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A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements

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ABSTRACT

Supply Chain organizations in the present global environment operate in market that is increasingly complex and dynamic in nature. Sustainable supply chain becomes inevitable to meet the aggressive change in the customer requirements. Based on the reviews, it is revealed that manufacturing companies need to speed up in shifting the focus towards sustainability and make use of technology like 'Internet of Things' (IoT) to meet the organization's goal. The objective of this research paper is to review the various aspects of SCM, ERP, IoT and Industry 4.0 and explore the potential opportunities available in IoT embedded sustainable supply chain for Industry 4.0 transformation. In this review, a comprehensive study on various factors, that affects the sustainable supply chain were analyzed and the results recorded. Based on the review, a framework for assessing the readiness of supply chain organization from various perspectives has been proposed to meet the requirements of the fourth Industrial Revolution. The conceptual framework model has been formulated from five important perspectives of supply chain management namely Business, Technology, Sustainable Development, Collaboration and Management Strategy. This study furnishes the criteria that can be assessed by companies to realize the readiness for industry 4.0 transformation.

1. Introduction

Digital disruption has become the order of the day. The convergence of information systems has become more complicated and dynamic in nature, which drives industrial organizations to invest on smart manufacturing (Wang, Wallace, Shen, & Choi, 2015; Ye & Wang, 2013). It is imperative for organizations to embrace the changing technology to cope up with shorter product life cycle and rapid environmental changes (Lucke, Constantinescu, & Westkämper, 2008). Information Systems (IS) tries to integrate the communication between people and technology. An IS, including Enterprise Resource Planning (ERP) system, provides seamless user experience in real time which is so intuitive to take informed decisions and support to manage the overall operations of the organization effectively (Zhang et al., 2014).

SCM is an integral part of ERP, which connects with various partners in Supply chain. Supply Chain comprises of vendors, producers, wholesaler, retailer and end client and it intends to synchronize demand and supply (Stefanou, 1999). The coordinated value creation process from raw material purchase to end-client usage can be effectively accomplished through ERP. The benefits of information systems are increased efficiency, increased productivity, reduced time, cost reduction, zero errors, optimized inventory (Barut, Faisst, & Kanet, 2002).

Globalization in the current scenario is confronted by constant growth of global demand in capital and consumer goods by persistently

Abbreviations: SC, Supply Chain; SSC, Sustainable Supply Chain; CLSC, Closed Loop Supply Chain; ERP, Enterprise Resource Planning; EOL, End-Of-Life; SCM, Supply Chain Management; SCN, Supply Chain Network; IoT, Internet of Things; IIoT, Industrial Internet of Things; CPS, Cyber Physical Systems; GSCM, Green Supply Chain Management; OT, Operational Technology; IT, Information Technology; IS, Information Systems; SRM, Supplier Relationship Management; CRM, Customer Relationship Management; AHP, Analytical Hierarchy Process; ISM, Interpretive Structural Modeling; MICMAC, Impact Matrix Cross-Reference Multiplication Applied to a Classification; CFA, Confirmatory Factor Analysis; ISM, Interpretive Structural Modeling; DEA, Data Envelopment Analysis; NGT, Nominal Group Technique; VIKOR, VlseKriterijumska Optimizacija I Kompromisno Resenje; ELECTRE, ELimination and Choice Expressing REality; RDT, Resource Dependence Theory; TRIZ, Theory of Inventive Problem Solving; RFID, Radio-frequency identification; TQM, Total Quality Management; HMI, Human Machine Interaction; RL, Reverse Logistics; RSC, Reverse Supply Chain; FSC, Forward Supply Chain; SME, Small and Medium Enterprises; M2M, Machine to Machine; IoP, Internet of People; IoE, Internet of Everything; IoS, Internet of Services; IIoT, Industrial Internet of Things; CMfg, Cloud Manufacturing; CCIoT, Cloud Computing and Internet of Things; ICPS, Industrial Cyber-Physical Systems; IWN, Industrial Wireless Network

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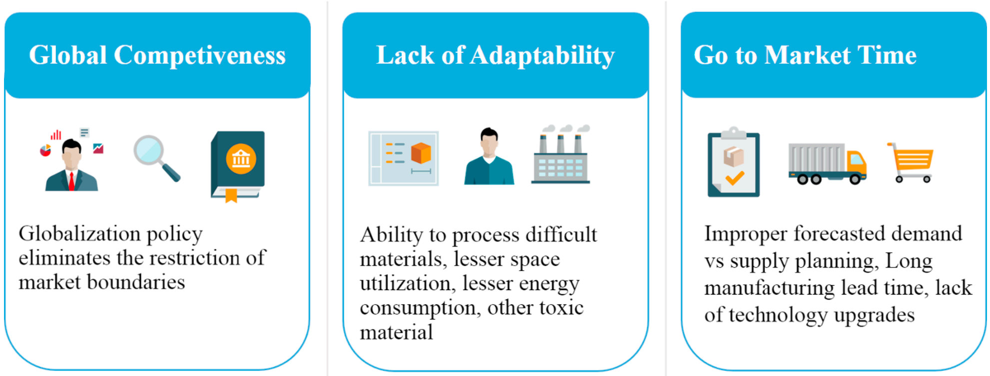

Fig. 1. Key challenges for supply chain organizations.

verifying overall interest for social, environmental and economic aspects (Pisching et al., 2015a, 2015b). To overcome this challenge, industrial supply chain is to be equipped to sustain and right now, supply chain value creation is formed by the advancement of Industry 4.0 (Bocken, Short, Rana, & Evans, 2014; Chen & Paulraj, 2004; Chen et al., 2004, 2014; Jayal, Badurdeen, Dillon, & Jawahir, 2010; Li, Ragu-Nathan, Ragu-Nathan, & Rao, 2006).

1.1. Challenges with supply chain

In today's dynamic and changing supply chain environment, organization faces many challenges in manufacturing space such as global competitiveness, lack of adaptability, go to market time as illustrated in Fig. 1 (Arif-Uz-Zaman & Nazmul Ahsan, 2014; Narasimhan & Kim, 2001).

In the past, most of the manufacturing processes were developed with the objective of economic viability for achieving higher productivity (Czajkiewicz, 2008). In recent past, globalization policy eliminates the restriction of market boundaries. The small and medium scale manufacturers are finding it difficult to compete with the global large manufacturers, as they are unable to adapt in the newer technologies to process difficult materials, optimize space utilization and consume less energy (Thomas & Trentesaux, 2013). Another challenge is introducing a new product and make it available to consumers at the right time.

The common challenge faced by manufacturers is to forecast the right demand versus supply and to reduce the manufacturing lead-time (Jovane et al., 2008). Consequently, it becomes inevitable for them to equip with right resources and processes along with technology to bring up revolutionary products and world-class services (Tajima, 2007). Factors that influences uncertainty in supply chain management are global competition, lack of adaptability, delayed entry into market. The technology IoT overcomes these challenges, which significantly transforms the supply chain industry (Atzori, Iera, & Morabito, 2010; Giusto et al., 2010). For instance, this technology can be leveraged to track the consignment location and speed of the vehicle and so that the users are alerted by late deliveries. IoT technology can be deployed on monitoring the condition of an equipment from a remote location (Qiu, Luo, Xu, Zhong, & Huang, 2015). Temperature sensitive products can be monitored with sensors and the data can be communicated through internet. For example, perishable products are wasted during transit. The confluence of internet, wireless, predictive analytics and cloud technologies can change the entire supply chain operations and bring more value out of it (Yang, Wu, Liang, Bi, & Wu, 2011). Using IoT, this wastage can be minimized as it monitors the condition of perishable products and sends the status to the stakeholders of supply chain (Accorsi, Bortolini, Baruffaldi, Pilati, & Ferrari, 2017).

Although many researchers are analyzing the IoT, SCM individually, the application of IoT in enterprises to meet the industry 4.0 requirements have not been reviewed much and it is still at the initial phase. From the literature study, it is revealed that organizations need to focus more on digital technologies and take initiatives to deploy industry 4.0. Further, studies unveil that this research is slightly limited to theoretical suitability and suggest for exploring more practice-oriented approach in the days to come.

The main objective of the paper is to review the various aspects of SCM, ERP, IoT and Industry 4.0 and examine the importance of digitalization and the role of IoT in the overall Supply Chain. Further, this study explores the criteria that can be assessed by companies to realize the readiness for industry 4.0 transformation.

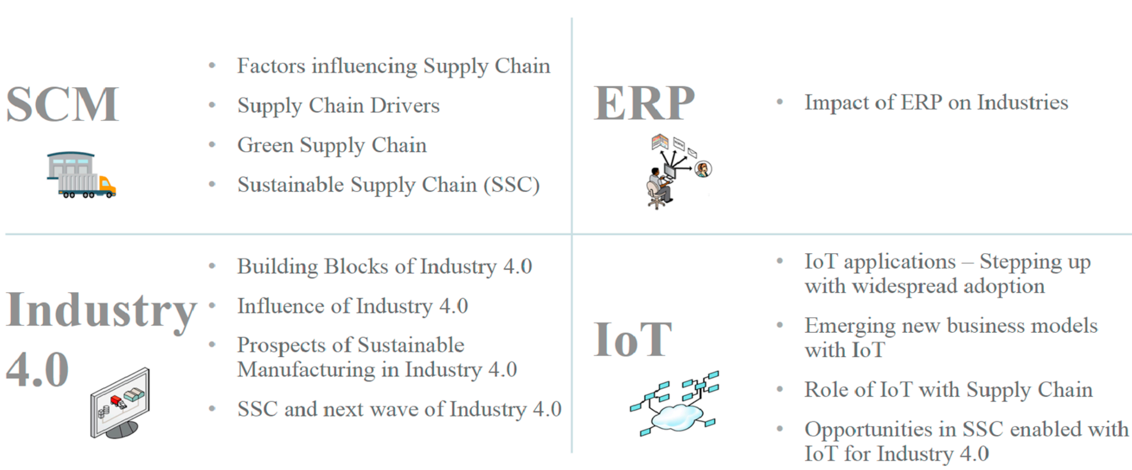

Fig. 2. Outline of the review carried out with four major areas.

The structure of the research paper is depicted in Fig. 2. The paper is organized under four major areas such as SCM, ERP, Industry 4.0 and IoT. The review on SCM with importance to GSCM and SSCM are analyzed. Later, literature on impact of ERP on various industries are studied. Further, Industry 4.0 is reviewed in depth to know the building blocks, influence of technology in various industries. In addition, IoT and its applications are reviewed from both industry and consumer perspective. Role of IoT on SCM is analyzed. Based on the analysis, a framework is proposed for assessing the readiness for Industry 4.0 transformation.

2. Literature review

There is a considerable growth and improvement in the industrial environment with respect to Supply Chain, ERP, Industry 4.0 and IoT for the past ten years. Literary articles were reviewed and analyzed from the past ten years on industrial growth perspective.

2.1. Structure of literature study

Based on the analysis, the literature section has been logically classified into four subdivisions. Initially, the focus is given to review the GSC and SSC practices in SCM. Later, it outlines the relationship between ERP and SCM. The study on Industry 4.0 and its emergence in various industries were studied. Further, it outlines the various investigations on IoT and how it influences into the digital world were discussed. The presence of IoT in industry is expanding rapidly Academicians and practioners have done many of IoT research and development in recent years. Further, focus should be given to modernize supply chain with IoT to increase the digital revenue (Iera, Floerkemeier, Mitsugi, & Morabito, 2010; Vermesan & Friess, 2013). In addition, companies are moving towards digitalization to make cost effective devices, business inter-connected on real time, collaboration across boundaries (Michahelles, Ilic, Kunze, Kritzler, & Schneegass, 2017; Ning & Wang, 2011). As manufacturing sector influences the global economy, organizations now looks beyond just automation and focuses on machine-to-machine communication at real time with the help of information systems (Karre, Hammer, Kleindienst, & Ramsauer, 2017). Thus, fourth industrial revolution appears more imperative now. Information systems, which are integrated to physical devices, can be termed as embedded systems, in other words Cyber Physical System (CPS) (Arrieta, Sagardui, & Etxeberria, 2014). A CPS is a system monitored by sensor integrated with the internet and communicates with its users (Kim, Kim, Lakshmanan, & Rajkumar, 2013).

From the Fig. 3a, it is interpreted that though the number of research reported on SSCM is gradually growing, the research on SSCM with Industry 4.0 and IoT is in the initial stage. For example, for the year 2017, though there were 6979 articles in SSCM, with the context of Industry 4.0, only 740 articles were published. Further, if IoT is also taken into consideration along with industry 4.0 in SSCM, there were only 115 articles. Thus, the present study attempts to focus on SSCM with industry 4.0 and also to study the role of IoT in SCM and suggestions were given for taking up Industry 4.0 to the next level.

The number of publications on the IoT and Industry 4.0 are shown in Fig. 3b. Technology diffusion speed can be calculated based on number of publications in the respective technology. For example, for IoT, the number of publications in the year 2012 is 3129 and the same in the year 2017 is 6173, which is 97.28% increase in the publications. Similarly, for Industry 4.0, the number of publications in the year 2012 is 7251 and the same in the year 2017 is 14,664, which is 102.23% increase in the publications. This data represents that the technology diffusion speed in last 5 years is almost double. This analysis reveals that although research on technology related publications has increased, the study on SSCM with IoT to meet industry 4.0 has not been focused much and hence it is identified as the literature gap for the present study.

2.2. SCM: present and future directions

The SCM has made tremendous growth in last six decades from the initial focus on improving manual labor process to the latest automation and connecting supply chain network effectively (Li, Rao, Ragu-Nathan, & Ragu-Nathan, 2005; Parkhi, Joshi, Gupta, & Sharma, 2015). Fig. 4 demonstrates the evolution of SC over the last six decades with a graph. In 1960s, manufactures concentrated on large-scale manufacturing to reduce the unit production cost as a primary objective and the system was not seamless (Bechtel & Jayaram, 1997).

In 1980s, integration of inventory management and material distribution took place (Inman & Hubler, 1992). This process empowered industrialization in 1990s and stimulated the concept of integrating all cross-functional modules such as production, warehouse, logistics and eventually all these elements became part of supply chain with primary objective of improving the operational effectiveness (Ragatz, Handfield, & Scannell, 1997). With the help of digital applications and mobile devices, the seamless integration in supply chain to connect partners was achieved (Linton, 2017). It enabled supply chain administration to control the data of product, finance streams efficiently (Barratt, 2004). Subsequently supply chain became cumbersome with continuous growth and complex networks as too many process to monitor and control (Fawcett, Fawcett, Watson, & Magnan, 2012). Later organizations felt the competition across the globe and started focusing on reducing the wastages in the material, machine-running time, removing the redundant processes (Mohammaddust, Rezapour, Farahani, Mofidfar, & Hill, 2017). Eventually this resulted in organizations look for lean manufacturing and look for world-class technologies to bring supreme quality and bring the manufacturing rate down by eliminating the waste and non-value added routine work (Qi, Huo, Wang, & Yeung, 2017). The focus on lean became predominant with the key influencing factors such as time, cost and material (Ruiz-Benitez, López, & Real, 2017).

