Exploring Industry 4.0 technologies as drivers of Lean and Agile Supply Chain Strategies

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Abstract

The present global competition is forcing companies to expand and connect their "internal improvement processes" with "external customers and suppliers". Ensuring success in the face of fierce competition requires careful adoption of Supply Chain (SC) strategies alongside innovative capabilities such as Industry 4.0 technologies to enable such SC strategies. To improve organization's competitiveness and performance, modern day businesses are exploring the integration of SC strategies. Lean and Agile are two critical strategies because the former ensures efficient use of resources while the latter involves matching supply with demand in turbulent/unpredictable markets. Several studies have considered integration of different strategies/paradigms and their associated impact on SC; however, few have considered how Industry 4.0 technologies could enable these SC strategies for improved performance. This study presents a conceptual model that matches various principles/practices of Lean and Agile SC with industry 4.0 technologies (as drivers) for overall performance improvement. The conceptual model provides a decision supporting tool for practitioners at identifying potential industry 4.0 technologies in the context of lean-agile by way of motivating them on specific pillars of industry 4.0 to adopt for specific lean-agile strategies in achieving overall organizational goals. Other managerial and theoretical implications of the work are highlighted.

Keywords
Industry 4.0, Supply Chain Management, Supply Chain Strategy, Lean practice, Agile practice

1.0. Introduction

The continuous competition in the global space is forcing companies to expand and connect their "internal improvement processes" with "external customers and suppliers". Indeed, the competition is progressively tilting away from the focal company and towards the supply chain (SC) level. This is attributed to diverse and erratic customer behaviour among others as the world becomes a global village. In order to remain competitive, organizations are compelled to develop innovative ways to strengthen their image and maintain relevancy. A conglomerate of companies collaborating together is simply an SC. It is regarded as a system whose constituent parts include material suppliers, producer/manufacture, distributors and customers who are usually connected by 2 way flow with the forward being material flow while the feedback is the information flow (Naylor et al., 1999; Soltan and Mostafa, 2015). The ultimate goal is to provide value in form of products or services to the customers. The management of such flows, i.e. material, information and even the tenable cash among the parties constituting the SC is referred to Supply Chain Management (SCM). A tilt from exclusive focus on the effectiveness and efficiency of separate business units to adopting strategic planning and designing SC as a whole has become a common practice among companies in the present global market. Survival of such SC will ultimately be hinged on careful adoption of strategies and business models in tandem with overall organizational goals.

Several SC strategies have been reported in literature among which are Lean, Agile, Resilient and more recently added due to the need to incorporate sustainability measures into SC operations is the Green SC strategy. Lean and Agile are critical strategies because of their abilities to maximize the efficiency by eliminating non-value adding elements, stock control & centralized management as well as optimizing distribution and production activities (in case of lean strategy). Agile strategy on the other hand proffers advantage by its capacity of response and flexibility to variable market needs plus risk hedging means. They have been proven to be "pertinent strategies" towards achieving "efficiency and responsiveness". The present hostile economic conditions highlight the need for organizations to integrate various SC strategies in order to compete favourably. Thus, the need for progressive improvement of SCM motivates incorporation of lean and agile practices and careful adoption of both strategies no doubt will lead to SC performance improvement. However, concerted efforts and commitments are essential among the SC entities; that is within production factory, network of suppliers and end-customers; in order to ensure better deployment of these two strategies to achieve desired efficiency in the entire SC.

Meanwhile, Stankevice et al. (2018) recognizes the era of innovative capabilities and advancement in manufacturing and the SC as a whole (e.g. era of smart factory; industry 4.0; smart logistics etc.), thus, express the need to include innovation into the discussion of leanness and agility. Similarly, Ghobakhloo and Azar (2018) obtained that advanced manufacturing technology (AMT) enhances development of lean and agile manufacturing strategies. These new technological trends enabled engineering of digital SC operations which could greatly improve the overall organization performance. Similarly, Duarte and Cruz-Machado (2017) opined that industry 4.0 presents a new way of creating customer value. Haddud and Khare (2018) also noted that digitizing SC via the use of digital technology trends otherwise called industry 4.0 era (e.g. Big Data, Cloud Computing, IoT etc.) improves their performance by enhancing the visibility along the chains as well as increasing the responsiveness of an SC to resolve any operational challenges. Hence, there is need for researches to explore innovative capabilities and AMT/ industry 4.0 related technologies capable of driving various SC paradigms for improved SC performance.

