procurement within food supply chain network either as raw materials or finished good to maintain their quality and keep their nutritional value is very important but could be so cumbersome [8], appropriate technology is needed to be in place to achieve this. Adequate temperature control is needed within any food supply chain for the fresh products to maintain their quality and keep every other natural feature intact. This temperature control has been reasonably achieved so far within the food industry using cold supply chain management (CSCM) technique. However, full integration of the new industry 4.0 in this cold supply chain management within the food industry will be a great breakthrough in enhancing the values of products in terms of cost and quality. The cold supply chain is defined as “the logistics systems of handling perishable agricultural products from the point of harvest until it gets to the final customer” [9]. It has to do with procurement of agricultural raw materials and finished foods in controlled temperature process within a food supply chain network, it is needed to protect the integrity of the handled and transported products [2].

Sustainable supply chain management (SSCM) is defined as “the concept of planning, execution, and control of a corporate value creation process considering the social, ecological and economic aspects of business for the purpose of long-term performance and improvement in general production and supply chain management” [10]. This has to do with creating an economic value in business with the mind of reducing negative social and environmental impact within a supply chain system. This is very important in every industry as it helps in the aspect of companies Corporate Social Responsibility (CSR) practices for improved logistics performance, better efficiency and resource utilisation [11]. A sustainable food supply chain management looks into how raw materials are converted into finish products with suitable management recovery systems within food processing and manufacturing settings [12]. This food supply chain management should be taken seriously because of the daily expansion of the food industry and the increase in demand within the sector as a result of the world population explosion. Researches have concluded that food production must double by 2050 to meet demand from world's growing population [13] and the world is expected to have about 9.8 billion inhabitants by the year 2050 and about 11.2 billion by the year 2100 [14].

B. Evolution and Key Components Industry 4.0

Industry 4.0 is the latest industrial revolution that is making the industrial sector smarter with the integration of different latest technologies. The idea is to create a smart manufacturing platform and supply chain systems within the industries to improve productivity by meeting every necessary need [15]. The summary has shown in Fig. 2, the history of industrialisation is dated back to the early 1800s with the use of water and steam engines known as Industry 1.0. This was overtaken by Industry 2.0 with the mass production that introduced assembly lines in production which prompt the use of electricity and combustion in the early 1900s. Meanwhile, by 1970s, electronics, IT and robotics were introduced to production to upgrade to Industry 3.0. The passion for manufacturing improvement and revolution prompted the introduction of Industry 4.0 with the addition of certain advanced Information and Communication Technology (ICT) to upgrade the industry putting some factors into consideration. This industry 4.0 deals with the building of intelligent networking using various new and advanced technologies that could manage processes and production within any organisation efficiently [16]. The idea of industry 4.0 was an initiative conceived by Germany to improve her industrial sector also to make her industry more relevance and productive seamlessly [17]. The components of industry 4.0 include; (1) Cyber-Physical System (CPS): comprises of different sets of networked agents and devices; it involves the coordination, integration, control and monitoring of physical and engineered system by computing and certain communication system [16]. It is simply the integration of computer operations with the physical process for better productivity in operations. (2) Internet of Things (IoT): is the system that deals with data exchange between materials world and the computers [19]; [17]. It controls and enables better interaction of materials world (human, animals etc.) with the computers to facilitate the interaction of general production processes [16]. (3) Big Data: deals with the management and analysis of advanced level data

that cannot be handled using traditional tools, it helps in logistic optimisation, operational efficiency, and in the quick and efficient management of data [15]; [19]. (4) Automation and Intelligent Robotics: plays vital roles in *modern manufacturing by completing task intelligently with or without human intervention* [15]. (5) Cloud Computing: deals with computer resources or data storage through the use of the *internet*, it is a substitute for physical computer information storage [16].