More recently, the rapid raise of automation in supply chain has become a major factor of the evolution process (MacCarthy, Blome, Olhager, Srai, & Zhao, 2016). Later the SSC has evolved from a perspective of social and environmental areas where many organizations started looking at supply chain not only from profitability perspective but to make eco-friendly products so that future generations also get benefited (Wang, Lee, Zhu, & Li, 2017). In addition, organizations have started measuring their sustainability in terms of their business operations and action plans are also being developed and implemented (Jabbarzadeh, Fahimnia, & Sheu, 2017; Rezaee, Dehghanian, Fahimnia, & Beamon, 2017).

2.2.1. SCM definitions

The scope and definition of SCM is evolving continuously. Bagchi, Chun Ha, Skjoett-Larsen, and Boege Soerensen (2005) suggests for having a standard SCM definition for better understanding, as definitions of SCM vary across academicians and practitioners. Table 1 lists the important SCM perspective definitions as defined by researches.

To sum up, supply chain definitions brings multiple perspectives by various authors and give different dimensions to it. Supply chain comprises of product, services, finances and information shared across the value chain (Handfield & Linton, 2017). Supply chain not only connects supplier, manufacturers and customers, it also connects several layers of supplier in upstream side and similarly it connects to the ultimate end users who are benefited from the value of the product or services in downstream side (Dutta & Hora, 2017). These definitions insist that the entire supply chain eco-system should be economically managed and the supply chain network should be integrated to obtain optimum productivity (Ângelo, Barata, da Cunha, & Almeida, 2017).

2.2.2. Factors influencing supply chain

Supply Chain management demonstrates better results in terms of better delivery time, improved customer satisfaction, better rapport

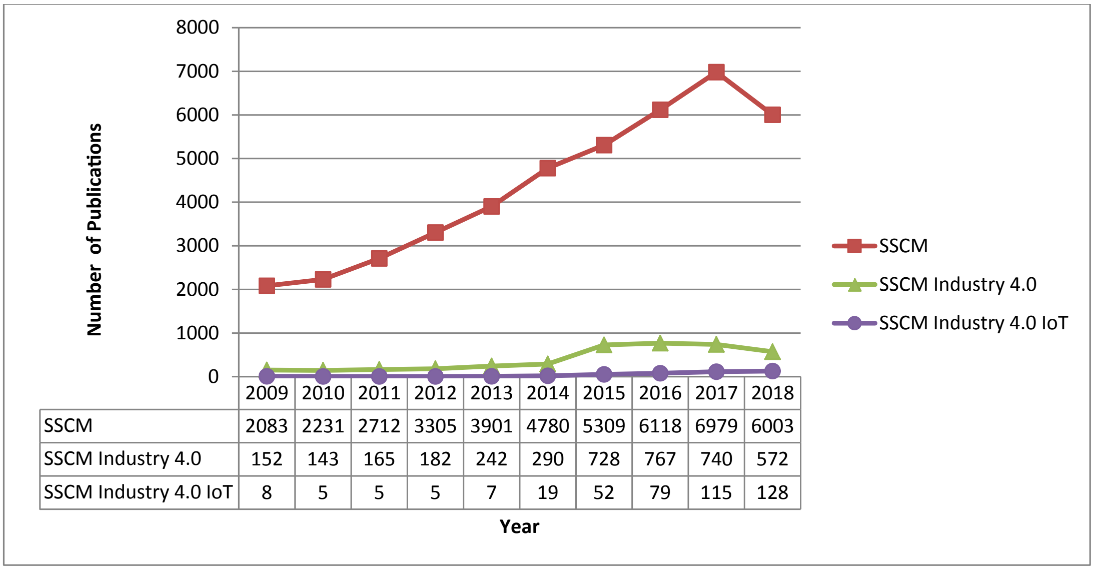

Fig. 3a. Number of publications in SSCM, Industry 4.0 and IoT and the trends.

with suppliers (Quesada, Gazo, & Sanchez, 2012). For better understanding of supply chain and its operations, it is inevitable to recognize the influencing factors which affect SCM (Fawcett, Ellram, & Ogden, 2013; Govindarajan & Ramamurti, 2011; Li, 2002; Williamson, 2008).

As illustrated in Fig. 5, the factors which influences supply chain management are

- Performance – responsiveness to change is an important measure to evaluate the performance (Senvar, Tuzkaya, & Kahraman, 2014)
- Technology – dynamic change in customer requirements especially hi-tech and consumer electronics need to take care (Gowen & Tallon, 2005)
- Environmental policy – Influence of Government regulations on environment is one of key strategic factor to consider (Vachon & Klassen, 2007)
- Economics – Finance is the essential part of which decides the strength of SCM (Pfohl & Gomm, 2009)
- Supply chain collaboration – SRM and CRM are the key functions of business practices (Camilleri, 2017; Zhu & Sarkis, 2004)
- Competition – the revenue generation is based on competition in the market (Rossetti, Handfield, & Dooley, 2011)
- Strategy – focus on sustainability is key for going forward strategy (Khonpikul, Jakrawatana, Sangkaew, & Gheewala, 2017)
- Customer engagement – Every stakeholder has different view, customer engagement is required to know the real expectation (Simchi-Levi & Simchi-Levi, 2003)
- Real time information – business expects that the planning and executing the plan depends on sharing the real time information (Ou, Liu, Hung, & Yen, 2010)
- Procurement – forecast the demand and ensures the supply is ordered optimally so that no over stock and no stock situation (Morgan & Monczka, 1995)
- Zero errors – in certain industry such as food supply chain, aerospace there is zero percent tolerance (Singer, Donoso, & Traverso, 2003).

2.2.3. Supply chain drivers

This section discusses the key drivers, which enhances the organization's performance related to material, logistics, and operations. Each of these drivers insist the overall supply chain responsiveness (Huang,

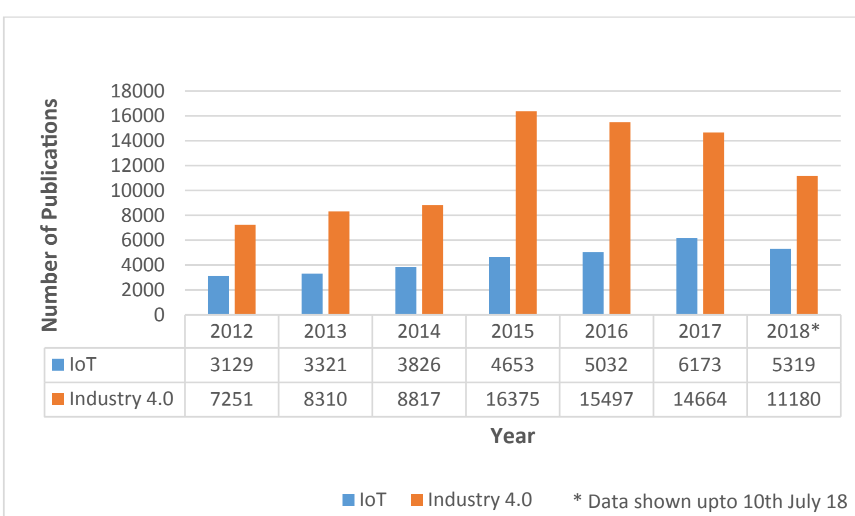

Fig. 3b. Number of publications in IoT and Industry 4.0.

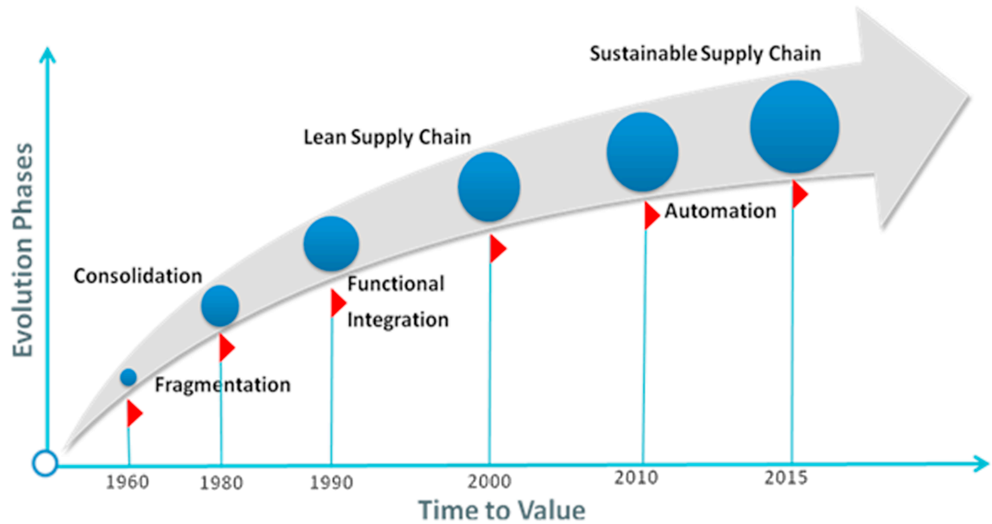

Fig. 4. Evolution of Supply Chain.

Huang, & Yang, 2017). Based on review, Table 2 outlines the SC drivers.

2.2.4. Advancements in supply chain operations

Supply Chain operations are important for business operations and have a considerable influence on costs and profits. SCM operations include process, infrastructure, systems to manage the flow of information, material and services from supplier to end consumer. Technological advances such as IoT, Industry 4.0 and automation helps to maximize the effectiveness of operations within the organization as well as across the Supply Chain partners. Khan, Hasan, Ray, Saha, and Abdul (2013) suggested autonomous sales order processing system using SMS based web integrated order processing software for food processing industry to improve the supply chain performance. Bienhaus and Haddud (2018) studied the impact of industry 4.0 on procurement, identified the potential bottlenecks and explored ways to overcome the bottlenecks and transform business into complete digital organization. Dolgui, Ivanov, Sethi, and Sokolov (2018) in their study, analyzed on production scheduling, Supply Chain and industry 4.0. Further, they explained the qualitative methods for optimal control of industrial engineering and production management. Hou, Chaudhry, Chen, and Hu (2017) presented the evolution of sustainable development in SCM. Saberi, Cruz, Sarkis, and Nagurney (2018) proposed a freight carriers linkage framework in multi-period Supply Chain where Supply Chain partners can maximize the net worth of their investment with ecological friendly technology. Tsang et al. (2018) presented IoT embedded risk detecting system for item quality and worker safety in cold environment.

2.3. Overview on GSCM

The effect of eco-friendly factors expands the SCM into a new horizon, which is termed as 'Green SCM' (GSCM). There are several contributions made on GSCM practices (Sarkis, 2003; Srivastava, 2007). Interestingly more than 300 research articles were authored by various researches in the past 15 years on the theme of GSCM and SSCM (Asrawi, Saleh, & Othman, 2017; Brandenburg, Govindan, Sarkis, & Seuring, 2014; Mathivathanan, Kannan, & Haq, 2018; Seuring, 2013). The primary focus in earlier stage of supply chain was financial characteristics, later the center of focus was to consider the environmental influences that influence the SC (Battini, Bogataj, & Choudhary, 2017; Piplani, Pujawan, & Ray, 2008; Sari, 2017; Seuring & Müller, 2008b).

Vachon and Klassen (2008) proposes a collaboration model, which supports environmental footprint assessment aimed at increasing the correctness and relevance of life cycle in supply chain. Vachon (2007) brings a relation between environment and supply chain practices to have little impact on pollution and encourage green supply chain practices. Mathiyazhagan, Govindan, NoorulHaq, and Geng (2013) studies an electronic industry to describe the significance of GSCM to ensure eco-friendly environment.

2.3.1. Method used for GSCM implementation

Several studies have been conducted to evaluate the method adopted to implement GSCM. Table 3 describes the summary of GSCM implementation with various approaches.

On the basis of literature, different approaches are used to evaluate supply chain industry to guard the environment. Bringing eco-friendly is one of the primary objectives of the global organizations all over the world. The study also discloses that the benefits are tremendous if the organizations adhere to produce environmental friendly products in the context of social, environmental and financial factors.

Table 1
List of definitions of SCM.

S. No.	Definition perspective	Source
1	Consumption of goods from macro organization perspective	Lummus and Vokurka (1999)
2	Business process perspective	Lambert and Cooper (2000)
3	Supply chain collaboration perspective	Mentzer et al. (2001)
4	Functions Integration perspective	Akkermans, Bogerd, and Vos (1999)
5	Organizational behavior perspective	Gunasekaran and Ngai (2003)
6	Optimization of value chain perspective	Gunasekaran and Kobu (2007)
7	Lean perspective	Melnyk, Lummus, Vokurka, Burns, and Sandor (2009)
8	Agile perspective	Machowiak (2012)
9	Digital procurement perspective	Hsin Chang, Tsai, and Hsu (2013)

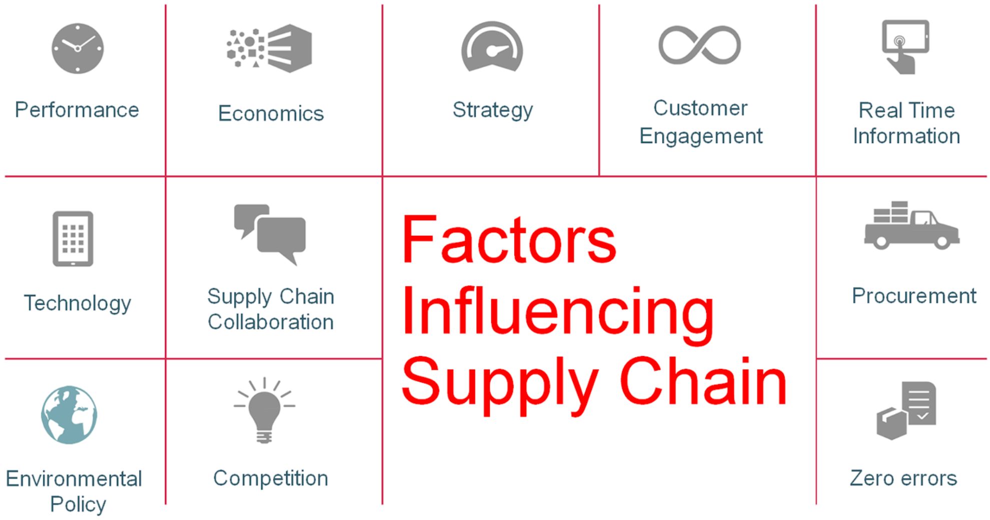

Fig. 5. Factors Influencing Supply Chain.