The concept of Industry 4.0, since its launch in 2011 in Germany within the sphere of its high-tech strategy, has gained significant attention to the extent that it was listed in the 2016 World Economic Forum's agenda as a main topic (Hofmann and Rüsch, 2017). There are several anticipated gains from industry 4.0 and related technologies; for instance, a highly flexible mass production is guaranteed to meet diverse customers' needs and varieties, real-time coordination and value chains optimization as well as spring up of new and efficient service and business models among others (Hofmann and Rüsch, 2017). Against this backdrop, we believe industry 4.0 and its related technologies could revolutionize the entire SC and not just the focal manufacturing unit. This was also noted by Strozzi et al. (2017) in their review work on "smart factory" where they pointed out the need to implement the concept of smart factory, otherwise called industry 4.0 at the level of entire supply chain and not just within the focal manufacturing unit.

With performance improvement in mind, several scholars have considered integration of different strategies/paradigms with associated impact on the SC. For instance, authors like Carvalho et al. (2011); Carvalho and Cruz-Machado (2011); Govindan et al. (2015); Azevedo et al. (2016); Lotfi and Saghiri (2017); Ruiz-Benítez et al. (2018) etc. studied the effect of various strategies on the performance of SC. Few authors are meanwhile beginning to realize the need to bring the topic of industry 4.0 into the manufacturing and SC paradigms/strategies. Notable among these are Duarte and Cruz-Machado (2017) who investigated if industry 4.0 could aid the operationalization of the "lean and green" SC. They proposed an un-validated conceptual model of the relationships between "industry 4.0", "SCM" and "lean and green" strategies which was solely based on literature review. Specific linkage of industry 4.0 technology to SC practices was not considered in the work. Also, Duarte and Cruz-Machado (2018) presented conceptual model linking lean and green characteristics to industry 4.0 concepts like smart product, smart operator etc. also without matching specific industry 4.0 technologies to SC practices.

Furthermore, Sanders et al (2016) analyze the connection between industry 4.0 and lean manufacturing by examining whether industry 4.0 is capable of implementing lean. They presented different probable barriers and challenges for implementing lean and evaluated how these could be mitigated through industry 4.0 technologies. However, organizational performance was also left out. Wagner et al (2017) also presented impact of some industry 4.0 technologies on some lean tools without considering the organizational performance.

On overall, very few studies have considered how Industry 4.0 technologies could enable SC strategies for improved organizational performance by specifically highlighting which technology could enable which SC practice with corresponding impact on organizational performance measures. To bridge this gap, this study presents a conceptual model that matches various principles/practices of Lean and Agile SC with industry 4.0 pillars (as drivers) for organizational performance improvement.

2.0. SCM Coordination and Integration

As firms continue to realize the need to compete at the SC level instead of focal company in the current dynamic and competitive market, the coordination and management of such SC becomes a vital subject for companies. The appropriate management of the SC signifies that the entire set of tasks should be viewed as "single system" whose aim is to ensure un-interrupted “flow between companies” so that the customers’ needs of product or service are fulfilled in the “right quantities”, “right time” and “place” for the “lowest possible cost” (Duarte and Cruz-Machado, 2017). For improving SC performance, the various entities in the SC need be coordinated and integrated (de-Vass et al., 2018). “The entities are the focal company interacting with the suppliers and customers and are usually linked by materials, information and cash flows” (Kainuma and Tawara, 2006; Duarte and Cruz-Machado, 2017). The integration of SC is described as the “collaborative inter- and intra-organizational management on the strategic, tactical and operational business processes to achieve effective and efficient flows of products, information and funds to provide the maximum value to the end customer at the lowest cost and the greatest speed” (Huo, 2012; Alfalla-Luque et al., 2013; Yu, 2015; de-Vass et al., 2018). Some scholars categorize integration into three arms – “Internal process integration; upstream supplier integration and downstream customer integrations” (Ataseven & Nair, 2017; de-Vass et al., 2018) which are both externally oriented.