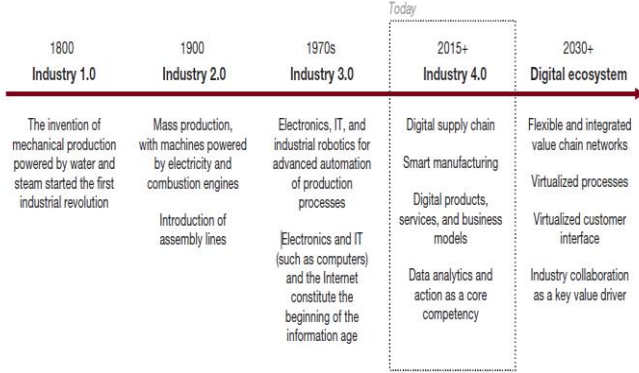


Fig. 2: Evolution of Industry 4.0 [18].

C. Adoption of Industry 4.0 in Food Sustainable Supply Chain Environments

Industry 4.0 known as the present day data exchange and automation process used in manufacturing technologies. This will be useful in the successful running of a standard and efficient food production and manufacturing from the start of its supply chain until it gets to the consumers' table. This is achievable as the food manufacturing supply and demand systems are being digitalised to reduce waste and promote sustainability [18]. Most of the processes of food production and manufacturing have to do with good logistics to properly control the food supply chain which requires an up-to-date equipment and logistics planning. Logistics can be seen as part of supply chain management because it involves the coordination and movement of goods and services [11]. Some of the equipment needed to achieve this controlled sustainable supply chain system are components of Industry 4.0.

Meanwhile, all these up-to-date ICT systems need to be programmed and automated for continuity for best quality finished products. The food industry in recent times has been able to manage and improve its sustainable and environmental factors with the use of innovations and advanced technology [20]. This has been achievable through raw materials and waste management including packaging through the use of the latest technology in the advanced food manufacturing processes. However, certain drivers like green warehousing, environmental conservation, strategic collaboration, improved information and communication technology, improved logistics, new product development and continuous improvement could successfully impact the practice of sustainable food manufacturing and supply chain management within any organisation [21]. Each of these drivers requires the integration of industry 4.0 to be effectively useful and impactful in the food supply chain.

III. METHODOLOGY

A. Research Approach and Case Study Selection

Literature and early researches stressed the importance of a case study in research clarifications, hypothesis validations and framework development [22]; [12]. This research had therefore engaged the full application of both primary and secondary research methods. Several kinds of literature were reviewed to fulfil the secondary aspect of the research getting some facts from different research literature on sustainability, supply chain, sustainable supply chain management, food sustainable supply chain management, industry 4.0 and its adoption within food supply chain management environments. The research further engaged the use of primary research method by careful selection of a case study to explore food supply chain within a food manufacturing environment and looked into how best the implementation and adoption of industry 4.0 had helped in the sustainability within the food supply chain management environment. Meanwhile, qualitative data were combined for analysis based on in-depth interviews with the key supply chain players within the selected food company. Visits and a few hours of on-the-job experience opportunity was given by this company to have practical experience for more knowledge of the company's operations management.

The case study selection followed a great scrutiny with different criteria taking into consideration to ensure the accurate value of the data for the research. The first consideration is the area where food manufacturing is common and the entire food supply chain will be accessible. The literature and facts led this research to Andalusia which is the southern part of Spain and part of the Iberian Mediterranean region that is well into agriculture and cultivation of food products. This selected area is known to be engaged in the production of arable products like fruits and vegetable all year round [23]; this and the food processing have served as a good source of employment for the people living around this region [20]. Based on net sales data, the Spanish food and beverage industry is ranked fourth in Europe and the eighth worldwide; the companies in the food and beverage industry represent 16% of the total manufacturing industry in Spain. Within this figure, small and medium-sized enterprises represent 96% of the total. The sector has a turnover of more than 93,000 million euros and directly employs almost half a million [24]. However, a complete food supply chain system and Industry 4.0 are important factors to be considered in this research and having considered Andalusia as one of the best areas where food production is prominent, questionnaires were sent out to different food manufacturing companies around this region to confirm the ones that engaged with the use of Industry 4.0 in their operations. Response to the short questionnaires came from a few of the companies and visits were scheduled for interviews and sites visit. The final selection of Company Z Group was done considering necessary factors that could help the research like access to information, open-minded and unbiased attitude, commitment to sustainability, a high level of commitment and cooperative approach.

