

THE IMPACT OF INDUSTRY 4.0 ON SUPPLY CHAINS AND SUSTAINABILITY

Sukhraj Singh Takhar

Subject Matter Expert – Materials Management and Chemical Reporting, Assent Compliance Inc. & PhD Research Student, College of Engineering and Technology, University of Derby, Derby, DE22 3AW, United, E-mail: Raj.Takhar@assentcompliance.com

Kapila Liyanage

College of Engineering and Technology, University of Derby, Derby, DE22 3AW United Kingdom, E-mail: K.Liyanage@derby.ac.uk

ABSTRACT

Industry 4.0 ushers in a new dawn of digitization, utilizing smart devices, communicating across manufacturing process and supply chains, gathering data on mass in a virtual model of a business to investigate areas for improvement, developing new product and service offerings. Industry 4.0 brings a potential shift from mass over production, to production system based on real end consumer demand requirements. Sustainability relates to reducing the amount of scarce resources being used in products, enabling repair, reuse and recycling of materials from products. Industry 4.0 has the potential to influence sustainability and supply chains. This paper establishes key concepts and issues, as well as a current state adoption review. Conclusions were drawn enabling the implementation of (1) industry 4.0; (2) sustainability and; (3) enhanced buyer-supplier supply relationships.

Keywords: Supply chain management, industry 4.0; sustainability; circular economy; big data.

1. INTRODUCTION

Industry emerged from the process of bartering, exchanging one article for another, to achieve some form of gain (Smith and Skinner, 1982). From bartering emerged the process of exchanging articles for precious metals (gold, silver), from which emerged the modern process of exchanging articles for items of monetary value. The role of modern industry is to generate profits, maximizing returns for shareholders. Milton Friedman once phrased this as “social responsibility of business is to increase profits” (Friedman, 1970). The first industrial revolution (circa 1780s) saw the implementation of steam driven machinery to replace human labour. The second industrial revolution (circa 1870-1920) saw the beginning of the mass production era, where an increased use of machinery and division of labour was utilized. Classical operational research was born in this era, investigating increasing productivity, driving costs down, while attempting to improve employee working conditions. The third industrial revolution (circa 1950-2000) began with the advent of microprocessors and semi-automated manufacture. The last quarter of the Twentieth century saw increasing technological advances such as Computer Aided Design (CAD), Computer Aided Manufacture (CAM) and Computerized Measuring Machine (CMM) inspection machines, which enabled products to be designed, built and tested using increased technology. During the third industrial revolution, there was a belief that humans would be become redundant and computers and robots would take over most jobs. This occurred to some

extent within manual labour roles whilst in other areas humans adapted to using computers, working with them to create new areas of expertise, learning to program machines and use data. The rise of the knowledge worker was a direct result of the third industrial revolution. Society has continually evolved from one generation to the next. Humans have adapted to their surroundings, gained knowledge and made progress in one form or another. Moore's law ([Moore's law wiki, 2018](#)) foretold a future of increasing technological advancements, this was reiterated in the rapid advancements in telecommunications, computing and media during the last quarter of the 20th century. The advent of the internet during the 1990's led to emergence of increased globalisation. Globalisation is defined as the mobility of goods, services, commodities, information, people and communications across national frontiers ([Hopper, Lassoud, Soobaroyen, 2017](#)). Products today are available from the global marketplace with global low-cost manufacturing supply and distribution networks. The fourth industrial revolution (from 2011) or Industry 4.0 as it has become commonly known, can be described as a union of computerization and automation to enable intelligent (smart) production and operation systems which operate efficiently with little human interaction. Industry 4.0 appeals to companies, industries and governments as a basis for achieving future competitive advantage, in a similar manner to the evolution of ecommerce at the beginning of the internet era.

The need for sustainable development was first mentioned in the Brundtland report ([WCED, 1987](#)). Society was consuming scarce natural resources with little regard towards the environmental, economic and social impacts. The aim of sustainability is: (1) produce products which do not rely on scarce natural resources; (2) produce products which last longer and do not require replacement or repair. In contrast the circular economy operates on the principles of repair, re-use and recycling of articles (back into secondary raw materials to be reused).