Internal integration entails facilitating on-time information sharing within organization by breaking barriers and bureaucracies capable of being a clog to smooth operations. “The goal is to promote strategic collaboration and coordination to attain improved organizational performance” (Yu, 2015; de-Vass et al., 2018). The “external integration” consist of “supplier and customer integration” with the former being information sharing and mutual collaboration between the focal company and its upstream suppliers while the latter represent such collaboration with the customers in the downstream all geared towards managing the synchronized processes (Yu, 2015; de-Vass et al., 2018). Organizations with significant degree of SC integration will undoubtedly experience improved performances as evident by Ataseven and Nair (2017).

Meanwhile, as SCs need to respond to diverse and erratic customers’ demands in the most effective and efficient manner; companies must take solace from careful adoption of strategies and business models to improve the supply chain. Lean and agile SC integration present a solution. This is because lean strategy has the ability to maximize the efficiency by eliminating non-value adding elements, stock control & centralized management as well as optimizing distribution and production activities. Agile strategy on the other hand proffers advantage by its capacity of response and flexibility to variable market needs plus risk hedging means.

3.0. Lean and Agile SC strategies

Lean approach is traced to have originated from the “Toyota Production System” with main spotlight on “efficient use of resources” via level scheduling (Ohno, 1988). It basically works fine in reasonably stable and foreseeable demand scenario and where variety is low. Conversely, agility, whose principal concern is responsiveness, is suited for situations with volatile demand and high variety requirement. It strives to “balance supply with demand in turbulent and unpredictable markets” (Christopher et al., 2006).

There exist diverse views about the two strategies. Using the logic of Krishnamurthy and Yauch (2007): “some hold that they are distinct and cannot co-exist” (e.g. Harrison, 1997), second view hold that they are “mutually supportive strategies” (e.g. Naylor et al., 1999), and others believe that “leanness must be a precursor to agility” (e.g. Hormozi, 2001). Realistically, with performance improvement in the face of global competition in mind, the two strategies can complement each other. In view of this, the combination of the two can be effected within effectively designed and operated SC via a “decoupling point” (Naylor et al., 1999; Soltan and Mostafa, 2015 etc.). This is termed “leagility”. Many researchers suggest that “combination of lean and agile by strategic location of ‘decoupling point’ improves the organizational benefits” (e.g. Naylor et al., 1999; Purvis et al., 2014; Soltan and Mostafa, 2015 etc.). Hence, careful adoption of both strategies no doubt will lead to organizational performance improvement.

3.1. Lean SCM

The rising competition for shorter lead times, improved quality and reduced costs ensures the incorporation of lean principles into the entire supply chain and not just the focal company (Cudney and Elrod, 2010; Tortorella et al., 2017). The lean approach which has been widely applied to manufacturing is now being adopted by firms to the SC both internally and externally. Its practices and principles must be adopted and implemented in the entire SC so as to derive all its potential benefits (Ruiz-Benítez, 2018). Applying the lean principles to the entire SC, from the supplier to the producer, distributor and the final customer engineers the “Lean supply chain management”. The main aim of lean SC strategy is to meet the demand of customers effectively at the lowest possible cost and progressive elimination of wastes along the SC. This permits product flow through the chain in response to the pull of the customer in pursuit of perfection.