Company Z group is a multinational company that deals in production and sales of a huge range of Olive oils, seed oils, edible oils, biodiesel, soap, olive and other varieties of consumer goods that respond to the need and preference of different

markets and segments. Company Z has farms sites, factory facilities and offices in various countries that include Portugal, Spain, Angola, Brazil, Chile, Morocco, China and the United State of America. The business owns its private farm or rented farmyards to grow olive groves for production, it has the largest private olive grove with more than 13,000 hectares [25]. It also manages its waste by converting it to animal feeds and biodiesel leading the company into an energy business oriented company with its oil extraction and refining business. Company Z group is the largest producer of olive oil and the largest Spanish olive oil exporter with exports to more than seventy (70) countries and remains the market leader in Portugal, Spain, USA and in central Europe with sales of €1.4Bn [25]. It has more than one thousand (1,000) employees with nine (9) factories and four (4) olive mills in four (4) different continents.

B. Data Collection

The main method of data collection is through semi-structured interview and on-site visits to the factories and other production facilities involved in the value chain (i.e. Olive grove farmyards, mills, refinery, bottling, packaging, warehouse and distribution). The conducted semi-structured interview featured the quality director, 2 quality managers, production director, 3 production managers, financial manager, sales manager, warehouse managers, 2 warehouse operators and distribution manager. The major people involved in this semi-structured interview were selected based on their knowledge of the company's value chain and supply chain management. They are however directly involved in the supply chain management and production systems within the company's operations environment. These interviewees had earlier been given questionnaires and a couple of the proposed interview questions for them to be familiar with the questions and do extended research and consultation if necessary or needed. This was for better response and clarifications of some questions and some facts that might need to be extracted from the company's records or archive.

IV. DISCUSSION AND CONCLUSION

A. Case Findings

The case study undergone with Company Z group was of the olive and seed oils production; the supply chain of the olive oil production has the simple typical value chain structure with raw materials sourcing (Production), Processing and Manufacturing (Transformation/Packaging), Distribution and lastly Sales (Retailers and Consumers).

1) *Raw Material Sourcing*: The main raw material for production in Company Z is agricultural products while the other ones are the packaging materials that come from an outsourced firm. Company Z works around its supply chain system to ensure sustainability is achieved at every level, distance consideration and control is one of the strategies employed when sourcing for raw materials. The company has incorporated Industry 4.0 in its raw materials sourcing and operations for easy monitoring, traceability and quality control of the agricultural products from the farm till they get to the main factory for full refining and packaging. Meanwhile, the

packaging material sourcing is outsourced with a production site provided within the factory to control the distance and movement of these materials. This is also to synchronise the operations of the outsourced firm with Company Z's Industry 4.0 operations to ensure better communication for just-in-time (JIT) and just-in-sequence (JIS) production purposes. This outsourced firm starts the packaging production in its main factory where pet bottles are produced and then blown into the required sizes and shapes in the production site of Company Z factory. This method will save the bulk movement and transportation of these packaging products thereby indirectly mitigating greenhouse gas emission. It however supports and synchronises with the industry 4.0 operations of Company Z's production.