1.1 Research objectives

This paper contributes to the field of industry 4.0, supply chain and sustainability literature by addressing the following research objectives:

1. Identify key concepts, developments and issues relating to the impact of industry 4.0 on supply chains and sustainability.
2. Identify areas of supply chain disruption, identifying strategies to deal with supply chain disruptions.
3. Assess the potential impact of industry 4.0 on supply chains and sustainability.

2. RESEARCH METHODOLOGY

This study follows a three-step approach to conduct the literature review. The research consisted of (1) initial literature search terms used were 'Industry 4.0', 'Supply Chain' and 'Sustainability', appearing within the title of an article, selecting the most relevant articles; (2) cross-referencing supply chain management articles; (3) application of previous work experience.

The literature review is based on the (1) down selected articles, and additional research on (2) supply chain management.

3. LITERATURE REVIEW

3.1 Industry 4.0

The underlying design principles within Industry 4.0, focus on: (1) interoperability, interconnected intelligent systems, enabled by smart sensors and devices communicating between each other using Internet of Things (IoT) / Internet of People (IoP); (2) information transparency the creation of Smart Manufacturing (SM) / Cyber-Physical Systems (CPS) / digital twin type systems; (3) technical assistance, initial use of automated systems and data modelling to assess

and provide information; (4) decentralized decisions, increasing levels of automation in tasks and via deep learning and AI techniques real-time decision making capabilities.

3.1.1 Interoperability

Traditional IT systems are often deployed storing information within themselves only with limited interoperability with other systems. Traditional systems can be considered as data silos, with potentially high levels of bespoke custom coding. Researchers observed: (1) potential issues with poor quality data within traditional systems; (2) costs estimates of 8% to 12% of revenue for a typical business; (3) for a service business costs were estimated at between 40% to 60% of expenses; (4) correlation between poor data quality and poor decision making taking place as a result (Wang, et al., 1995; Redman, 1996; Redman, 1998; Wang, 1998; Dyson and Foster, 1982). Interoperability enables an extensive data sharing platform, as shown in Figure [1]. The internet plays a pivotal role acting as a gateway enabling digital communications to take place between different systems. As improvements have been made to the speed of internet traffic, new offerings such as cloud hosted solutions Vs physical server on-premise servers, have become more accepted due to cost and implementation time savings.

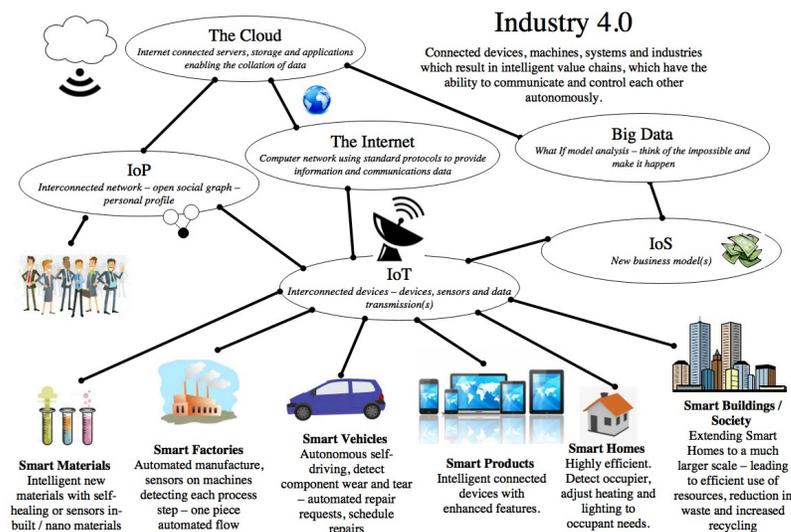


Figure 1. Industry 4.0 - A conceptual overview of elements

The cloud offers internet connected servers providing server, storage, application support, enabling mass data collection facilities. IoT refers to a series of smart interconnected devices, communicating between each other through standard protocols. IoT devices were initially used in manufacturing to trace materials being converted into products, detecting, managing production flows, and detecting potential errors. IoT enables interoperability between systems. IoP refers to a network designed to collate attributes that create an open social graph, which enables people-to-people, people-to-company as well as tracking device-to-device communications. IoP can be considered as the reverse of IoT in that it tracks people and traits. IoP enables interoperability between individuals and their devices.