Thus, the lean SCM is defined as a "collection of firms who are directly linked by upstream and downstream flow of products, services, funds and information that collaboratively work to reduce cost and waste by efficiently pulling what is needed to meet the needs of individual customers" (Vitasek et al., 2005; Tortorella et al., 2017). Waste is any activity that creates no value to the customer and for which associated costs represent a loss to the organization. Wastes are usually created not only by inappropriate information, materials and funds flow in the SC, but also the human movements (Jasti and Kodali, 2015). Lean SC proffers some significance which makes it essential for any business model. For instance, it strives to attain high level of customer satisfaction via its philosophy of meeting customers' needs in the shortest time duration.

3.2. Agile SCM

Agility has its principal concern in responsiveness. That is, "the ability of a system to promptly respond to changing market environment" (Carvalho et al., 2011). "It strives to match supply with demand in turbulent and unpredictable markets" (Christopher et al., 2006). The paper by Richards (1996) relayed how the term 'agility' was initially coined by the US Air Force strategists which to them means ability to change manoeuvre rate of aircrafts before subsequently becoming acceptable strategy to the entire military as the ability of friendly forces to be more proactive and reactive faster than the enemy. The paper stressed how the notion of agility applies to the business concept where the strategy is for the competitors to fight for customers. He defined agility in manufacturing as the "ability of an enterprise to thrive in a competitive environment of continuous and unanticipated change by responding quickly to rapidly changing markets driven by customers' valuation of products and services" (Richards, 1996). As the lean philosophy, agility has also been applied in the SC context. For instance, Swafford et al. (2008) define agility in the context of SC as its "capability to adapt or respond in a speedy manner to a changing marketplace environment". In contrast to lean SC whose focus is on waste elimination, agile SC focuses on the ability to comprehend and respond swiftly and cost effectively to volatile market changes (Carvalho et al., 2011). Organizations adopting agile SC are better positioned to profit from the market competition because of their ability to timely respond to unanticipated occurrences.

4.0. Industry 4.0 concept

Industry 4.0 also regarded as the "fourth industrial revolution" represents the current advancement in industrial processes. It signifies the confluence of technologies ranging from several digital technologies to novel materials and processes (OECD, 2016). The technologies are reported to have impact on manufacturing/production and distribution of goods and services with ultimate upshot on productivity and performances (OECD, 2016).

Beginning as an initiative of the German government to ensure competitiveness in the country's manufacturing sector, "Industry 4.0 was announced at the Hannover Messe in 2011" (Drath and Horch 2014; Buer et al., 2018). Since its launch in 2011, industry 4.0 has gained significant attention to the extent that it was listed in the 2016 World Economic Forum's agenda as a main topic (Hofmann and Rüsch, 2017). Despite being one of the main topics among academia and practitioners in recent times, there is no agreed clear and succinct definition of the concept, meaning no unique acceptable definitions yet (Hofmann and Rüsch, 2017; Mrugalska and Wyrwicka, 2017; Buer et al., 2018). Some studies meanwhile offer some definitions based on different construct. For instance, Moeuf et al (2017) state that Bidet-Mayer (2016) reported German telecommunications association (BITKOM) revealing over a hundred different definitions of Industry 4.0. Thus, the concept and goal of research determines the definition to adopt. Since this paper centres on how industry 4.0 technologies affect SC strategies; thus, definition limiting the applicability and utility of industry 4.0 to focal manufacturing alone will be unsuitable. In line with the goal of this research, industry 4.0 could be defined according to Pfohl et. al (2015) as "the sum of all disruptive innovations derived and implemented in a value chain to address the trends of digitalization, autonomization, transparency, mobility, modularization, network-collaboration and socializing of products and processes". It represents "a new level of value chain organization and management across the lifecycle of products as well as a collective term for technologies and concepts of value chain organization" (Kagermann and Helbig, 2013; Mrugalska and Wyrwicka, 2017).
One of its notable technologies, the "Internet of Things and Services" allows "networking" the entire factory to becoming a "smart environment" (Sanders et al., 2016). "Digitally developed smart machines, production facilities and logistics/warehousing systems enable end-to-end information and communication systems-based integration of the SC from inbound logistics to production, marketing, outbound logistics and service" (Kagermann et al., 2013; Sanders et al., 2016). Industry 4.0 no doubt presents new possibilities to disrupt the traditional approach of managing supply chain.