2) *Processing and Manufacturing*: This part of the supply chain in Company Z comes in two main stages running in different factories but connected and synchronised with the use of Industry 4.0 communication systems to ensure the best quality. The first stage of this production is referred to as transformation which processes the raw olive groves from the farm through milling and expression of the oils from the groves. The process involved in this could include, cleaning, sorting, weighing, grinding etc. Other processes like refining, centrifugation, decantation, testing and batching come afterwards to complete the transformation process. The second stage is the packaging which involves the bottling and labelling of the finished products according to the required sizes and markets. The material needed for the packaging and labelling of these finished products are being handled by the outsourced company but the operations were synchronised with Company Z's for continuous production. The blown bottles automatically go into a production line of the factory where they are automatically filled with the required content. Every operation is fully integrated into Industry 4.0 where most of these operations are been done with the use of software and other Industry 4.0 components that include Cloud Computing, Automation/Intelligent Robotics, Cyber-Physical Systems, Internet of Things (IoT), with little application of the new Big Data. The company is working on full implementation of the evolving Big Data technology.

3) *Distribution/Warehousing*: This part of the supply chain that comes after the products had been packaged, labelled and ready to be passed down to customers for consumption. The warehousing and distribution operations in Company Z is made smart using the integration of the Industry 4.0 components. The company has two warehouses that use the Industry 4.0 components for operations and to communicate with the manufacturing (Production line) for stock control. One of these warehouses is fully automated and therefore does not require any human operator but the second warehouse is semi-automated and it is being operated by three to four operators that use software for distribution processes. The software attached to forklifts operated by the operators is equipped with Radio Frequency Identification (RFID) and barcodes that gives full information of products. This information helps with how

stocks are sorted for distribution (locally or international maritime shipping).

4) *Sales/Customers*: This aspect of the supply chain gets the products to the consumers and gets information as feedback from the consumers. Company Z has been able to integrate some Industry 4.0 components into this part of its supply chain for better and easier operations. Basic Industry 4.0 like Cloud Computing, Internet of things and a bit of Big Data is being used to improve the marketing and sales of products to the final consumers. These components also help in getting first-hand information and feedback from the consumers for production improvement and better demand forecast that helps in sustainable warehousing operations and management.

B. Result and Discussion

The study was able to come up with a novel framework/Model that represents the impact of full implementation of Industry 4.0 within the sustainable food Supply Chain environment. This integration as highlighted in Fig. 3 has really supported sustainability within the food production and its entire supply chain environment. This was able to impact the main Three Bottom Line (TBL) of sustainability dimensions which are Environmental, Social and Economic Sustainability. This food manufacturing company uses the components of industry 4.0 which include Internet of things (IoT), cloud computing, Cyber-Physical Systems and Big Data to manage both the information and material flow to achieve sustainability in the “Production Order” within its supply chain. The red lines in Fig. 3 from the production order show relationships with every part of the supply chain. It manages how the supply and demand are met within the chain through the acquisition and conversion of raw materials to finished products in needed quantity [26]. “Production Planning” strictly works with information on how customers’ future demand could be met [17], therefore, uses the components of Industry 4.0 like Cyber-Physical Systems, Big Data, Internet of things (IoT), and Cloud Computing to relate with every part of the supply chain (as shown by the blue lines) to aid sustainable production.