Table 2
List of SC drivers.

S. No.	SC drivers	Description	Source
1	Supply chain information systems	The key drivers for information systems are strategic planning, infrastructure, IT knowledge, business-to-business or business to consumer models, enterprise management, and implementation.	Agus and Ahmad (2017)
2	Responsive supply chain	Supply chain must be responsive. Ability to respond meaningfully within a stipulated lead-time to change in demand or market requirements.	Banchuen, Sadler, and Shee (2017)
3	Supply chain analytics	Using business intelligence, improving the effectiveness of supply chain is a critical offering in organization's competiveness.	Sahay and Ranjan (2008)
4	Supply chain automation	Due to globalization, supply chain networks are highly intersected and located at different geographies. Automation combined with advanced technologies such as internet connected software oriented technologies is the key to manage such supply chain networks.	Viswanadham (2002)
5	Supply chain transportation and logistics	Enormous financial impact of transportation costs on organizations related to environment is predicted.	Speranza (2018)
6	Big data for supply chain	The emerging technology big data stimulates the growth of organization and make right decisions at critical times especially in supply chain, manufacturing, healthcare and finance sector.	Zhong, Newman, Huang, and Lan (2016); Addo-Tenkorang and Helo (2016)
7	Supply chain collaboration	Relationship with supply chain partners improves the visibility and response time to the change in market requirements.	Cao and Zhang (2011)

Table 3
List of implementation methods.

S. No.	Approach	Description	Source
1	Fuzzy multi criteria approach	Global business environment has enforced many organizations to build eco-friendly products. Fuzzy multi criteria approach is used to assess environmental friendly vendor's performance.	Shen, Olfat, Govindan, Khodaverdi, and Diabat (2013)
2	ISM	ISM is used to visualize the key pressures faced by manufacturing industries from government and regulation policies categories to implement GSCM.	Diabat and Govindan (2011)
3	DEA model	DEA is one of the techniques that can be used for evaluating GSCM to develop environmental performance.	Tavana, Mirzagoltabar, Mirhedayatian, Saen, and Azadi (2013)
4	NGT and VIKOR with fuzzy method	Developing environmental friendly suppliers is crucial for GSCM. NGT is a method, which can be used to evaluate green supplier initiatives. VIKOR helps to rank the green supplier and proposes relevant programs for deployment.	Noshad and Awasthi (2015)
5	ELECTRE and VIKOR approach	The ELECTRE and VIKOR approaches were used to assess environmental aspect of supply chain, which considers services.	Chithambaranathan, Subramanian, Gunasekaran, and Palaniappan (2015)
6	AHP	This method studies the factors of GSCM and evaluates the adoption level to meet customer requirements fulfilling eco-friendly principles.	Mathiyazhagan, Diabat, Al-Refaie, and Xu (2015)
7	Mixed Methods (ISM, MICMAC, CFA)	GSCM enablers are critical in managing financial and environmental performance, which uses various methods. The key factors influences GSCM are management strategy, SRM, CRM etc.	Dubey, Gunasekaran, Papadopoulos, and Childe (2015)
8	RDT	This method helps in evaluating the performance of SSCM and their relationship with organizational performance.	Esfahbodi, Zhang, and Watson (2016)
9	TRIZ	This method is used to identify the Green Supply Chain (GSC) issues.	Moussa, Rasovska, Dubois, De Guio, and Benmoussa (2017)
10	Big data analytic approach	This method is an optimization technique, which evaluates GSCM with many objectives that capitalizes big data.	Liu, Choo, and Zhao (2017)

2.3.2. Drivers of GSCM practices

The key drivers of GSCM practices are illustrated in the Fig. 4. The key drivers of GSCM are studied by the following authors:

- TQM (Gavronski, Klassen, Vachon, & do Nascimento, 2011; Kaynak, 2003)
- CRM (Rao & Holt, 2005)
- SRM (Bai & Sarkis, 2010; Carter & Jennings, 2004; Rao, 2005)
- Carbon Emissions (Hong & Phitayawejwiwat, 2005)
- Institutional Pressure (Kauppi, 2013; Zhu & Sarkis, 2007)
- Green adoption (Testa & Iraldo, 2010; Vachon & Klassen, 2006)

The digital SCM ecosystem have picked up its pace for the deployment, management, and integration of services that can power Industrial Internet applications (Angeles, 2005). The interconnected ecosystem can adapt and respond to shifting demands by itself. To achieve this, CPS is seen as next generation system, which integrates information systems, RFID, sensors, devices, equipment (Schirner, Erdogmus, Chowdhury, & Padir, 2013). CPS monitors physical processes and communicates the status to human in real time who can access it from anywhere which improves the human-machine interaction (HMI) (Lee, 2008; Shafiq, Sanin, Szczerbicki, & Toro, 2015).

Based on the review, digital SC should be considered as key driver of GSCM as illustrated in the Fig. 6.

2.3.3. Uncertainty in supply chain from green perspective

The conception of uncertainty is an important area within risk management. Uncertainty leads to delay in product delivery, reduces the performance of supply chain. It is essential to deal with uncertainties by better planning, with buffer inventory level and timely deliveries. In this section, literature on uncertainty in supply chain from green perspective has been reviewed.

Tseng, Lim, Wong, Chen, and Zhan (2018) established a model for assessing the services of SC and uncertainty over environment service operations. Foerstl, Meinlschmidt, and Busse (2018) explores the sustainability related uncertainties in various industries of supply chain and proposes information-processing method for sustainable supply management. Ghelichi, Saidi-Mehrabad, and Pishvaee (2018) suggests a stochastic programming model, which was applied to green SCN under uncertainty. Entezaminia, Heidari, and Rahmani (2017) studied on production planning in GSCM under uncertainty over RSC. Some of the green practices such as wastage reduction, carbon emissions related to logistics were studied. Wu, Liao, Tseng, and Chiu (2015) explored the decisive factors in GSCM under uncertainty for automobile manufacturer and found that recovering and recycling used products are the primary factors, which affects the economic performance.

2.4. Overview on SSCM

SSC is one of the important concept in SCM which establishes several discussions in the recent past (Brandenburg & Rebs, 2015; Majumder & Groenevelt, 2001; Vachon & Mao, 2008). The drastic increase in combining sustainability into SCM is an emerging area where it demonstrates the open relations with SCM and its interactions (Ashby, Leat, & Hudson-Smith, 2012; Fallahpour, Olugu, Musa, Wong, & Noori, 2017; Madani & Rasti-Barzoki, 2017; Springett, 2003). Sustainable supply chain takes care of goods, information, financial flows with the key measurements of sustainability, which are derived from all the stakeholders of supply chain (Tan, Kannan, Handfield, & Ghosh, 1999).

SSCM is integrating the key organizational information systems to generate well defined supply chain by keeping the socio-economic environmental considerations which effectively manages goods, information and finance flows associated with cross functional modules such as materials management, production, sales, order fulfillment (Pagell & Shevchenko, 2014). Kadambala, Subramanian, Tiwari, Abdulrahman, and Liu (2017) studied the CLSC, which comprises of supplier, manufacturer, distributor, retailer and customer. It reviews the transportation life cycle of the containers.

2.4.1. Definitions of SSCM

This subdivision narrates the SSCM definitions from literature available as tabulated in Table 4 and the definitions are classified based on key characteristics of sustainability.

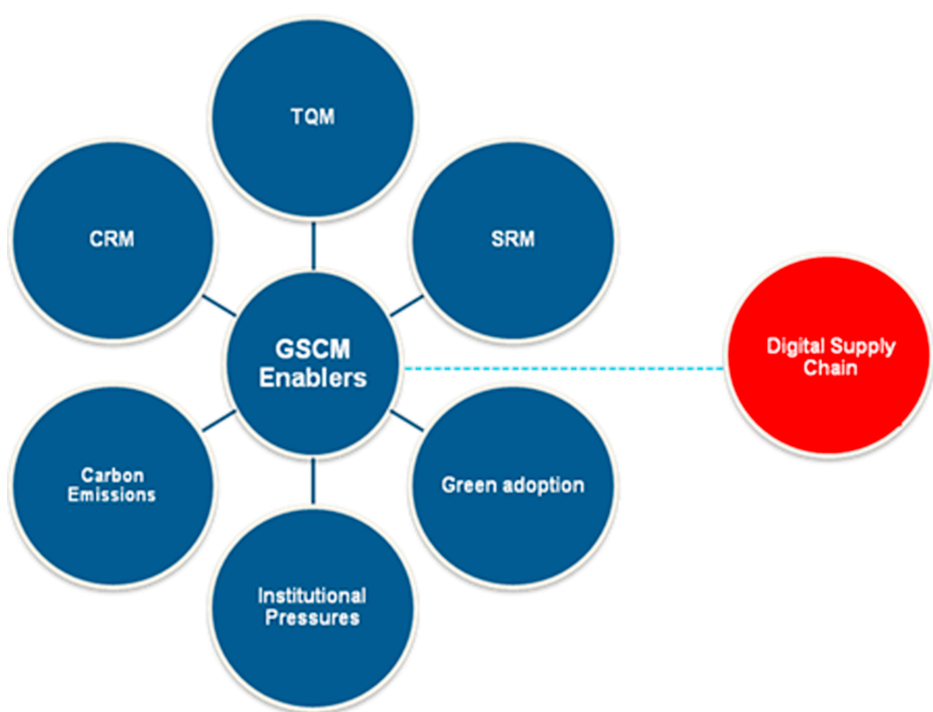

Fig. 6. Drivers of GSCM.

Table 4
List of Sustainable Supply Chain (SSC) characteristics from the definitions.

S. No	SSC characteristics	Source
1	Collaboration focus	Seuring and Müller (2008)
2	Environmental focus	Badurdeen et al. (2009)
3	Social focus	Wittstruck and Teuteberg (2011)
4	Manufacturing focus	Wolf (2011)
5	Production system focus	Ahi and Searcy (2013)

The key outcome is that the socio-environmental perception has been the central focal point for SCM practices. Although there were many definitions given from business and social perspective, the technology focus was not recorded by any of the published definitions. Overall, the outcome shows that the definitions for SSCM stressed largely on environment problems.

2.4.2. Review on CLSC

Organizations started adopting CLSC recently to improve value addition, make the environment more eco-friendly. The new technology facilitates return of goods well-handled and tracked resulting in cost savings (Atasu, Guide, & Wassenhove, 2008). Managing uncertainties in reverse logistics such as quality, cost calculation, customer perception are the key challenges in deriving the success of CLSC (Battini et al., 2017; Wei, Govindan, Li, & Zhao, 2015). Thus, studying the uncertainties in managing SC and their influences on CLSC is vital (Guide & Van Wassenhove, 2009).

SSCM has developed interests in business as well as academicians for the impact it makes to the environment. There are two phases in sustainable supply chain lifecycle (Govindan, Soleimani, & Kannan, 2015). The first phase is termed as Forward Supply Chain (FSC) and next phase is termed as Reverse Supply Chain (RSC) or Reverse Logistics (RL). FSC takes cares of the forward business flow where value is added at each process to meet the customers' requirements. RSC brings the returned products from the customer and applies 6Rs namely Recover, Reuse, Remanufacture, Recycle, Redesign, Reduce to extend the product life cycle (Khor & Udin, 2012; Sasikumar & Kannan, 2008a, 2008b).

A typical CLSC model is shown as referred in Fig. 7, which contains both FSC and RSC. In FSC, supplier supplies raw materials, manufacturer produces the finished goods, distributor distributes the products through their distribution channels; retailer sells the product to consumer. RSC essentially brings the returned products and improves the sustainability of the end item to protect the global environment (Chanintrakul, Coronado Mondragon, Lalwani, & Wong, 2009; Kumar & Rahman, 2014; Qiang, 2015; Savaskan, Bhattacharya, & Van Wassenhove, 2004; Zheng, Yang, Yang, & Zhang, 2017).

RSC helps to re-process the returned/life ended product by the following ways:

- Refurbish the product (Guide, Teunter, & Van Wassenhove, 2003)
- Make the returned product components as spare parts (Zailani, Govindan, Shaharudin, & Kuan, 2017)
- Explode the Bill of Material and re-use the components as raw material wherever

possible (Amelia, Wahab, Haron, Muhamad, & Azhari, 2009; Gelbmann & Hammerl, 2015; McKenna, Reith, Cail, Kessler, & Fichtner, 2013; Pappis, Rachaniotis, & Tsoulfas, 2005)

- Resell the unused parts to the supplier who deals with scraps for recycling (Guide, 2000; Inderfurth, de Kok, & Flapper, 2001; Lin, 2013; Nagalingam, Kuik, & Amer, 2013)

2.4.3. Sensor embedded product and reverse supply chain

One of the high priorities for Supply Chain stakeholders is to deliver the products on time to customer in good condition. This requires complete visibility of the product condition across Supply Chain. Establishing sensor-embedded products can transform Supply Chain management to next level. In case of RSC, the used product that has reached end of life can be recovered with various processes such as reuse, recycle, repair or dispose.