3.1.2 Information transparency

3.1.2.1 Smart manufacturing (SM)

SM refers to the union of manufacturing systems, with interconnected data gathering systems. The benefits of using SM: (1) less material usage needs; (2) less waste as fewer materials used; (3) enhanced opportunity for waste being reused and recycled; (4) reduced energy

consumption needs; (5) greater supply chain integration; (6) improved operational efficiencies as resources can be scheduled automatically (Davies, et al., 2012; Cornado, et al., 2018).

3.1.2.2 Cyber-Physical Systems (CPS)

Increasing interconnectivity between the technological and physical worlds coined the phrase cyber-physical systems. CPS systems can be described as technologies that enable communication and interactions between humans, machines (IoT, smart factories) and systems (Lee, Bagheri and Kao, 2015; Wang, Törngren, Onori, 2015; Cornado, et al., 2018). (Davies, et al., 2012) outlined the 5C architecture concept to enable CPS system development. The benefits of using CPS: (1) strong design methodologies which enable definitions, modelling, scalability, validation and verification taking place; (2) strong security measures to protect data traffic; (3) self-diagnostics, ability for CPS systems to scheduling repair and maintenance activities; (4) increases the rate of manufacture, using autonomous infrastructure; (5) enabling faster development cycles for new products; (6) enabling sustainability using systems which have adaptable manufacturing capability to produce a wider range of products, reduced energy consumption (Davies, et al., 2012; Lee, Bagheri and Kao, 2015; Wang, Törngren, Onori, 2015).

3.1.2.3 Digital transformation

Digital transformation is the name given to the process of moving a business from its current-state traditional IT system processing, towards a unified digital model known as the digital twin. The main aim of the digital twin is to mimic current state behaviours against which different modelling actions can be undertaken looking for areas of efficiency gain and innovation.

3.1.3 Technical assistance

3.1.3.1 Automation

Automated sourcing, manufacture, distribution, sales, maintenance and recycling activities are all elements of industry 4.0. Increasing automation will result in more efficient processing of both manufacturing and back-end processing, enabling organizations to gain competitive advantages over competitors. Automation will result in the need for less manual workers, required in the manufacturing cycle, thereby reduced direct labour costs.

3.1.3.2 Big data

Big data evolved as a natural progression from the data silo centric view of traditional IT systems. Big data goes beyond traditional data structure view as it considers data in its entirety rather than at a specific system level (ERP, PLM) type views. Big data begins with the collation of large amounts of data, structured and unstructured into a single application, which normally due to its sheer size and volume, would not normally be contained within a traditional database (Zikopoulos, et al., 2012). Big data uses very large data sets to uncover unforeseen patterns which can result in new strategic offerings, such as: (1) rental of a product Vs outright purchase; (2) embedding smart sensors and communication capabilities into products; (3) automated diagnostics and scheduling of maintenance, and; (4) additional post-sales service offerings. Big data has been described as combing the use of computer science with mathematical, statistical, behavioral science to develop analytical tools to enable predictive modelling in conjunction with the digital twin, thus enabling business to achieve potential competitive advantage (Zikopoulos and Eaton, 2011; Barton and Court, 2012; Zikopoulos, et al., 2012)

3.1.4 Decentralized Decisions

3.1.4.1 Artificial Intelligence (AI)

20 years ago, the potential of AI being used to replace human thought was conceptual, the technology was a work in progress, the use of Man Vs Machine tournaments between large super

computers and the human chess grand masters were early examples of machine learning and AI development, tested against human endeavor. AI today encompasses mass data and perform a wide range of analytical modelling via machine learning.

3.1.4.2 New product and service offerings

The union of IoT, IoP, big data, and AI brings with it great potential for increasing efficiency and identification of new areas of growth, by identifying new product and service offerings, at an unprecedented rate. The Internet of Services (IoS) is a by-product of industry 4.0.