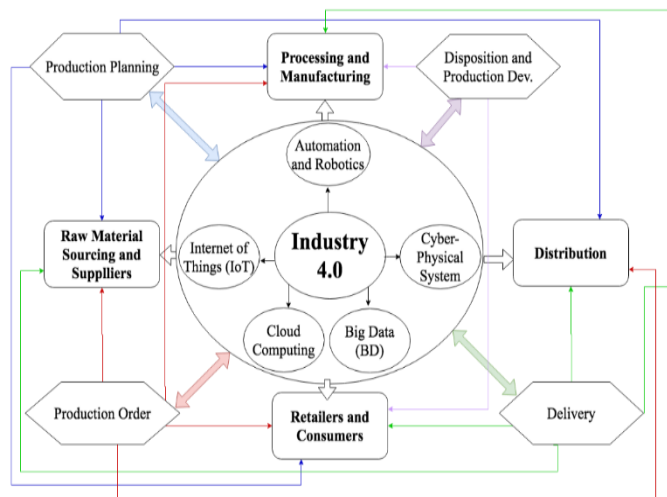


Fig. 3: Integrated Industry 4.0 in Company Z's SC System

Meanwhile, the “Disposition and Production” process only relates with two parts of the supply chain which are manufacturing and consumers (as indicated by the purple lines). This deals with the how production meets the consumers’ specifications and requirements which could be achieved using a continuous improvement process of new product development [27]. This process, therefore, uses certain tools of Industry 4.0 like Big Data, Automation & Robotics, Cyber-Physical Systems, Internet of things (IoT), and Cloud Computing to achieve this and ensuring sustainable production. The process of “Delivery” within the supply chain deals with the distribution of materials where they are needed. It, therefore, relates to every part of the supply chain (as indicated with the green lines) using every necessary Industry 4.0 tools like Automation & Robotics, Big Data, Cyber-Physical Systems and Cloud Computing. Furthermore, all the four processes involved in the food manufacturing will be able to use the components of Industry 4.0 to promote sustainability across the entire supply chain.

The environmental sustainability was achieved with the emphasis and management of energy, water and other natural resources all through the supply chain including the production process. However, management and control of greenhouse gas emission within the supply chain through travel distance reduction control and by engaging the latest energy savings equipment through Industry 4.0 technology during production and transportation. Economic sustainability was met with good management of financial resources through resource control in both natural and human resources aspect. The company’s sustainability plans led to a reduction in raw materials used in the production of the packaging materials through reshaping and control of the thickness of the plastic bottles used to meet sustainable conditions. The orientation of waste reduction in production has also been helpful in saving some natural resources in the production process.

Meanwhile, the use of Cyber-Physical Systems (CPS), automation and intelligent robotics resulted in savings on human resources with reduced employees in both production lines and warehousing operations. This could be seen as a drawback in terms of social sustainability but could be well managed as training on the software and other operations of Industry 4.0 could be given to empower more employees for them to be useful in the latest technology’s operations. The social sustainability is a bit difficult to measure but it can be concluded that it deals with how people and their living are affected i.e. the management of social resources. The care, health and safety of the employees are guaranteed with the integration of the Industry 4.0 and the company’s engagement and encouragement of the practices of “reduce, reuse and recycle” has been socially impactful. Good waste management and environmental control processes will also have positive social impacts. The case study had been able to identify the potential impacts of Industry 4.0 in a sustainable food supply chain environment. The study has also made contributions for a deeper understanding of Industry 4.0 within food manufacturing and supply chain environment which could be helpful in food production procedures and supply chain management with reasonable environmental implications and

also shows the extent the food manufacturing integrates industry 4.0 into their practices.

C. Conclusions and Future Research

Sustainability is paramount in every manufacturing and service organization at this crucial period of climate change. It is a good idea as different standards and regulations to control organisations' footprints are springing up to encourage adoption and effective use of sustainable practices. This research has contributed both in theoretical in terms of literature review and also in practise in terms of the case study. Meanwhile, this research and few earlier ones had been able to suggest that adoption of Industry 4.0 within supply chain environment of any sector could contribute immensely to the achievement of the Sustainable Development Goal (SDG). Achieving sustainability in any organisation's supply chain environment is very good and paramount because almost every goods and service come through the supply chain cycle. This research is a case study that had only considered the integration of Industry 4.0 within the food supply chain environment and other practices for sustainability in developed nations, further research will be done in the same manner within some emergent nations to equally identify the gaps before a general framework will be developed for use in Sustainable Food Supply Chain Management (SFSCM). I also hope that it will be necessary to compare this case to others belonging to the same sector by increasing the number of case studies and various locations in different areas of the world considering levels of development. Future research could also investigate the level of involvement of Industry 4.0 for sustainability in other manufacturing sectors.

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