Ilgin and Gupta (2011) discusses the challenges on disassembly of parts and the uncertainty over missing items in reverse supply chain and studies the performance measures, which influences sensor-embedded products that can detect missing items prior to disassembly. Ondemir, Ilgin, and Gupta (2012) developed a model that deals with the products, which are embedded with sensors. The developed model

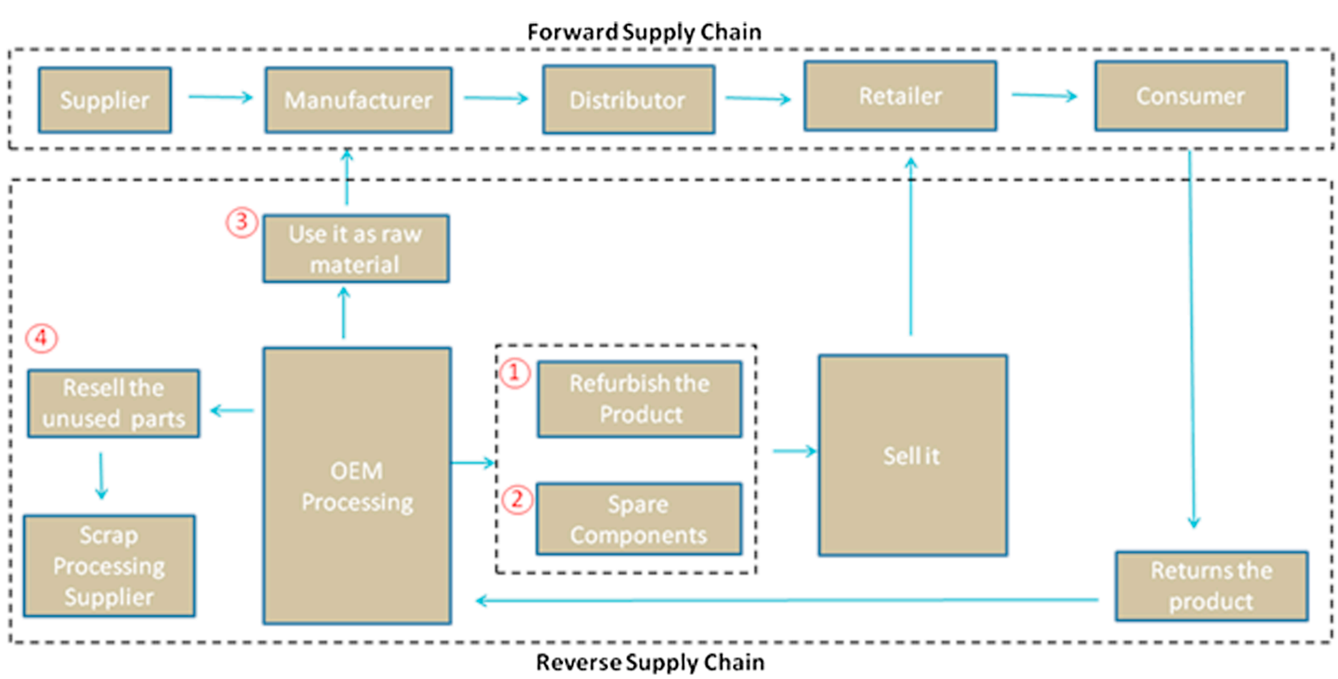

Fig. 7. Typical CLSC.

Table 5
List of publications in SSC and CLSC.

S. No.	Focus	Explanation	Source
1	Food SC	The food SC is a primary beneficiary of SSC. The framework focuses on the re-usability of food items inside a country and scopes out the outside country impacts.	Yakovleva, Sarkis, and Sloan (2012)
2	Healthcare	Focuses on sustainability issues in health care. It discusses on waste management and resource management in hospital management.	Grose and Richardson (2013)
3	Apparel industry	Customer involvement and management strategy are the key factors, which drives the SSC performance. Apparel industry goes lean and sustainable by leveraging SSC methodologies.	Kozlowski, Searcy, and Bardecki (2015)
4	Manufacturing	Industrial growth induces new opportunities, adhering to new technologies, improves ergonomics from SSC perspective.	Siemieniuch and Sinclair (2015)

determines the process to handle the EOL product in CLSC using sensor-embedded product. Yang et al. (2018) evaluated the importance of recovery information for reusable containers recorded by sensors in closed loop supply chain management. Pal and Kant (2018) discussed the opportunities that exists with sensor-based infrastructure to monitor food supply chain which can reduce the food waste and keep the food fresh till it reaches the end consumer. Bibi, Guillaume, Gontard, and Sorli (2017) reviewed RFID sensors, which can be used in food supply chain to track food condition so that spoiled foods can be avoided.

2.4.4. Focus of sustainability in different sectors

The SSCM is a topic of interest for various research studies. It has been found that SSCM affects performance and growth of the supply chain industry as they need to meet the government regulations on environmental policies and compliance (Gotschol, De Giovanni, & Vinzi, 2014; Wiese, Kellner, Lietke, Toporowski, & Zielke, 2012). Distribution of the SSC, CLSC literature are listed in Table 5.

The literature review reveals that various organizations are taking measures towards sustainability. It demonstrates the addition of SSC into an organization which many institutions take it as pressure (Bhakoo & Choi, 2013; Hult, Ketchen, & Arrfelt, 2007). Reviews suggest that the entire supply chain including the partners should start implementing SSC methods (Alblas, Peters, & Wortmann, 2014; Foerstl, Azadegan, Leppelt, & Hartmann, 2015; Lange, Driessen, Sauer, Bornemann, & Burger, 2013; Leppelt, Foerstl, Reuter, & Hartmann, 2013; Sarkis, Zhu, & Lai, 2011; Sharma, Iyer, Mehrotra, & Krishnan, 2010; Zhu, Sarkis, & Lai, 2013).

2.5. Influence of ERP on industries

Information and communication technology is significantly changing the dynamics of business as several companies have already implemented ERP to manage their business efficiently (Min & Zhou, 2002; Wu & Olson, 2008). ERP system helps an organization to manage their daily business activities through information systems, which integrates all the functions and departments so that sharing information across department is easy and communication happens within the system (Huang, Chang, Li, & Lin, 2004; Sun, Ni, & Lam, 2015). The role of ERP in an organization is to effectively manage their business strategy, operations and resources (McAdam & Galloway, 2005; Newell, Tansley, & Huang, 2004).

The important factor to evaluate an organization is to measure the optimal utilization of their resources with efficient way of tracking their business routines (Gürbüz, Alptekin, & Alptekin, 2012; Mexas, Quelhas, & Costa, 2012; Wei, Wang, & Ju, 2005).

The influence of ERP in various industries are analyzed based on resource usage, project management, cost and time that considerably brings the better service possible to the organization (Sedera & Gable, 2010). In this subsection, list of industries, that has an impact on ERP systems, have been provided as illustrated in Table 6.

This literature review attempted to categorize the industries where the ERP systems has been deployed successfully. The ERP system influences the performance of supply chain management (Willcocks & Sykes, 2000). Successful ERP integration with SCM requires proper demand forecast, production planning, resource utilization (Li, 2011; Vandaie, 2008). Instead of managing the individual functions, interconnect the operations through ERP systems so that the information is visible to external stakeholder of supply chain (Palanisamy, 2008). An example is that the purchasing department places orders as appropriate. At the supplier end, sales takes up the order and work towards fulfilling the order. Later the original equipment manufacturer manufacturers the product; distributes it through distribution channel; then to retailers and finally it satisfies the customer demand. The entire process can be managed effectively with help of integrating ERP systems to the SCM (Acar, Zaim, Isik, & Calisir, 2017). SCN is a collaborative effort from buying agent, suppliers, vendor managed inventory and more importantly willingness to share the relevant information with the supply chain partner (Li et al., 2017).

The review revealed that researchers studied the influence of ERP on SC and other industries but effort on sustainable supply chain with ERP system has not been made so far. Organizations that have implemented ERP and part of supply chain should uncover the opportunities available from sustainable perspective, which ultimately improves the effectiveness of the organization.

2.6. Study on industry 4.0

Industry 4.0 is a blend of digital technology, which transforms the industrial production to next level. The fundamental platform for the success of this technology is the revolution in technologies that consists of CPS, IoT and IoS. It is flexible and intelligent to interconnect machines that enables making customized products (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014). The Industry 4.0 literature is reviewed to know the future growth in supply chain industries.

Industry 4.0 will alter the complete production, operations and maintenance of products and services through interconnected components, machines, humans. With the influence of Industry 4.0, the industrial production systems are expected to perform 30% faster than earlier and 25% more efficient (Rüßmann, Lorenz, Gerbert, Waldner, Justus, Engel, & Harnisch, 2015).

The phenomenon of Industry 4.0 was first proposed by Germany to take strategic initiatives in 2011 (Bauernhansl et al., 2014; Drath & Horch, 2014; Kagermann, 2015). Initially the perception on Industry 4.0 is twofold. First, it was expected that industrial revolution make a huge impact on economy. Second, Industry 4.0 promises highly on operation effectiveness and gives a path to adopt new business models (Kagermann, 2015). Wan, Cai, and Zhou (2015) researches that Germany is the global leader in manufacturing, automotive, electronics, sports equipment industry. German Government is investing on industry 4.0 and promoting this revolution in response to European debt crisis. Oztemel and Gursev (2018) studied the impact of industry 4.0 in manufacturing systems, provided a vision to establish a roadmap for digitalizing the manufacturing setup and explored the ways to transform machine driven manufacturing to digital driven manufacturing.

Table 6
List of industries impacted by ERP Systems.

S. No.	Industry sector	Description	Source
1	Supply chain	SCM modules namely master planning, demand and fulfillment, SC optimizer are tightly packed and interfaced with conventional ERP functions such as Materials, Procurement, Manufacturing, Finance, Sales and Human Resources.	Stefanou (1999)
2	Healthcare	ERP integration with supply chain triggers ripple effects in a complex environment such as health care. It requires change in mindset that encourages people to work closely together following new ways of performing their tasks while sharing common objectives and goals.	Stefanou and Revanoglou (2006)
3	High-tech	Quality management on material and service are critical criteria in High Tech Industry, which tremendously affects an ERP system.	Chien and Tsaur (2007)
4	Semi-conductor related industry	Analysis suggests that modified service quality gap model assists industrialists to assess the involvement of ERP in improving service quality for the customers by removing quality issues.	Yeh, Yang, and Lin (2007)
5	Automobile	Employed a decision making model to implement ERP systems in automobile industry. The benefits of the model reduces the risks of decision-making and improves the implementation success rate of the project.	Hakim and Hakim (2010)
6	Pharmaceutical	Examines the role of ERP in pharmaceutical industry and discusses the features of business process reengineering. The study shows that proper management decision with well-coordinated information systems is the key for successful ERP implementation.	Bosilj-Vukšić and Spremić (2005)
7	Engineering and Construction	Introduces a prototype system called SC Collaborator. This system assists supply chain of construction industries by leveraging web-based technologies. The benefits of the system are more economical and customizable to integrate supply chain partners, which shares information across SC partners.	Cheng, Law, Bjornsson, Jones, and Sriram (2010)

2.6.1. Industry 4.0 definitions

The vision of smart factory based on the concept of Industry 4.0 where CPS connects the digital and physical world to make decentralized decisions (Bücker, Hermann, Pentek, & Otto, 2016). The connection of human, parts and systems creates self-guided, dynamic, real-time value added interconnections across the value chain (Gorecky, Schmitt, Loskyll, & Zühlke, 2014). Industry 4.0 is a strategic approach, which uses latest technological innovations in the area of manufacturing converging information and communication systems (Schuh, Potente, Wesch-Potente, Weber, & Prote, 2014).

The literature reveals that Industry 4.0 model is successful because of the tightly integrated system, which is mainly built based on CPS (Lee, Bagheri, & Kao, 2015). The collaboration of information platform and mobile devices with internet-connected technology is a key factor for success of CPS to realize a smart manufacturing system (Baheti & Gill, 2011). This leads industry 4.0 to become more digital, self-assistant, information-led (Lee, Kao, & Yang, 2014).

2.6.2. Layers of cyber physical system

CPS is an interconnected system, which is monitored or managed by information system. In CPS, the digital and physical object are interconnected, they interact each other and take decentralized decisions (Jazdi, 2014; Rajkumar, Lee, Sha, & Stankovic, 2010; Riedl, Zipper, Meier, & Diedrich, 2014).

CPS requires three layers as illustrated in Fig. 8 (Jing, Vasilakos, Wan, Lu, & Qiu, 2014).

- connected devices
- data stored in cloud in a network infrastructure
- Application system or Information System

The physical machines, assets, components are digitally connected and share the information in real time (Frazzon, Hartmann, Makuschewitz, & Scholz-Reiter, 2013; Strang & Anderl, 2014). Data is stored in cloud and transmitted to the networked system. Application System or Information System is the intelligent system which assists people virtually and allows users to have real-time interactions between products, services and connected devices (Sun, Mohan, Sha, & Gunter, 2009).

2.6.3. Evolution of industry 4.0

In the previous industrial revolutions, users have seen the developments in mechanical, electrical and information technology with

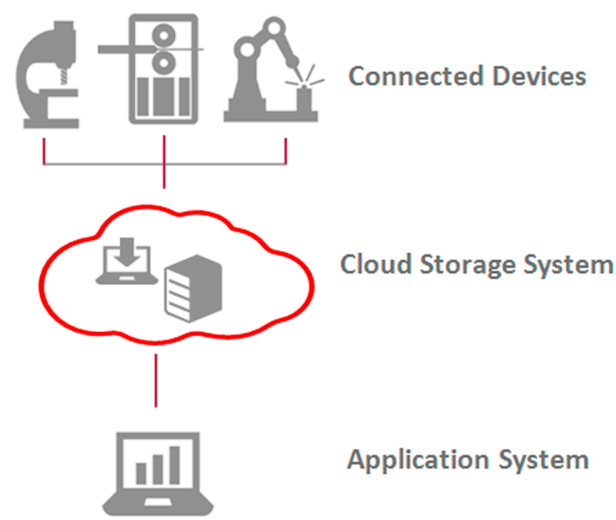

Fig. 8. Interconnected devices form a "digital line" (Cyber Physical Systems).

focus on productivity of production system. As illustrated in Fig. 9, the first industrial revolution is said to be 'age of steam' that uses steam power, which is also termed as hydropower to develop machine tools and increase the performance of the production system. The second industrial revolution leverages electricity and makes volume of production to optimize the electrical power. The third industrial revolution stimulates the concept of automation for the routine work by combining knowledge based systems and electronics. The fourth in this category is industry 4.0, which accelerates the industrial growth, leverages latest CPS technology to combine the digital and physical world with information technology.

Manufacturability or production feasibility is the primary objective when physical labor involved in production but flexibility in every instance of the production system is the key driver for Industry 4.0 (Brettel, Klein, & Friederichsen, 2016). Smart cities, smart factories, smart industry are now becoming reality with Industry 4.0 where physical world and digital systems are interacting with each other (Wollschlaeger, Sauter, & Jasperneite, 2017).