3.2 Supply Chains and Sustainability

The underlying aims of any supply chain are: (1) improve efficiency (operational and process); (2) profitability, and; (3) achieve competitive advantage over competitors within the supply chain (Min and Zhou, 2002).

3.2.1 Technological supply chain evolution

The internet gave rise to the evolution of online marketing channels, and the global marketplace. Products can now be purchased from just about anywhere in the world and transported consumers as desired (via air, land, sea transportation). The lines between local, regional and national supply chains have blurred, as a typical supply chain today, consist of many actors from many regions. An example of typical supply chain relationships is shown in Figure [2], this shows the basic flow of chemical substances, mixtures and materials, through a production cycle, through to the consumer via distribution channels.

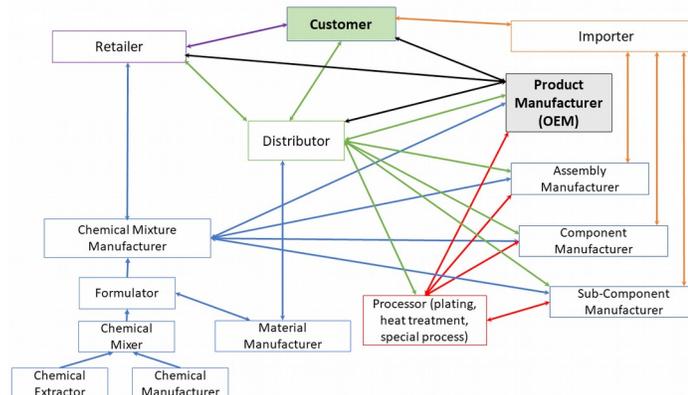


Figure 2. Typical Supply Chain Relationships

Traditional Supply Chain Management (SCM) / Purchasing and Supply Chain Management (PSM) strategies focused on the delivery of raw materials and basic materials to support operations management, in the most economical cost and efficient manner. The evolution of outsourcing has increased amount of operations being sent externally to the supply chain. There are clear parallels between emergence of literature on supply and value chains and the role of the purchasing function moving towards becoming more strategic (Pralhad and Hamel, 1990; Freeman and Cavinato, 1990; Lee and Humphreys, 2006; Barney, 2012; Úbeda, et al., 2015).

3.2.3 Supply chain management and sustainability

Purchasing plays a pivotal role in ensuring the economic prosperity of an organization is maintained by purchasing products and services required to meet the resource needs of an organization. The emergence of sustainability, required a change in direction for managing a supply chain transition towards sustainable practices. Sustainable Supply Chain Management (SSCM) has emerged as a strategic supply chain vision, requiring the development of strong

relationships between supply chain tiers, acceptance of mutual needs, enabling shared growth between supply chain actors (Krajic, 1983; Gunasekaran, Patel, McGaughey, 2004; Shepherd and Gunter, 2006; Moreira et al, 2010; Walker and Jones, 2012; Govindan, et al., 2014; Katiyar, et al., 2018; Mülling Neutzling, et.al, 2018).

3.3 Sustainability in Industry 4.0

3.3.1 What is sustainability?

The need for sustainable development was first mentioned in the Brundtland report (WCED, 1987). The report highlighted four key areas: (1) sustainable developments; (2) environment protection; (3) economic growth and (4) social equity. The key areas from the Brundtland report have formed the basis for most sustainability frameworks (economic, social, environmental). Growing consumer awareness of environmental issues have given rise to green purchasing and green supply chain management. Consumers can influence the effects of environmental damage, buy purchasing products which are environmentally friendly. Additionally, Non-Governmental Organizations (NGOs), media attention has led to manufacturers focusing on the production of more and more sustainable products. (Kanchanapibul, et. al, 2014; Joshi and Rahman, 2015; Kumar and Rahman, 2015).

3.3.2 UN Sustainable Development Goals (UN SDGs)

The UN SDGs (UN, 2018) were established in 2015, to set out 17 high level goals, and over 165 lower levels to achieve sustainable social and economic development by 2030. The UN SDGs were signed by 195 members of the UN. The UN SDGs can be shown to provide a set of enlarged set of objectives and goals, extending from the work of the original Brundtland report (WCED, 1987). The UN SDGs provide the basis of indices and input data which can be fed into environmental framework analysis and development, however a lack of consistent data collection hinders understanding issues.