4.1. Industry 4.0 technologies

The various technologies of industry 4.0 connect the machines, equipment, devices, products and logistics tools to facilitate "real time" communication among them in a way that the system inherently generate and feed information thereby "adding value to the manufacturing process" (Wang et al., 2016; Kamble et al., 2018). The combination of software, sensors, processors and other communication technologies facilitates the interconnection (Bahrin et al., 2016; Kamble et al., 2018). Several technologies of industry 4.0 capable of revolutionizing not just the manufacturing facilities, but entire SC have been identified in literature.
Notable among them are highlighted as follows.

4.1.1. Internet of Things (IoT)

The IoT is one of the digital technologies of industry 4.0 capable of disrupting business processes and operations. Firstly used in 1999 by a researcher named "Kevin Ashton" working on how to improve SC performance through the use of "Radio Frequency Identification (RFID)" at the AutoID lab of the MIT-Massachusetts Institute of Technology (Gubbi et al., 2013; Haddud and Khare, 2018); IoT has become a notable technology for digitizing an SC. IoT signifies a progression in technological innovation linking objects and devices over the internet (de-Vass et al., 2018). It is the incorporation of several physical items and objects to ensure inter-communication without human interaction while the data transfer is achieved over a network and via the internet (Haddud and Khare, 2018). An SC adopting IoT in its operations will enable clear visibility of the end-to-end activities whereby the location and attributes of the connected members become available at any point in time (Geerts and O'Leary, 2014; Haddud and Khare, 2018). It also provides unique levels of visibility, agility and adaptability to manage diverse SC challenges (Ben-Daya et al, 2017). IoT facilitates virtualization of an SC thereby allowing buyers to track and trace movement of goods along the SC alongside quality control checks and planning (Verdouw et al., 2013; Ben-Daya et al. 2017).

4.1.2. Cyber-physical systems (CPS)

The CPS is regarded as a system that connects the physical and virtual world. It signifies the "integration of computing" with "physical processes" that are vital elements of "industry 4.0 implementations" (Oztemel and Gursev, 2018). Structurally, CPS has 2 important elements which are the physical network consisting of the objects and components communicating via the internet as well as the virtual environment otherwise known as cyber-network (Hofmann and Rüsch, 2017; Ivanov et al., 2019). With these connections, CPS ensures real time data and information transmission among the elements of physical and the virtual environment thereby allowing a high degree of synchronization, control, transparency and efficiency along the SC members which brings about productivity and performance improvement.

4.1.3. Big Data Analytics (BDA)

As supply chains become more complex, it is expected that the quantity of data generation for analysis and planning will become larger. "Processing chunk of data has been a challenge for production planning and controlling functions" (Babiceanu and Seker 2016; Moeuf et al., 2017). Hence, intelligent techniques need be explored for exploiting large chunk of data in an SC. According to Keogh and Henry (2016) in Haddud and Khare (2018) Big Data "is typically used to refer to computerised analytical systems that interrogate extremely large databases of information in order to identify particular trends and correlations" (Haddud and Khare, 2018).

Ten advantages derivable from implementing Big Data driven SC are identified by Agrahri et al. (2017). These include: "improved visibility across SCs, better quality of service, higher demand forecasting accuracy, improved manufacturing efficiencies, better inventory planning, ease of solving complex distribution network problems, greater SC networks collaboration, improved network responsiveness, ordering process optimization, and efficient planning of delivery route".