2.6.4. Design principles of industry 4.0

The design principles assist organization in selecting prospective industry 4.0 components for their initial development projects and then

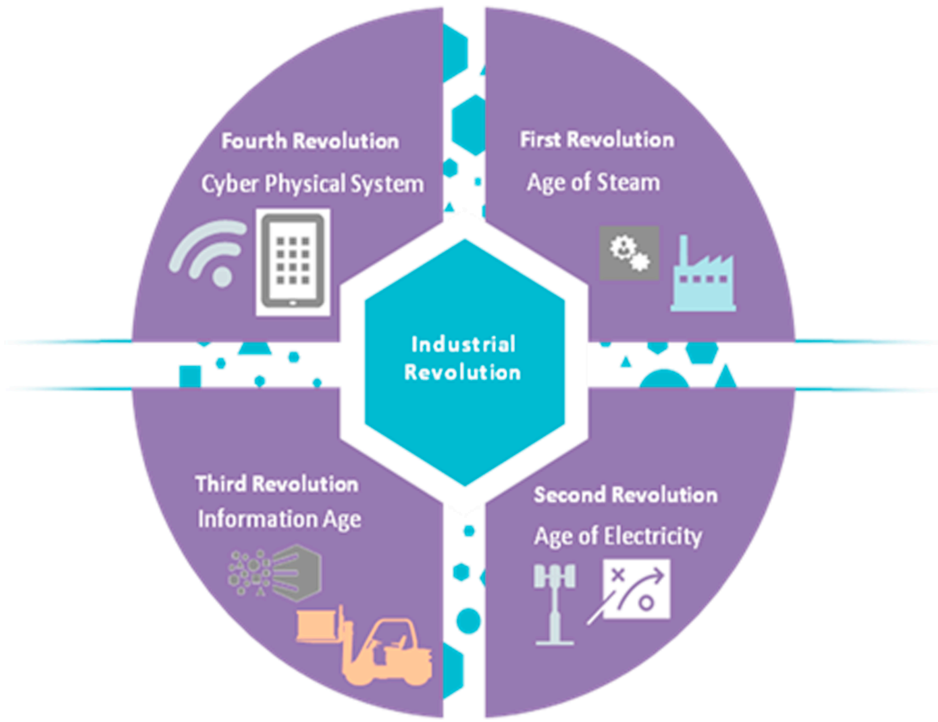

Fig. 9. Four phases of the industrial revolution.

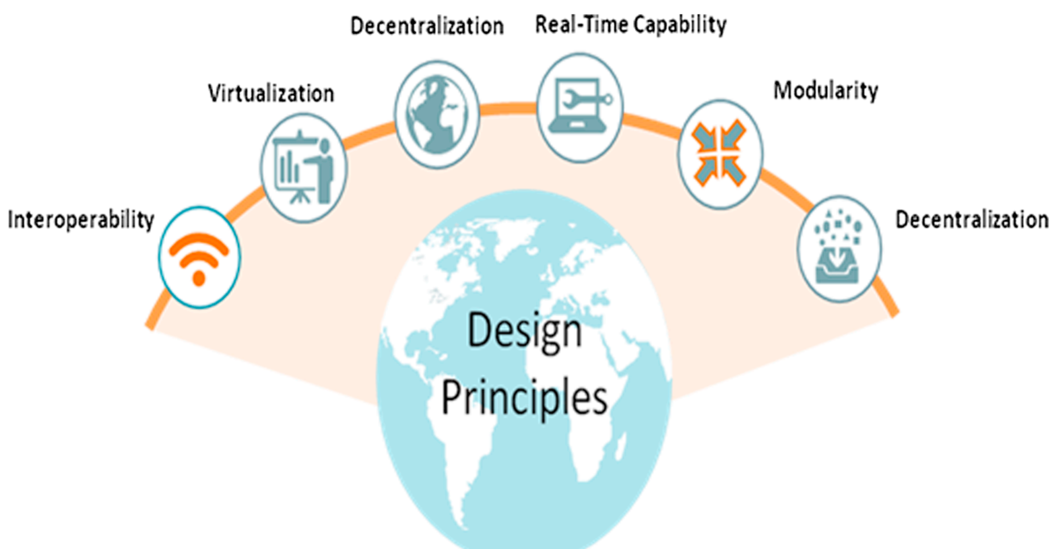

Fig. 10. Industry 4.0 design principles.

go for full implementation (Waschull, Bokhorst, & Wortmann, 2017). Industry 4.0 design principles are shown in Fig. 10.

The fundamental principle is to integrate machines, sites with information systems that can work independently and manage each other (Thuemmler & Bai, 2017). Organizations can leverage the six design principles of Industry 4.0 in an effort to make their manufacturing process digitalized and automated (Gregor, 2002; Hermann, Pentek, & Otto, 2016). They are discussed as illustrated in Table 7.

Based on literature review, six designs principles were reviewed in this article; further research is encouraged from an academic or practical perspective.

2.6.5. Building blocks of industry 4.0

The manufacturing sector is a central focal point for implementing new technologies (Erol, Jäger, Hold, Ott, & Sihn, 2016). Digital re-invention in industrial revolution is set to redefine every entity in manufacturing value chain. Digital Data, connectivity, automation, mobility are the digital disruptions happening with industry 4.0 (Cisneros-Cabrera, Ramzan, Sampaio, & Mehandjiev, 2017). The lists of technological trends are described in Table 8, which are instrumental in contributing to industry 4.0 growth.

These innovative technologies in manufacturing results in increased speed to market, accuracy on the product, customized output as required by customer and improved overall efficiency (Schweer & Sahl, 2017). The advancements in technology, coupled with connected intelligence that amplifies the value of digitalization are the foundation of Industry 4.0, form the foundation as illustrated in Fig. 11. It is estimated that industry 4.0 will redefine the businesses for the next decade

Table 7
Industry 4.0 design principles.

Design principle	Description	Application	Source
Virtualization	Information systems that creates virtual replica of the physical world information into digital data.	CPS, Smart Factory	MacDougall (2014)
Interoperability	Ability of equipment, components to get interconnected and communicate with each other and humans through internet.	CPS, IoT, IoS, Smart Factory	Saldivar et al. (2015)
Decentralization	Ability of the digitally connected systems to take autonomous decisions and carryout appropriate actions. Human interaction is only required during exceptions, conflicts with the anticipated output.	CPS, Smart Factory	Gilchrist (2016)
Real-time Capability	Ability of the system to communicate the information concurrently for making quick and better decisions by human resources.	Smart Factory	Vogel-Heuser and Hess (2016)
Service orientation	Ability of the system to serve organizations and humans as a service using internet which can used by other stakeholders both internally as well as externally.	Internet of Services	Sanders, Subramanian, Redlich, and Wulfsberg (2017)
Modularity	A system, that adheres to dynamic modifications in the requirements by adding or replacing various modules.	Internet of Services	Peres, Rocha, Coelho, and Oliveira (2017)

(Foehr et al., 2017). IoT influenced Industry 4.0 provides greater efficiencies in production with fully integrated, automated, and optimized process (Vermesan et al., 2013).

2.6.6. Influence of industry 4.0 on various necessities

This emerging technology is not only for manufacturing industries, it can be applicable for any industry where there are many product variants produced such as food, beverages, and automotive industries. In places where there is a need for high quality and precision such as semi-conductors and pharmaceuticals are also benefited (Kochan & Miksche, 2017). Organizations need to decide the appropriate infrastructure to get the new technological advancements in industry 4.0.

Technological advances in industrial revolution dramatically increase the productivity responding to customer needs (Riel & Flatscher, 2017). It lays basis for bringing new innovative business models that fulfills various necessities of humans. A brief list is provided in Table 9, that is influenced by industry 4.0.

The above analysis discloses that the adoptions of digital technologies are growing faster. Organizations need to introduce new innovative products with digital capabilities to incur rapid development and revenue (Bagheri, Yang, Kao, & Lee, 2015). The internet based smart services on business analytics will expand industry growth (Evans & Annunziata, 2012). The strength of Industry 4.0 is the ability to communicate data seamlessly with the new technologies, which creates value in the entire eco system (Lee, Lapira, Bagheri, & Kao, 2013). Key trends in Industry 4.0 shows that there is clear transformation in market dynamics from high-tech to industrial equipment digitally (Basl, 2016).

2.6.7. Prospects of sustainable manufacturing in industry 4.0 – a way beyond

One of the challenges in growing economy is that there is a higher demand for industrial system, at the same time organizations should focus on sustainability of their products (Bocken et al., 2014). The development in Industry 4.0 gives tremendous opportunities realizing sustainable manufacturing (Schaltegger & Wagner, 2011). Stock and Seliger (2016) provided an overview on opportunities available for sustainable manufacturing in industry 4.0.

With the help of CPS and retrofitting approach, organizations can extend the equipment life by studying the eco-friendly characteristics of sustainable product manufacturing. The viable option for SMEs is to reuse the equipment, as they may not be able to afford huge capital to procure new manufacturing equipment (Spath, Gerlach, Hämmerle, Schlund, & Strölin, 2013).

The basics of sustainability in Industry 4.0 suggest that organizations should realize closed loop life cycles for product. Organizations should leverage the opportunities to enable ways to re-use and remanufacture the products for achieving higher-level throughput (Duarte & Cruz-Machado, 2017).

Table 8
Technologies that transforms Industrial Production (Industry 4.0).

S. No.	Technology	Description	Source
1	Big data based quality management	Algorithms based on historical data detect quality concerns and decrease product failures.	Rüßmann et al. (2015)
2	Cyber security	Cyber security measures takes high priority as it recognizes the new vulnerabilities and challenges that interlinks industrial management processes and systems digitally.	Flatt, Schriegel, Jasperneite, Trsek, and Adamczyk (2016)
3	Auto coordinated Production	Automatically coordinated machines optimize their utilization and output.	Zhang, Zhao, and Qian (2017)
4	Smart supply linkage	Monitor the supply network which allows for better supply judgements	Radziwon, Bilberg, Bogers, and Madsen (2014)
5	Self-transported vehicles	Fully automated transportation systems used logically within the industry.	Kai et al. (2017)
6	Augmented job, maintenance and repair operations.	Emerging method, which facilitates maintenance guidance, remote support and service.	Paelke (2014)
7	Lean modernization	Lean automation brings flexibility and eliminates redundant manufacturing effort for a whole range of machines.	Kolberg and Zühlke (2015)
8	Additive manufacturing	Products are created using 3D Printers that reduces product development cost.	Huang, Liu, Mokasdar, and Hou (2013)
9	Manufacturing operations simulation	Simulation helps in optimizing the assembly line using optimization applications.	Zhou, Liu, and Zhou (2015)
10	Maintenance cloud service	Manufacturers offers maintenance services, rather than a product. Build private clouds to save appropriate manufacturing details and processing.	Yue, Cai, Yan, Zou, and Zhou (2015)
11	Flat and Hierarchical system integration	Integrate cross-functional departments as well as seamless supply chain co-ordination among SC partners by automating the process wherever necessary.	Satoglu, Ustundag, Cevikcan, and Durmusoglu (2018)
12	Robot-aided manufacturing	Flexible, intelligent robots performs operations such as assembly and packaging independently.	Wang, Zhang, and Zhu (2017)
13	IIoT	This technology is an essential part within industry 4.0 equipped to interact and communicate with the Smart Factory and supply chain.	Sadeghi, Wachsmann, and Waidner (2015)
14	Intuitive predictive maintenance	Remote monitoring of equipment permits repair prior to breakdown.	Wang (2016)

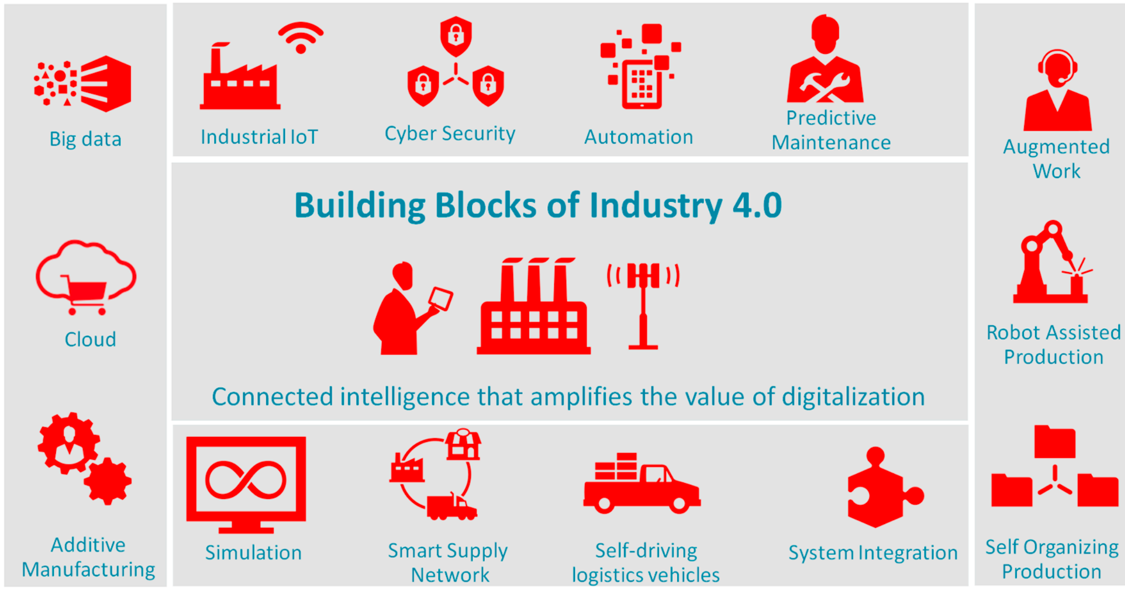

Fig. 11. Industry 4.0 Foundation.

Industry 4.0 uses the technologies IoT, CPS, Cloud Manufacturing (Trappey, Trappey, Govindarajan, Chuang, & Sun, 2017; Upasani, Bakshi, Pandhare, & Lad, 2017). A new platform termed as advanced manufacturing cloud of things along with the application of Automatic Virtual Metrology achieves the goal of zero defects in wheel machining automation, which extends a way to the next phase, Industry 4.1 (Lin et al., 2017).

2.6.8. Next wave of industry 4.0 with SSC

Industry 4.0 can be realized only when organizations are ready to transform towards digital technology (Liao, Deschamps, Loures, & Ramos, 2017). With the influence of Industry 4.0, traditional supply chains has a great potential to transform a highly efficient digital supply chain by smartly connecting right from product development, procurement, manufacturing, logistics, suppliers, customers and service (Brettel, Friederichsen, Keller, & Rosenberg, 2014). The entire ecosystem will be benefited if industry 4.0 can go one-step further in accommodating sustainability of digital supply chain (Farahani, Meier, & Wilke, 2017).

Fig. 12 visualizes the extensive interconnection of components, machines, systems, processes and various stakeholders of supply chain to form a digital SCN with future Industry 4.0 (Atanasov, Nikolov, Pencheva, Dimova, & Ivanov, 2015; Pfohl, Yahsi, & Kurnaz, 2017). Disruptive business models can offer smart product and services to serve the customers in a complete digital ecosystem (Kölsch, Herder, Zimmermann, & Aurich, 2017). The digital cyber network is the focal point, which shares the information across supply chain mainly distinguished by taking decentralized actions, from a remote location with the tightly integrated platform (Ivanov, Dolgui, Sokolov, Werner, & Ivanova, 2016; Zuehlke, 2010). The reviews reveal that the studies are

Table 9
Influence of Industry 4.0 on various necessities summary list.