3.3.3 Sustainability frameworks

Whilst traditional business models have focused solely on the creation of profit, sustainability business models and frameworks have emerged, leading to companies behaving in a more responsible manner, as they become more aware of environmental and social concerns, not just the generation of economic gains (Krajic, 1983; Henderson and Clark, 1990; Gunasekaran, Patel, McGaughey, 2004; Shepherd and Gunter, 2006; Carter and Rogers, 2008; Montalvo, Diaz-Lopez and Brandes, 2011; Jayaram and Avittathur, 2015; Kumar and Rahman, 2015).

3.3.4 Regulations and Standards

Regulations exist to impose a consistent set of norms / behaviours upon society. Regulations are created by national / international regulatory authorities. Regulations can enforce mandatory actions / behaviours on impacted industries and society. Standards are created because of the voluntary efforts of individuals, groups, businesses creating standards via some form of Standards Body Organization. The requirements of regulations and standards place burdens on industry to collate, analyze and report data as required. This can influence the ability of an organization to manage its supply chain actions, as well influence the way sustainability is adopted.

3.3.5 Extended producer responsibility (EPR)

Increasing reliance on landfill sites for waste processing, led to several European Union (EU) regulations aimed at reducing the cycle of waste to landfill. These regulations included: (1) packaging directives (EC Packaging and Packaging Waste Directive, 1994); (2) end of life vehicles (EC End of Life Vehicles, 2000); (3) controls on waste collection (EU Waste Framework Directive, 2008), and; (4) waste electronics (EU WEEE, 2012). The regulations resulted in

industry adopting mandatory EPR waste collection schemes for products at the end of their useful life. EPR schemes enabled producers to work collaboratively to create industry collection schemes, paying a fee upfront based on the amount of product placed onto the market place. (EPR Wiki, 2018; EC, 2014). The fee is used to fund collection and recycling processes (OECD, 2016). EPR makes producers consider both product life cycle and circular economy factors, designing products which can be more easily repurposed and recycled (OECD, 2001; Thun and Müller, 2010; EC, 2014; Agrawal, 2014).

3.3.6 Circular economy

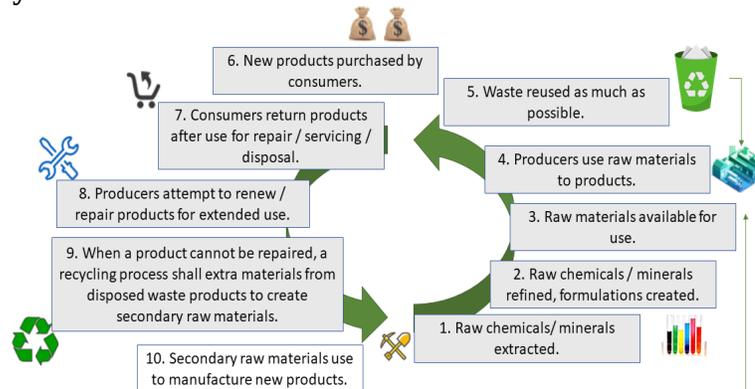


Figure 3. Circular Economy Overview

The aim of the circular economy is to design waste out of product design (EC, 2015), Figure [3] depicts an overview of the circular economy. The circular economy enables products to be designed in terms of: (1) longevity, ultimately products are produced that last longer, needing less disposal; (2) products are produced with high recyclable content, thereby enabling the creation of secondary raw material easily; (3) enhancing sustainability efforts in that a reduction in need for scarce materials is applied. The circular economic system extends the traditional linear economic system (extract materials, produce products, disposal of products) by implementing restorative and regenerative processes by design (Ellen MacArthur Foundation, 2018).

A synergy exists between the circular economy and sustainability, both focus on: (1) designing environmentally sound products, which don't consume scarce substances or contain hazardous substances; (2) minimizing environmental impacts of production, reducing energy consumption and waste; (3) increased recycling and use of secondary raw materials, which have been created from recycled waste (EC, 2015; Zeng, et al., 2017; Ellen MacArthur Foundation, 2018).