4.1.4. Cloud Computing

Supply chain consists of several players from suppliers to focal company, distributor and consumers who are usually at different location. For efficient and real time information and data exchange among the entities regardless of geographical location, cloud computing technology provides a solution. Cloud technology signifies a simple online information and data storage and retrieval platform using web-based applications requiring no installation (Nuñez et al. 2017; Oztemel and Gursev. 2018). It provides planning and operational convenience for the entire SC members thereby improving organizational performance and effectiveness (Haddud and Khare, 2018). That is, concerned members of the SC can access the data and information almost at the same time thereby ensuring prompt operational decision making. It offers an "effective collaboration and efficient data, knowledge and information exchange for solving problems in real time" (Botti et al., 2017; Haddud and Khare, 2018). Since little or no physical assets are needed for operational information storage, it thus reduces operational costs in terms of assets acquisition and maintenance.

4.1.5. Machine – To - Machine (M2M) communication

Machine – To – Machine is regarded as "direct communication" between devices via "wired or wireless channel" (Oztemel and Gursev, 2018). Such communication occurs in a way that a "remote network of machines" passes information to a central server for analysis and would be relayed back into a dedicated system such as computer system. The technology enables organizations institute a wireless communication from the machines to the information centres for processing (Oztemel and Gursev, 2018). When signals capable of causing emergency halt in operation arise on one machine along the line, the information centre is able to notify the necessary personnel so that real-time remedial actions are taken. This prevents unnecessary downtimes thereby improving organizational performance outcomes.

4.1.6. Virtual Reality (VR) and Augmented Reality (AR)

"Augmented (AR)" and "Virtual Reality (VR)" technologies are becoming popular in modern day manufacturing processes (Moeuf et al., 2017). They are "useful for simulating an environment comprising simulated and real objects that can be used to enhance the design and manufacturing processes" (Lee et al., 2011; Moeuf et al., 2017). AR and VR based systems can enable a variety of services to the organizations. For instance, "AR could serve as potential tool to prepare and assist procurement team visitation to suppliers" (Ivanov et al., 2019). In production, AR could be used to display operating instructions in sequential order of assembly processes. It can also aid maintenance activities whereby service personnel gets instructions of sequential tasks to perform on defective component (Kamblea et al., 2018; Ivanov et al., 2019). It can also be used in locating spare parts in a warehouse (Kamblea et al., 2018).

4.1.7. 3D Printing and Additive Manufacturing (AM)

Unlike traditional machining processes such as drilling, milling, cutting etc. that rely on material removal, "3-D printing" involves "additive manufacturing process" in which products are formed by "building successive layers" of materials thereby avoiding any need for components and parts assembly (Kamblea et al., 2018). According to Ivanov et al. (2019), the major application of AM to SCM is the "applicability of 3-D printers at different stages along the SC in order to increase manufacturing flexibility, proffer shorter lead times, reduction in inventory and increase product customization". These benefits will improve the performance of and competitiveness of an SC.

Other technologies capable of transforming SCs include Robotics system useful in the production facilities and warehousing; Cyber security to protect against cyber attacks and data thefts as well as Drones or Unmanned Aerial Vehicles for component transfer and delivery processes.

5.0. Lean and Agile SC in the Industry 4.0 – Conceptual model

Industry 4.0, otherwise known as "the fourth industrial revolution", signifies a new paradigm that applies "advanced information and communication systems" with high technology. The technologies can assist SC to become more adaptive network thereby creating new opportunities for competitiveness of the SC. It no doubt presents new possibilities to disrupt the traditional approach of managing supply chain. SC paradigms like Lean and Agile can be enabled for SC performance improvement through the "technologies of Industry 4.0". Integrated Lean and Agile SC approach eliminate "non-value adding activities" as well as making SC robust and responsive to erratic market behavior. This no doubt improves organizational competitiveness and performance.
Individual studies have been carried out on various technologies of industry 4.0 and usually their applicability to manufacturing/production operations and strategies (e.g. Kolberg and Zühlke, 2015; Sanders et al., 2016; Wagner et al., 2017; Hofmann and Rüsch, 2017; Tortorella and Fettermann, 2017 etc.). However, the potential of the technology to drive supply chain strategies is still rarely explored. As stated earlier, this paper aims at contributing to the body of knowledge by identifying potential industry 4.0 technologies that could enable lean and agile SC strategies.