S. No.	Necessities	Description	Source
1	Wireless requirements	Challenges in key wireless communication evaluated with technology. The three main design criterions are latency, longevity and the reliability of communication in machine-to-machine communication	Varghese and Tandur (2014)
2	Manufacturing systems	CPS that closely monitors and synchronizes networked machines with machine-to-machine collaboration and information system.	Theorin et al. (2017)
3	Psychological requirements	New activities in occupational psychology and manufacturing science are emerging with technology.	Dombrowski and Wagner (2014)
4	Small and medium enterprises (SME)	SMEs explores opportunities with Industry 4.0 to optimize their business process.	Faller and Feldmüller (2015)
5	Smart factory	Industry, which uses self-controlling machines and autonomous robots controlled by CPS. With advancement in wireless communication system, these systems are not only intellectual; it has the adaptive intelligence to take necessary actions based on the pre-defined instructions.	Wang, Wan, Zhang, Li, and Zhang (2016)
6	Smart products	Smart products are able to self-connect and communicate with the help of internet and sensor in the production process.	Schmidt et al. (2015)
7	Multi-vendor production systems	With industry 4.0, multi-vendor production line are relatively flexible and self-adaptable within production systems.	Weyer, Schmitt, Ohmer, and Gorecky (2015)
8	Industrial wireless networks	Wireless networks helps to access data in real time from remote location. Scalability is crucial to bring the cost down, adoptability and improve the performance. It plays a key factor to make industry 4.0 commendable and brilliant decision-making system.	Li, Wu, Zong, and Li (2017), Li, Liu, Liu, Lai, and Xu (2017)
9	Smart manufacturing	Smart Manufacturing is the collaboration of internet connected technology which helps the industry to manufacture goods with less human involvement and self-assisting capability.	Kang et al. (2016)
10	Smart cities	The foundation for smart city is IoT and IoS, aimed to provide better quality of living space for citizens.	Lom, Pribyl, and Svitek (2016)
11	Smart Operators	Brings flexibility to human operators and helps to work in dynamic environment with high capabilities. The solution leverages augmented reality to connect men-machine for the functional requirements.	Longo, Nicoletti, and Padovano (2017)

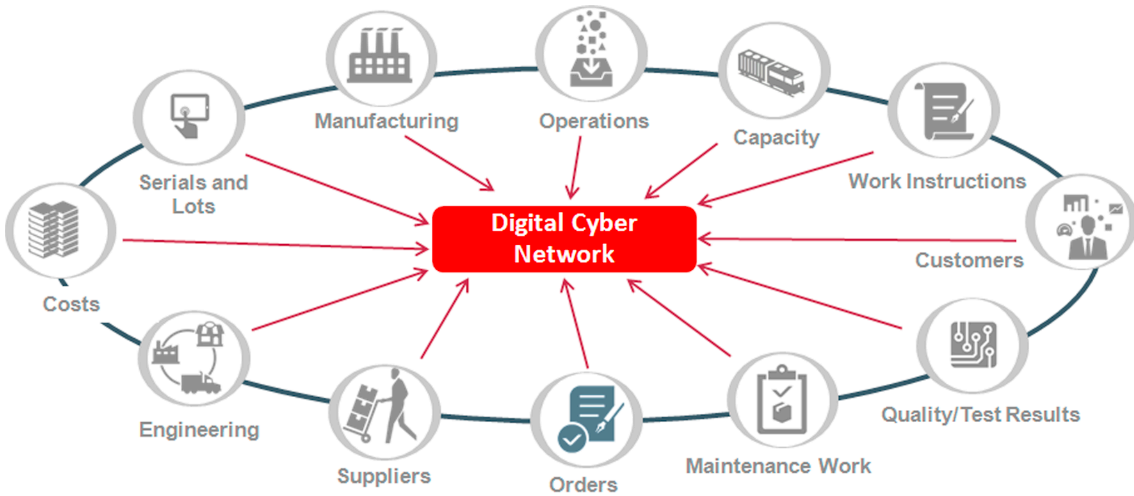

Fig. 12. Sustainable Supply Chain Network with future 'Industry 4.0'.

happening on industry 4.0 but SCM with sustainability as the key criteria and IoT based SCM systems are not explored much from academic as well as industry perspective.

2.7. Overview on IoT

The term IoT refers to the robust communication between digital and physical world (Internet Reports, 2005). From this viewpoint, IoT brings the convergence of connected products and sensors to offer new competence. IoT is applied in various industry segments including automotive, healthcare, manufacturing, home and hi-tech electronics to make the products, services and operations smarter (Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012).

Forrester Research has estimated that by 2020, the global IoT revenue will be 30 times those of the internet. The information and communication technology sector will grow by trillion-dollar connecting 25 billion applications everywhere (Pye, 2014). IoT is an emerging technology, which offers potential solutions to alter the operation and role of manufacturing, supply chain and logistics industries. The term IoT was initially used to describe the interoperable connected devices with RFID technology (Ashton, 2011).

2.7.1. Defining IoT

Various definitions have been proposed for IoT. The essence of the definitions from author perspective based on the key characteristics collected from literature has been provided in Table 10.

2.7.1.1. Researcher's proposed definition. After reviewing various definitions meticulously, a new definition is proposed. IoT can be articulated in every surface of human lives across the globe; hence IoT can be defined as a '*technology which is intuitive, robust and scalable that enables digital transformation of the connected world through internet and communicates all the relevant information in real time across the value chain'*.

IoT has evolved from powerful emergence of wireless technologies, sensors and internet. IoT connects the networked systems and other devices through internet. The systems are aware of the environment and so intuitive with the help of sensors where devices transmits massive amount of data every day. These connected systems are easy to use and understand each other with the help of internet.

2.7.2. Rapid evolvement of Internet of Things (IoT)

Influence of IoT is picking up its pace in various organizations namely aerospace, supply chain, construction and manufacturing sector (Ji, Ganchev, O'Droma, Zhao, & Zhang, 2014). IoT looks feasible and scalable considering the advancements in internet application, mobile communication, adaptive intelligence, machine learning in various sectors and bring significant influence on enterprise systems (Dong, Mingyue, & Guoying, 2017).

During 1980, RFID technology was used for warehouse management especially to identify the goods and monitor the stocks as illustrated in Fig. 13. In 1990s, wireless devices began emerging; as a result, sensors were used in various fields such as automotive, production, healthcare. In the 2000s, internet medium was used for standard communication and later it slowly started providing useful information by accessing the various systems in enterprise sector. But the challenge was that the devices still require human interaction. From 2009 onwards, the IoT started gaining moment and drastically altered the industrial and consumer applications. The unique innovation of IoT technology is sharing the information in real time from a remote location. This technology operates dynamically and react to things how a human will act in such situations.

Table 10
List of IoT definitions from author perspective.

S. No.	Definition perspective	Source
1	Technology Perspective	Uckelmann, Harrison, and Michahelles (2011)
2	Interoperable communication perspective	Van Kranenburg (2008)
3	Application perspective	Yaqoob et al. (2017)
4	Business perspective	Sundmaeker, Guillemin, Friess, and Woelfflé (2010)
5	Environment Perspective	Shaikh, Zeadally, and Exposito (2017)
6	Analytics Perspective	Gubbi, Buyya, Marusic, and Palaniswami (2013)
7	Development perspective	Burkett and Steutermann (2014)
8	Process perspective	Zhang, Qian, Lv, and Liu (2017)
9	Networking perspective	Song et al. (2016)

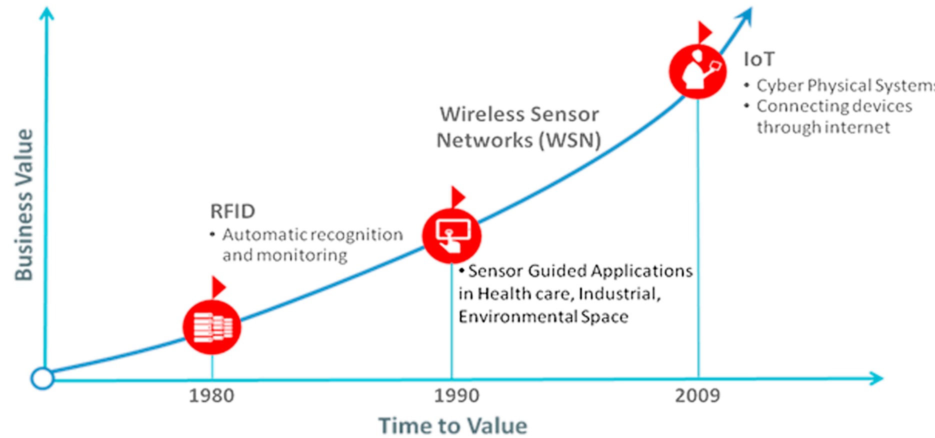

Fig. 13. Evolution of IoT.

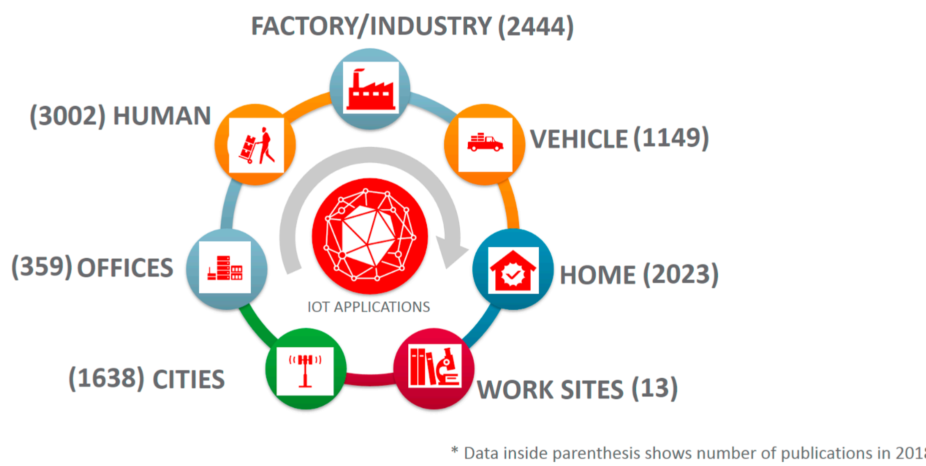

Fig. 14. IoT Applications.

2.7.3. *Current trends and future impact*

Many of the researchers have mentioned that IoT is one of the major advancements in the digital internet era. Nevertheless, prioritization of the industries has not been mentioned (Fleisch, Weinberger, & Wortmann, 2015; Wortmann & Flüchter, 2015). IoT plays an important role in different industries but to make it more real, academicians and practitioners need to further analyze and research on IoT (Zheng, Simplot-Ryl, Bisdikian, & Mouftah, 2011).

As a result, the information coming from the physical systems will rise drastically as more and more new business opportunities starts coming in. The information of the digital world is estimated to grow ten times by 2020 (Shah, 2016).

Yan, Zhang, and Vasilakos (2014) reviewed that trust management is important in IoT for the data security, user privacy, and cyber security. The success of this technology depends on consistency and scalability. IoT provides interoperability, dependability, trustworthiness and effective operations on an international scale (Bandyopadhyay & Sen, 2011).

2.7.4. *IoT applications – stepping up with widespread adoption*

Fundamentally, the essence of IoT is to connect physical and digital objects with the help of internet and information systems (Hwang, Lee, Park, & Chang, 2017). IoT is emerging into various sector considering its capability to self-monitor and take right decisions (Khan, Khan, Zaheer, & Khan, 2012). Irrespective of the application area, IoT brings sophisticated and flexible industry system, which help organizations across the globe (Chen, Xu, Liu, Hu, & Wang, 2014). On the basis of literature, as shown in Fig. 14, application of IoT can be classified into various sectors such as factory/Industry, vehicle, home, work sites, cities, offices and human (Borgia, 2014; Wang, Gunasekaran, Ngai, & Papadopoulos, 2016). Fig. 14 shows that IoT on Human, Factory/Industry and Home applications are the areas mostly studied by researchers.

Each sector is not completely independent as some of the applications are mutually benefited (Tragos et al., 2014). For example, consignment tracking uses the applications related to work sites, factory and vehicle.

One of the significant development of IoT is the acceptance by wide spread of many industries and consumers otherwise this technology may not be accepted by community (Coetzee & Eksteen, 2011).

In this section, various IoT applications were discussed and value addition it brings to industries and society. Few applications such as ‘Health Monitoring Wearables’, ‘disease management devices’ enabled by IoT produces rich information and transmits the data of physical health (Hassanalieragh et al., 2015; Lymberis & Olsson, 2003). Various appliances at home can be managed efficiently and comfortably using smart control system, which leverages IoT technology. The smart control systems such as ‘Home Controllers’ and ‘Security Systems’ monitor the appliances, home security, and electricity consumption and so on (Gaikwad, Gabhane, & Golait, 2015; Wang, Zhang, Zhang, Zhang, & Li, 2013). Using IoT devices such as ‘Energy Management Controllers’ and ‘Industrial Security Systems’, energy consumption of office building is monitored and energy saving methods is suggested (Lee & Lee, 2015; Wei & Li, 2011).

IoT stimulates the growth of automation where regular and repetitive operations can be automated in factories. In addition, industrial

Table 11
IoT in various industries.