3.3.7 Corporate Social Responsibility (CSR)

CSR is a multidisciplinary methodology which can be applied across all functional areas of a business (Zhou and Eyun-Jung, 2018). CSR researchers have observed: (1) CSR today has gained more and more credence as the benchmark performance by which companies want to be judged in the wider world in terms of being a responsible organization; (2) CSR enhances company reputation and brand awareness; (3) CSR establishes communication across stakeholders; (4) CSR can lead to increased customer loyalty; (5) CSR enables potential premium pricing methods to be applied (Kirat, 2015; Lim and Greenwood, 2017; Zhou and Eyun-Jung, 2018; Zhang, et al. 2018; Kudłaka, et al., 2018). CSR benchmarking works more effectively as part of an overall sustainability strategy encompassing a stepped approach as shown in Figure [4]:



Figure 4. Stepped approach towards embedding sustainability

3.4 Enhancing supply chain relationships

3.4.1 Understanding supply chain disruptions

Increasing interconnected supply chains have the potential to be affected by disruption. Supply chain disruptions are defined as events that impact the movement of goods or services along a supply chain (Craighead, et al., 2007). Supply chain disruptions can cause significant impacts on business, examples of supply chain disruption can be observed as: (1) service failures; (2) increasing costs; (3) declining sales (Park, Min, Min 2016). Organizations need to be cognizant of potential supply chain risks and adopt appropriate plans. Organizations are more likely to handle the effects of a supply chain disruption than those companies with no strategies or plans in place.

3.4.2 Building buyer-supplier relationships

Early researchers observed: (1) the crucial need to develop strategic buyer-supplier relationships, and; (2) balance in power issues can cause issues to arise (Harrigan, 1988; Leenders, et al., 2002). The types of buyer-supplier relationship behaviours have been observed in terms of: (1) traditional relationships where buyers exerting power over suppliers (dominance), or; (2) cooperative behaviours where buyers and suppliers work in a collaborative manner (egalitarianism), or; (3) allowing suppliers to gain control (submissiveness) (Kraijic, 1983; Gunasekaran, Patel, McGaughey, 2004; Huang and Chiu, 2018; Andreasen and Gammelgard, 2018; Gölgeci, et. al, 2018) Building supplier relationships entails time, effort and cost (Ellram, 1995). Developing trust in buyer-supplier relationships is not a simple task, issues may arise: (1) in terms of trust and acceptance of risk, and; (2) initiating requests / action and responsive behaviours (Sako, 1992; Gölgeci, et. al, 2018).

4. CONCLUSIONS

4.1 Summary

Industry 4.0 is a natural evolutionary step. it cannot be avoided, companies will need to adapt to it, to enable economic gain, if you don't adopt it in some shape or form, you can bet your competitors are using it and generating efficiency and economic gains that you are not achieving.

The Industry 4.0 awareness survey results suggested: (1) a basic understanding of industry 4.0; (2) there was an awareness of industry 4.0 benefits; (3) concerns over security risks and implementation costs prevented internal adoption; (4) fear of disruption and lack of supplier awareness prevented supply chain adoption; (5) in terms of current state implementations, few respondents went beyond the basic understanding stages; (6) IT, manufacturing and purchasing were the internal functions identified as being most affected by industry 4.0.

One of the core tenets of industry 4.0 is the creation of a digital ecosystem where all actors across a supply chain have a digital model of their organization. With all actors represented, enhanced 'what if' scenario modelling can be undertaken. Moving towards the digital ecosystem will see greater integrations across supply chains.

Jumping towards industry 4.0 is not a short-term quick win type of activity. It really should be classed as a medium to long-term strategy for any type of organization, which requires not only a digital transformation, but also a cultural transformation internally; across a supply chain; through to the consumers of your products and / or services. Companies need to: (1) slow gradual steps as opposed to rapid adoption; (2) improve operational efficiency using lean methodologies first, eliminate waste first.