S. No.	Industry	Description	Source
1	Mining production	IoT devices predict the unsafe situations in mine and sends the alert to stakeholders and workers before an unforeseen situation happens. This enables the team to act proactively and save lives, cost, time.	Qiuping, Shunbing, and Chunquan (2011); Da Xu, He, and Li (2014)
2	Logistics	The smart products are interconnected with the IoT devices. The logistics organizations are tracking the physical objects real-time and ensures that the SC partners are informed with realistic goods availability time.	Zhang et al. (2012)
3	Food SC	The dynamics of food industry is time bounded as it deals with perishable items. The quality of item need to be tracked from farmland until the customer consumer consuming it. There are several process happens and value is added in every process. IoT addresses the challenges faced in food processing industry; it tracks, forecasts the shelf life of the items and estimates the expiry of the item at real time.	Pang, Chen, and Zheng (2012); Doinea, Boja, Batagan, Toma, and Popa (2015)
4	Healthcare	Several IoT devices has come into the market from healthcare perspective. Human condition is monitored in real time virtually from anywhere. The sophisticated information system is also helpful during emergency to alert and attend the needy people with medicine and necessary equipment continuously.	Pang (2013)
5	Emergency response management	IoT emerges has a boon in emergency response management operations to track the information and act immediately to take quick decisions where time is the crucial factor.	Yang, Yang, and Plotnick (2013)
6	Hospital	The management of healthcare equipment is an important task of administration department as it becomes critical sometimes. IoT is a feasible and economical solution on hospital supply chain management, as it helps in predicting the equipment maintenance time, automatically informs stakeholders to take immediate action.	Peng, Su, Chen, and Du (2017)
7	Household	From a social standpoint, adoption of IoT and its impact towards the society especially to households and their occupants were investigated.	Olsson, Bosch, and Katumba (2016), Perera, Zaslavsky, Christen, and Georgakopoulos (2014)
8	e-retailers	For e-retailers, IoT helps in delivering the product timely and efficiently to the customers. In addition, IoT drives the flexibility and brings healthy relationship among logistic providers and retailers resulting in on time product deliveries, which eventually satisfies the customers.	Jie, Subramanian, Ning, and Edwards (2015)
9	Fire fighting	IoT devices helps in pre-detecting fire possibilities and sends early warning by raising automatic alarm to disaster handling team. This technology is proving its worth during emergency.	Rosas, Aguilar, Tripp-Barba, Espinosa, and Aguilar (2017)
10	Warehouse management	IoT devices enable supervisors to track the location of components from a remote location. It helps to provide live instructions to workers to handle special equipment and sensitive materials. Wearable devices increases productivity and speed shipment. Moreover, it brings accurate visibility into stocks availability in warehouse and informs warehouse manager automatically.	Reaidy, Gunasekaran, and Spalanzani (2015)
11	Energy management	IoT helps organizations to save cost by reducing energy wastes. The intelligence of IoT is the ability to get the real time data, which will be helpful bringing smart lighting with sensors. Energy management in smart factories based on the IoT is the new business model, which is emerging with a focus on the sustainability.	Shrouf, Ordieres, and Miragliotta (2014)
12	Manufacturing and logistics	With the advent of IoT, a real-time visibility on machines, component and status improves product quality. Similarly, IoT provides visibility into physical objects status, which improves service quality. Overall, SC effectiveness is increased with the help of IoT.	Papakostas, O'Connor, and Byrne (2016); Chuang et al. (2016)
13	Industrial Systems	Today security and privacy of sensitive data in Industrial IoT systems is critical. The next generation applications uses cyber physical systems which promises to explore on security and have strong connectivity of embedded devices.	Tao, Cheng, and Qi (2018)
14	Construction	As a sustainable construction technology, prefabrication is a process adopted to build new houses to mitigate the risk of labor shortage, deliver on time with safety and environmental protection. Digital technology assists to circumvent the constraints and build the prefabrication based houses fast.	Li et al. (2016)
15	Product life-cycle energy management	IoT for product life-cycle energy management is still in early stage. Industries are trying to employ IoT to reduce energy consumption.	Tao, Wang, Zuo, Yang, and Zhang (2016)
16	Telecommunication	Sustainable IoT is prioritized in telecommunication industry to make it more efficient and scalable.	Zarei, Mohammadian, and Ghasemi (2016)
17	Fashion apparel/footwear	With the help of industry 4.0 and IoT embracing ERP into account, a major leap has happened in fashion apparel and footwear industry to improve the operational performance.	Majeed and Rupasinghe (2017)

production can reach the next level by utilizing the machines to the optimum level leveraging IoT. Few examples are smart factory with optimum workload and capacity schedulers, controller for automating regular operations (Shrouf & Miragliotta, 2015).

IoT can be deployed in worksites. Using IoT, the potential risks of shipment delay can be identified. For instance, riders and the stakeholders are alerted on travel disruptions due to traffic diversions and road conditions using IoT application. Vehicles can be monitored dynamically and alert message can be sent to the maintenance department based on usage. In addition, vehicle administration system can improve the road traffic tremendously (Leng & Zhao, 2011). Considering workers safety, health monitoring system and predictive maintenance on machines can be implemented in mining industry (Jung, Zhang, & Winslett, 2017).

Focus on urban IoT system is expected to support sustainable smart cities. IoT based car parking system, traffic monitoring and control system, resource management are few applications for making a successful smart city (Vlacheas et al., 2013; Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014).

The investment on IoT from industrial standpoint has increased significantly. The term IoT has become a key highlight in the industry as many organizations trying to prioritize their objective of making

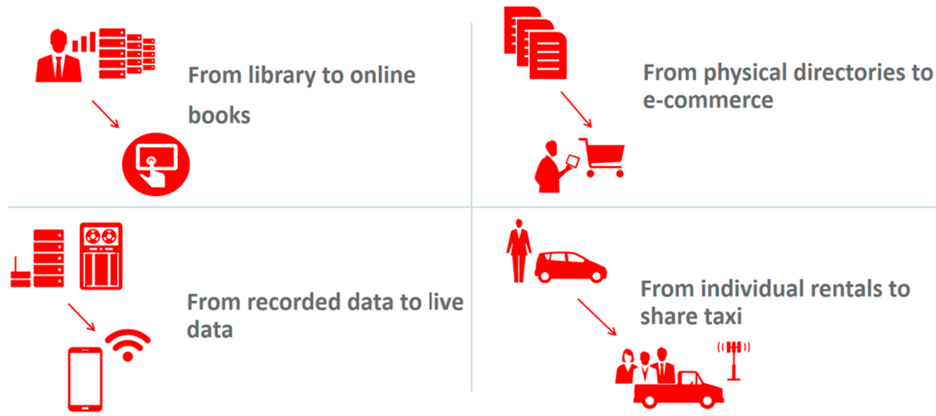

Fig. 15. New business models with the influence of IoT.

industry digitalized (Jeschke, Brecher, Meisen, Özdemir, & Eschert, 2017; Kiel, Arnold, & Voigt, 2017). The subsequent section focuses on IoT on various industries.

2.7.5. Internet of things in industries – expanding the boundaries

IoT provides a potential opportunity to develop robust industrial systems with the key technologies such as RFID, sensor and wireless communication. Various industrial IoT applications have been commercialized and started spreading across the globe. In this section, the literature review on current research of IoT in industries is studied as described in Table 11.

Based on the analysis, IoT applications are developed for both industrial and consumer purposes. But the focus on supply chain industry to improve the end to end value chain has not yet been focused. IoT is instrumental in improving the overall effectiveness of supply chain by providing real time data. Further, with adaptive intelligence, stakeholders are provided with informed decisions.

2.7.6. Emerging new business opportunities with Internet of Things

Global companies are continuously looking for innovative business opportunities to serve the customers and explores new business models to make a profitable organization (Yan, 2017). Many opportunities are offered by IoT, which can be leveraged in several business. Wide range of applications can use IoT these days such as smart factory, smart cars, etc. Moreover, it is used in different sectors: healthcare (Wu et al., 2017), defense (Sha, Xiao, Chen, & Sun, 2017), home appliance (Patel & Kanawade, 2017), disassembling the operations (Wang, Zhang, Liu, Li, & Tang, 2017) or logistics (Hofmann & Rüsch, 2017).

Several IoT business model successfully exists today and growing exponentially in terms of demand versus supply. New business models are emerging with the influence of IoT where IoT act as a platform and connect users digitally with the help of wireless and internet (Zhou et al., 2016).

As illustrated in Fig. 15, in this internet age the business is shifting from

- Convention library to online books
- Businesses started using e-commerce market place to find goods and services than physical directories
- Fast transformation is happening in communication technology, users are moving from recorded data from physical gadgets to live data
- Riders started thinking wisely to share their taxi with others instead of individual taxi that offers more benefits in terms of cost, time (Siemens, 2016). It also helps in protecting the environment with considerable percentage of reduction in carbon footprint (Dijkman, Sprenkels, Peeters, & Janssen, 2015).

All the above said business models are possible only because of internet and devices started connecting intelligently and helping the world a better place to live.

2.7.7. The digital transformation with IoT enablers

There are numerous business opportunities with IoT technology, that provides the smartness in the devices, products and services. This section focuses on IoT enablers, which assists businesses or society to improve on their value chain. The cloud, big data and IoT are indivisible technology used to share volume of data in real time without any performance lag (Gunasekaran, Kumar Tiwari, Dubey, & Fosso Wamba, 2016). A literature has been studied to review the impact of key enablers of IoT in various applications. The lists of key enablers of IoT with its applications are shown in Table 12.

The study reveals that the key enablers of IoT are imperative to achieve success of the any application such as industrial systems, health care, etc which uses IoT. Big data connects massive quantity of data that can be both structured and unstructured. IoT is essentially the means that collects and sends data so that users takes informed decisions. To sum it up, Big Data and Cloud are the fuel, and IoT is the brain to realize the future of a smart connected world.

2.7.8. Role of IoT with various supply chain

IoT is one of today's most influential technologies which impact the businesses. The research firm Gartner estimates that the growth of internet connected physical devices increases exponentially by 2020 which will change the business of how the supply chain operates (Shrouf & Miragliotta, 2015).

In last decade, businesses were using passive sensors where the data is static. But with IoT, controlling supply chain dynamically and execute the decisions on external location is viable. The logistics operations is a key function of SCM where asset tracking or in-transit components are complex. IoT helps in monitoring the logistics operation (Qu et al., 2017).

The review has been done on various supply chain methods including GSCM/SSCM practices. Table 13 describes the summary of the observations made.

The study discloses that IoT influences the future supply chain. Information, material, finance details are shared across supply chain partners. The study on SSCM with the influence of IoT technologies is inadequate now and researchers are encouraged to focus on this area.

2.7.9. IoT based SCM systems

IoT is set to offer efficient and quick solutions required to meet the supply chain challenges by enabling sensor based technology and share the information through internet. Some of the key supply chain challenges are addressed using IoT enabled SCM systems. Tu, Lim, and Yang (2018) proposed IoT enabled manufacturing transportation system in

Table 12
Key enablers of IoT with its applications.

S. No.	Enabler	Application	Description	Authors
1	Big data	Manufacturing Systems	Manufacturing sector pushing to next transformation 'predictive manufacturing' with the help of IoT and CPS, to maximize productivity and reduce downtime.	Wang, Törngren, and Onori (2015)
2	Cloud	Multiple (Healthcare, Logistics, Automotive)	Technologies such as Cloud and IoT blend with information system. Industry 4.0 can be applied in hospital health care management, logistics and automotive industry.	Botta, De Donato, Persico, and Pescapé (2014)
3	Cloud	Manufacturing System	The applications of the technologies IoT and CC in manufacturing systems provides an intelligent perception and connection from M2M forms Cloud Manufacturing (CMfg). In addition, it shares the on-demand use and optimal resources allocation of various cloud manufacturing capabilities so that CCIoT-CMfg framework is established.	Tao, Cheng, Da Xu, Zhang, and Li (2014)
4	Cloud centric IoT	Precision Agriculture	IoT can be used to track production to transportation in agriculture industry. Stakeholders get real time information on the condition of the inventory. Cloud helps in supporting the agriculture SC with the support of IoT.	Satpute and Tembhurne (2014)
5	Software-as-a-service model (SaaS)	Logistic Systems	IoT communicates to SaaS application, in turn SaaS sends real time alert messages to the stakeholders in logistic industry about the status of shipped goods.	Chen, Chen, and Hsu (2014)
6	Enterprise modeling	Manufacturing	Emerging Internet of Things (IoT) supports Enterprise System in modern manufacturing which is actually a complex system comprises real-time data collected from machines, processes and business environments. IoT assists in dynamic decision-making activities.	Bi, Da Xu, and Wang (2014)
7	Big data	Industrial systems	The 'Unique Sense' implementation model for fourth industrial revolution with big data holds the innovative smart computing focuses towards dynamic customization, reusability, eco friendliness for next generation controlling and computation power.	Vijaykumar, Saravanakumar, and Balamurugan (2015)
8	Cloud	Industrial Systems	Integration of cloud technologies and industrial cyber-physical systems (ICPS) becomes increasingly important, in manufacturing chain and business services. ICPS will promote the manufacturing efficiency, increase quality of production, and enable a sustainable industrial system and more environmentally friendly businesses.	Sanislav, Zeadally, and Mois (2017)
9	Big data	Sustainable Economy	Combination of Big data and IoT improves the usage of sustainable products and reduces wastages.	Nobre and Tavares (2017)
10	Software-defined IIoT	Industrial Systems	IIoT and its enablers provides more flexibility to manage physical devices.	Wan et al. (2016)
11	Big data	Industrial Systems	Big data helps in industrial systems such as aircraft industry to gain the insight on analytics considering the huge amount of data gets generated.	Voss, Sebastian, and Pahl (2017)
12	Cloud	Health care	IoT plays a vital role in connecting medical devices and sensors in healthcare industry. To circumvent any aggravating sufferings on patients' health, it is mandatory to have real time health check on essential and crucial basis.	Hossain and Muhammad (2016)

Table 13
Study the influence of IoT with various SCM.

S. No.	SCM method	Description	Source
1	Traditional	Analyze the pharmaceutical industry supply chain and the specific application model of internet of things in drugs supply chain and how to realize drugs information retrieval.	Yan and Huang (2009)
2	Sustainable	Establishes alert system with help of IoT in food processing industry to identify the risk and provides recommendation to protect the food and improve the quality. It also identifies pattern of abnormalities and performs an expert analysis to increase the sustainability of food manufacturing organization.	Wang and Yue (2017)
3	Agile	The emergence of internet helps sharing information with stakeholders to accelerate material flows via SCM execution.	Ung and Kun (2010)
4	Lean	IoT helps lean SCM of construction enterprises to achieve better operational efficiency. IoT connects the assets, resources, equipment and helps to achieve on time delivery of work packages, improve on downtime.	Lian-yue (2012)
5	Traditional	IoT helps collaborated business eco system in SCM. This article used 6C framework model to examine the patterns of SCM by leveraging IoT based business eco system.	Rong, Hu, Lin, Shi, and Guo (2015)
6	CLSC	Many companies focuses to retrieve and treat their end-of-use products in order to contribute to the environment. IoT helps to track, detect, store the returned product process for the optimization of procurement, manufacturing, recovering and disposal decisions.	Zhong et al. (2017); Wang and Wang (2017)
7	CLSC	An intelligent RSC uses internet as a medium to connect sensors, information systems, RFIDs. This sophisticated RSC modernizes manufacturing industries to go greener, reduces non-environment friendly resources, saves energy and ensures optimal utilization of products by recycling the scraps.	Parry, Brax, Maull, and Ng (2016)
8	Green	IoT system in GSC enhances decision-making in green inventory management.	Chen (2015)
9	Traditional	Innovation has become key element in SCM to gain the competitive advantage. IoT based SCM system helps to achieve that advantage.	Li and Li (2017)

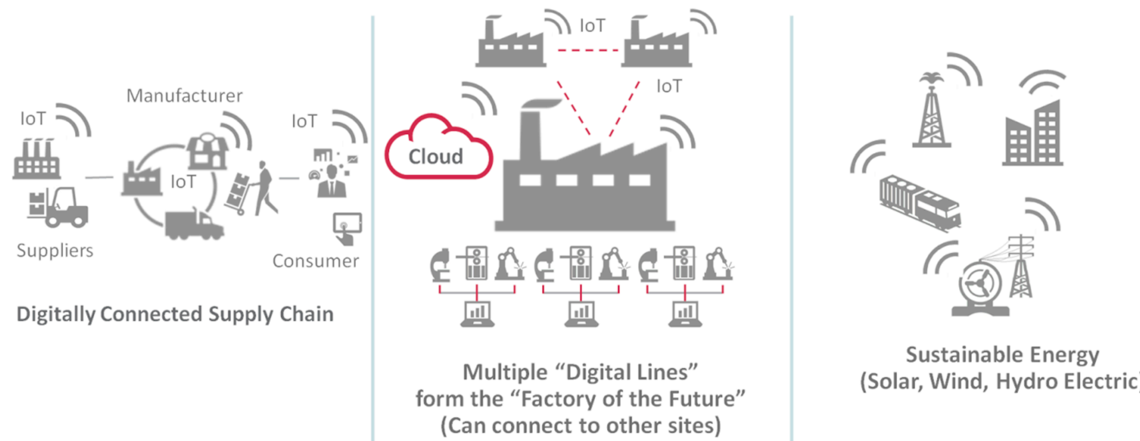

Fig. 16. Factory of Future in Sustainable Supply Chain Eco System with Industry 4.0.

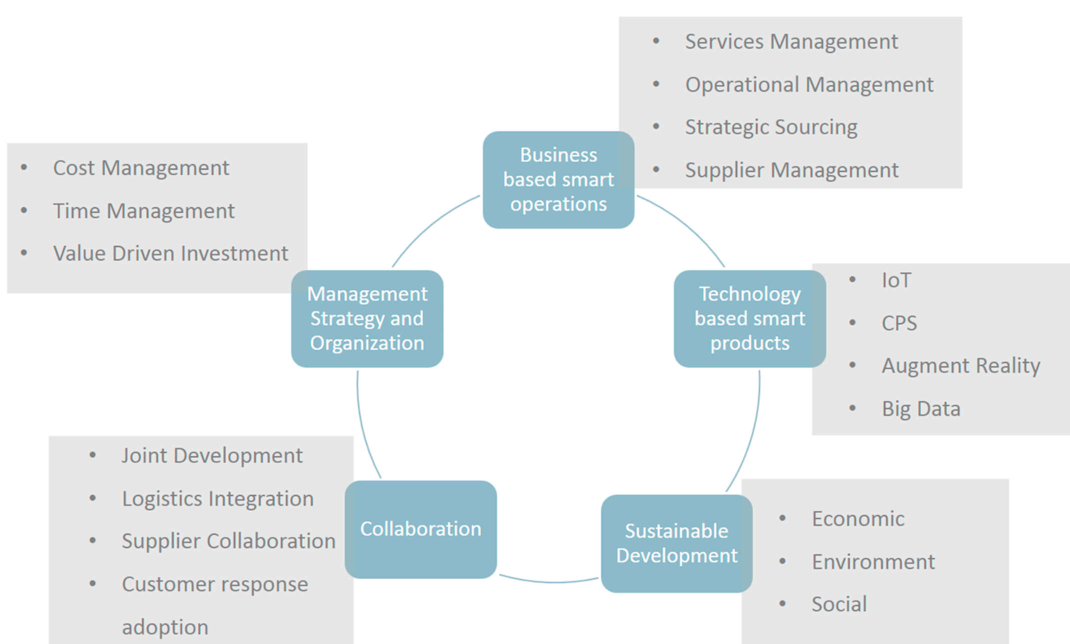

Fig. 17. Framework for assessing SSCM for Industry 4.0.

Table 14
Framework for assessing SSCM for fourth industrial revolution.

Enabler	Criteria	Attribute	Source
Business based smart operations Perspective	Services Management	● Streamline and monitor execution of service ● Track services performance ● Achieve complete view of services spend to know it is in compliance	Kathawala and Abdou (2003); Youngdahl and Loomba (2000); Balsmeier and Voisin (1996).
	Operational Management	● Automate routine work/transactions ● Align operations to business needs ● Respond to exceptions before business is affected ● Manage Spend and reduce waste	Corbett and Kleindorfer (2003); Kleindorfer, Singhal, and Wassenhove (2005); Kocabasoglu, Prahinski, and Klassen (2007).
	Strategic Sourcing	● Maximize realized savings ● Get right suppliers and right materials ● Structure negotiations for quality outcomes ● Enforce appropriate contract verbiage	Anderson and Katz (1998); Croom, Romano, and Giannakis (2000); D'Amico, Mogre, Clarke, Lindgreen, and Hingley (2017).
	Supplier Management	● Simplify and automate supplier audits ● Analyze supplier performance ● Orchestrate supplier evaluation by various departments	Saeed, Malhotra, and Grover (2005; Jayaram, Xu, and Nicolae (2011); Prajogo, Chowdhury, Yeung, and Cheng (2012); Ataseven and Nair (2017)
Technology based smart products Perspective	IoT	● Monitor entire supply chain network ● Introduce Cyber Security ● Sense the environmental risks upfront ● Manage resource and systems	Tu, Chung, Chiu, Chung, and Tzeng (2017); Nagurney, Daniele, and Shukla (2017); Rodger and George (2017); Kache and Seuring (2017).
	CPS	● Assess the real-time information sharing ● Self-monitor and control the process ● Predict actions or needs of users ● Self-organizing production	Monostori (2014); Monostori et al. (2016); Barthelmey, Störkle, Kuhlenkötter, and Deuse (2014)
	Augment Reality	● Emergency management ● Remote assistance and guidance in maintenance activities ● New ways of coordination of design and manufacturing process	Mourtzis, Doukas, and Bernidaki (2014); Ong, Yuan, and Nee (2008); Salonitis and Stavropoulos (2013)
	Big Data	● Proactive risk alerts based on historical data ● Deplete quality issues and product failure ● Flexible in consolidating data for business intelligence ● Predictive Analytics and Forecasting Tools	Hazen, Boone, Ezell, and Jones-Farmer (2014); Wang, Chaudhry, and Li (2016), Wang, Wan, Li, and Zhang (2016); Gunasekaran et al. (2017)
Sustainable Development Perspective	Economic	● Financial Stability ● Study risk exposure across organization ● Investment on technological improvements ● Retrofitting approach to extend the equipment life before considering new equipment	Anderson (2007); Fahimnia, Sarkis, Gunasekaran, and Farahani (2017); Genovese, Acquaye, Figueroa, and Koh (2017); Sauer and Seuring (2017); Zeng, Chen, Xiao, and Zhou (2017);
	Environment	● Reduce nonrenewable energy resource ● Global warming with air pollution ● Release of water and soil pollutants	Coyle, Thomchick, and Ruamsook (2015); Dam and Petkova (2014); Zhu, Geng, and Lai (2011)
	Social	● Enforce health and safety practices ● Adhere to government regulations ● Awareness on macro-economics	Krause, Vachon, and Klassen (2009); Mani, Gunasekaran, Papadopoulos, Hazen, and Dubey (2016); Kogg and Mont (2012)
Collaboration Perspective	Joint Development	● Collaborate across lines of business ● Usage of product data management (PDM) systems ● Reduction of non-value added costs	Jafari, Hejazi, and Rasti-Barzoki (2017); Irani, Kamal, Sharif, and Love (2017); Thomson et al. (2017); Niesten, Jolink, de Sousa Jabbour, Chappin, and Lozano (2017)
	Logistics Integration	● Visibility on in-transit consignment Location, status and allocations ● Remove obstacles impacting delivery or cost variation ● Leverage technology & enable information driven decision-making.	Farkavcova, Rieckhof, and Guenther (2018); Qaiser, Ahmed, Sykora, Choudhary, and Simpson (2017); Boenzi, Digiesi, Facchini, Mossa, and Mummolo (2017); Sayyadi and Awasthi (2017).
	Supplier Collaboration	● Improve the cost performance index by ensuring right material ● Establish collaboration with suppliers using online systems ● Bring the visibility to Strategic Initiatives ● Leverage long term supplier relationship	Chen et al. (2017); Squire, Cousins, Lawson, and Brown (2009); Canzaniello, Hartmann, and Fifka (2017)
	Customer response adoption	● Customer Satisfaction – Cost, Quality, Timeliness ● User experience – universal adoption, maximize savings ● Reduce go-to-market time by automating processes	Kuo et al. (2017); Lim, Tseng, Tan, and Bui (2017); de Camargo Fiorini and Jabbour (2017); Yawar and Seuring (2017)
	Cost Management		

(*continued on next page*)

Table 14 (*continued*)

Enabler	Criteria	Attribute	Source
Management Strategy and Organization Perspective		• Improve cash flow predictability and visibility throughout the supply chain • Monitor price-movements of components that impact profitability • Adapt to changing spending patterns • Manage, process, the remarket products and services	Um, Lyons, Lam, Cheng, and Dominguez-Pery (2017); Keramydas, Mallidis, Dekker, Vlachos, and Iakovou (2017); Wu, Wu, Redouté, and Yuce (2017); Scholten and Fynes (2017)
	Time Management	• Automate Expensive Data Management • Ensure compliance for procuring timely services • Mobile based communication systems	Tarafdar and Qrunfleh (2017); Blome, Schoenherr, and Rexhausen (2013); Braunscheidel and Suresh (2009); Pagell and Wu (2017)
	Value driven investment	• Generate demand for goods and services • Manage supply base across multiple product categories • Anticipate risks and provide mitigation plans	Liao, Hu, and Ding (2017); Busse, Schleper, Weilenmann, and Wagner (2017); Christopher and Holweg (2017); He (2017)

supply chain. The proposed system can track finished good and various items of the finished goods along the supply chain. Leng, Jin, Shi, and Van Nieuwenhuyse (2018) studied on the agriculture logistics and supply chain based on RFID based technology. It further explored the application of RFID in the manufacturing process of agricultural products and testing the efficiency of the system. Rezaei, Akbarpour Shirazi, and Karimi (2017) suggested a model for supply chain performance using IoT, which allows the stakeholders to take dynamic decision based on real-time information. Li et al. (2017) suggested a live monitoring system for food SC based on IoT and shares the information with stakeholders, which improves the food quality of prepackaged food.

3. Opportunities on IoT embedded SSC in industry 4.0 era

IoT influences in supply chain is still at the initial stage where the study suggests that supply chain industry should step up to extract the benefits of next generation technologies. The study also uncovers the opportunities available with IoT, Big data for Sustainable Supply chain. Any typical supply chain organization needs to invest on such technologies to reap the benefits in long run.

Further, sustainable supply chain practices encourages the usage of sustainable energy. As illustrated in Fig. 16, the vision of Industry 4.0 in SSC is that the entire business should be connected digitally; reduce the carbon footprint and help the stakeholders to take dynamic decisions on real time. IoT enables interconnecting the machines, components, devices and users within an enterprise. Further, it is not only to connect with one manufacturing site, by leveraging cloud and internet it should be possible connecting multiple sites forming many digital supply chain lines (Hazen, Skipper, Ezell, & Boone, 2016).

The literature study suggests that the sustainability on supply chain leveraging IoT with Industry 4.0 was not focused earlier and thus it is considered as a gap. Based on the literature, a new framework for assessing sustainability in supply chain management for industry 4.0 is proposed as illustrated in Fig. 17. The conceptual model has been formulated from five perspectives of SSCM namely business, technology, sustainable development, collaboration, management strategy to meet the requirements of the fourth industrial revolution.

The framework has three layers as tabulated in Table 14. First layer contains five enablers, which influences the sustainability; second layer comprises of 18 sustainability criteria; third layer comprises of 62 attributes. This framework is a complete model for assessing sustainability in SC organization from Industry 4.0 perspective.

4. Managerial implications

The implications as a result of this analysis to assess the SSCM in industry 4.0 is explained in this section. This article analyses the various aspects of SCM, ERP, IoT and Industry 4.0. It discusses the importance of digitalization and the influence of IoT in the overall SCM. With IoT, stakeholders are equipped with technology to manage their resources efficiently and remotely. The reviews revealed that IoT applications on Human, Industry/Factory, home are the areas mostly studied by researchers. Organizations are also motivated to make environment-friendly products by using renewable raw materials, establish close loop supply chain and recover the end-of-life products to reduce the carbon footprints and increase their economic performance. This initiative will enrich their sustainability goal of the organization.

The research also shows that few industries have started investing on technology to improve their overall operational efficiency thereby increase the margins. From the review, it reveals that the organizations can be integrated in real-time with the stakeholders such as suppliers, manufacturers, retailers, and customers in Industry 4.0 environment. This benefits the entire supply chain with shared information in business processes, building innovative solutions and the emergence of new business opportunities. This study explores the criteria that can be assessed by companies to realize the readiness for industry 4.0 transformation.

5. Conclusion

Organizations are gradually moving towards implementing digital technology, IoT for enhancing the outcomes. It guarantees wide prospects to gain competitive advantage and set the tone for the future sustainable supply chain practices. Industry 4.0 offers quick response to customer demand. It improves the productivity and allows the stakeholders to make quicker decision in real time. It certainly pave ways to adopt new business models, improve manufacturing process.

In this review, the various aspects of IoT, SSC, and Industry 4.0 have been investigated in detail. The literatures were analyzed to know the trends and explored the potential of IoT opportunities available in sustainable supply chain space for industry 4.0. Based on the investigation, a new framework for assessing the preparedness of SCM for a sustainable growth to meet industry 4.0 is proposed. The conceptual model has been formulated from five perspectives of SCM namely business, technology, sustainable development, collaboration, management strategy perspectives. The framework provided can be the foundation to transform into industry 4.0 organization. At the completion of this transformation, organizations will become complete digital enterprise. The digital enterprise will operate with supply chain partners in organizational digital ecosystems.

The analysis shows that there are good opportunities available to perform further research in sustainable supply chain as it is still in infancy stage for industry 4.0 requirements. In order to improve operational effectiveness, academicians and practitioners are encouraged to investigate on leveraging latest digital offerings such as IoT, Industry 4.0 in SSCM.

5.1. Limitations and future research direction

The study on literature suggests that it is inevitable to invest on technology to yield the benefits of industry 4.0. In addition, transforming to industry 4.0 requires proper IT security solutions, workforce with required skill sets, sharing information in integrated environment with business partners. Small-scale industries may find it difficult to implement industry 4.0 as they lack sufficient financial resources to make investments. Thus, it will be challenge for small-scale industries to implement industry 4.0. The proposed framework for assessing SSCM is generic for all organizations. In future, there can be few more additions to the criteria in the framework for industry specific deployment of Industry 4.0.

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