4.2 Contributions to Theory

The purpose of this paper was to examine the impact of industry 4.0 on supply chains and sustainability. The following propositions are presented because of this research:

Proposition 1: The circular economy will gain more prominence as increasingly scarce materials become an issue, and raw material prices begin to rise sharply as a result.

Proposition 2: The consistent norms with the adoption of sustainability practices is (1) enhanced stakeholder engagement; (2) increased supply chain integration; (3) increased reputation and brand awareness; (4) increased customer loyalty; (5) potential application of premium pricing upon sustainable products and services.

Proposition 3: Industry 4.0, brings the possibility of enhanced integrations between disparate systems, networks, people, organizations to create the potential for increased automation, data gathering, machine learning, big data analytics and use of AI for decision making purposes.

Proposition 4: Should products still be mass produced or should manufacturing be based on real consumer demand? In a world of ever diminishing resources, should we continue to mass produce articles at the lowest possible price, selling for maximum economic gain, generating high volumes of waste materials consuming vast amounts of energy, labour and other resources? Industry 4.0 could be used to induce a state of intelligent consumer demand-based manufacturing. In such a state of production, big data would need to harvest sales / consumer demand data and then use AI to intelligently estimate accurate article production needs, which could be planned within a given value chain, sounds simple, but it could become the new norm.

Proposition 5: OEMs and part manufacturers need to be aware of their environmental, social and economic impacts, across a supply chain in both downstream to a consumer and upstream to the extraction of raw materials. To truly embed sustainability across a supply chain requires all participants to be involved.

Proposition 6: Companies must accept their environmental, social and economic obligations as part of normal business operating conditions. Acceptance of these obligations requires a change in (1) buyer-supplier relationships; (2) moving towards development of sustainability frameworks; (3) investigation of EPR and circular economy opportunities, and; (4) adopting CSR reporting.

Proposition 7: Increasing regulations and standards relating to chemical substances, present the requirement to trace substances used across a supply chain, with applicable reporting to regulatory bodies, and declaration statements to consumers.

Proposition 8: Industry 4.0 presents an opportunity to trace the use of substances across a supply chain, using IoT devices, and sensors embedded into materials. For example, if a chemical substance is distributed with an embedded micro sensor which transmits data to a IoT sensor at various stages across the manufacturing cycle. This real-time traceability could be used in several

different ways for example: (1) compliance reporting of substances in products; (2) identifying sources of supply when substances become scarce; (3) identifying products that require extra care if a substance is deemed to be hazardous; (4) at a product end of lifecycle state, substance could be identified which can be recycled from a given product, thereby aiding recycling and reuse within circular economy. The concept is not as far-fetched as it seems, Intel has placed micro sensors the size of a grain of rice onto bees to trace movements, to aid conservation projects (Intel, 2016).

Proposition 9: Industry 4.0 offers the potential to switch from mass production, to producing only what is required for consumer consumption, thereby offering potential utilize production facilities to produce different types of products, thereby still enabling economic gain, but also enabling manufacturers to adopt more versatile production lines, using less resources. There is the potential for multiple manufacturers to share production facilities.

Proposition 10: A common step methodology is proposed for enabling enhanced supply integration, implementing sustainability and industry 4.0: (1) define existing business practices in depth; (2) application of lean methodologies to optimize existing practices, ahead of any additional activities; (3) engage with internal stakeholders to illicit a future state vision for the business; (4) identify internal stakeholder requirements; (5) invite external stakeholders (suppliers, customers affected by change) to a review, discuss the vision, take comments and make adjustments as required; (6) identify external stakeholder requirements; (7) define a through set of requirements to proceed with; (8) identify the people, system and processes required to meet the requirements; (9) create a roadmap for implementation; (10) enact implementation project against roadmap, schedule resources; (11) capture risks, apply mitigation activities; (12) define education and training plans, enact as implementation reaches different milestones on roadmap.

5. ACKNOWLEDGMENT

A special thanks would also go to (Berners-Lee, 1999) in developing the initial footprint for the world wide web and (Barlow, 1996) in asserting the need for a free and open internet environment, without which interconnected devices, the cloud and the overall industry 4.0 conceptual model would not have emerged.

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