Sequel to the brief highlights on the various technologies of industry 4.0 in the preceding section, the various practices of lean and agile SC strategies are firstly presented after which the conceptual model linking the industry 4.0 technologies with lean and agile practices are proposed.
The various practices/principles of lean and agile SC are presented in table 1 as follows.

Table 1: Practices of Lean and Agile SC strategies

SC Strategy	Code	Practices / Principles	Literature Sources
LEAN STRATEGY	LP 1	Just – in – Time delivery: Delivery of items just at the time of need.	Anand & Kodali, 2008; Azevedo et al., 2012; Sanders et al., 2016; Tortorella and Fettermann, 2017; Lotfi and Saghiri, 2017.
	LP 2	Supplier feedback and relationship	Anand & Kodali, 2008; Sanders et al., 2016; Tortorella and Fettermann, 2017.
	LP 3	Customers Involvement in operational decisions	Anand & Kodali, 2008; Sanders et al., 2016; Tortorella and Fettermann, 2017.
	LP 4	Pull flow / production	Shah and Ward, 2003; Anand & Kodali, 2008; Sanders et al., 2016; Wagner et al. et al, 2017.
	LP 5	Inventory (Material, in-process and finished goods) minimization	Carvalho et al., 2011.
	LP 6	Total productive/preventive maintenance	Sanders et al., 2016; Tortorella and Fettermann, 2017; Lotfi and Saghiri, 2017.
	LP 7	Setup time reduction	Sanders et al., 2016; Tortorella and Fettermann, 2017
	LP 8	Lead time / Takt time reduction	Carvalho et al., 2011; Wagner et al., 2017.
	LP 9	Employee involvement / People and team work	Sanders et al., 2016; Wagner et al, 2017; Tortorella and Fettermann, 2017;
	LP 10	Statistical Process Control / Total Quality Management (TQM)	Shah & Ward, 2003; Sanders et al., 2016; Lotfi and Saghiri, 2017.
	LP 11	Standardisation of work procedures	Anand & Kodali, 2008; Wagner et al., 2017;
AGILE STRATEGY	AP 1	Centralized and collaborative planning	Agarwal, et al., 2007.
	AP 2	Increase frequency of new product development / introduction	Agarwal, et al., 2007; Lotfi and Saghiri, 2017.
	AP 3	speed in improving customer service / response to customer needs	Agarwal, et al., 2007; Swafford, et al., 2008; Carvalho et al., 2011; Lotfi and Saghiri, 2017
	AP 4	Use of IT in coordinating / integrating design and development activities	Agarwal, et al., 2007
	AP 5	Use of IT to coordinate/integrate Manufacturing / company activities	Agarwal, et al., 2007; Swafford, et al., 2008; Lotfi and Saghiri, 2017.
	AP 6	Supplier's flexibility / ability to change delivery time of supplier's order	Swafford, et al., 2008; Carvalho et al., 2011.
	AP 7	Use of IT to coordinate/integrate procurement activities	Swafford, et al., 2008
	AP 8	To accommodate changes in production mix / Flexible equipment to produce different products / accommodate changes in production mix	Swafford, et al., 2008; Lotfi and Saghiri, 2017
	AP 9	Increasing level of product customization	Swafford, et al., 2008;

5.1. The conceptual model

Firstly, we present a framework of industry 4.0 technologies enabling lean and agile SC strategies for improved performance in figure 1. The framework shows the inter-relationship between industry 4.0 technologies, lean and agile strategies together with organizational performance. For clarity and neatness of the conceptual model, the specific matching of industry 4.0 technologies with lean and agile practices was first presented in a "relationship matrix" shown in table 2. Subsequently, the matrix was transformed into a "conceptual model" as shown in figure 2.

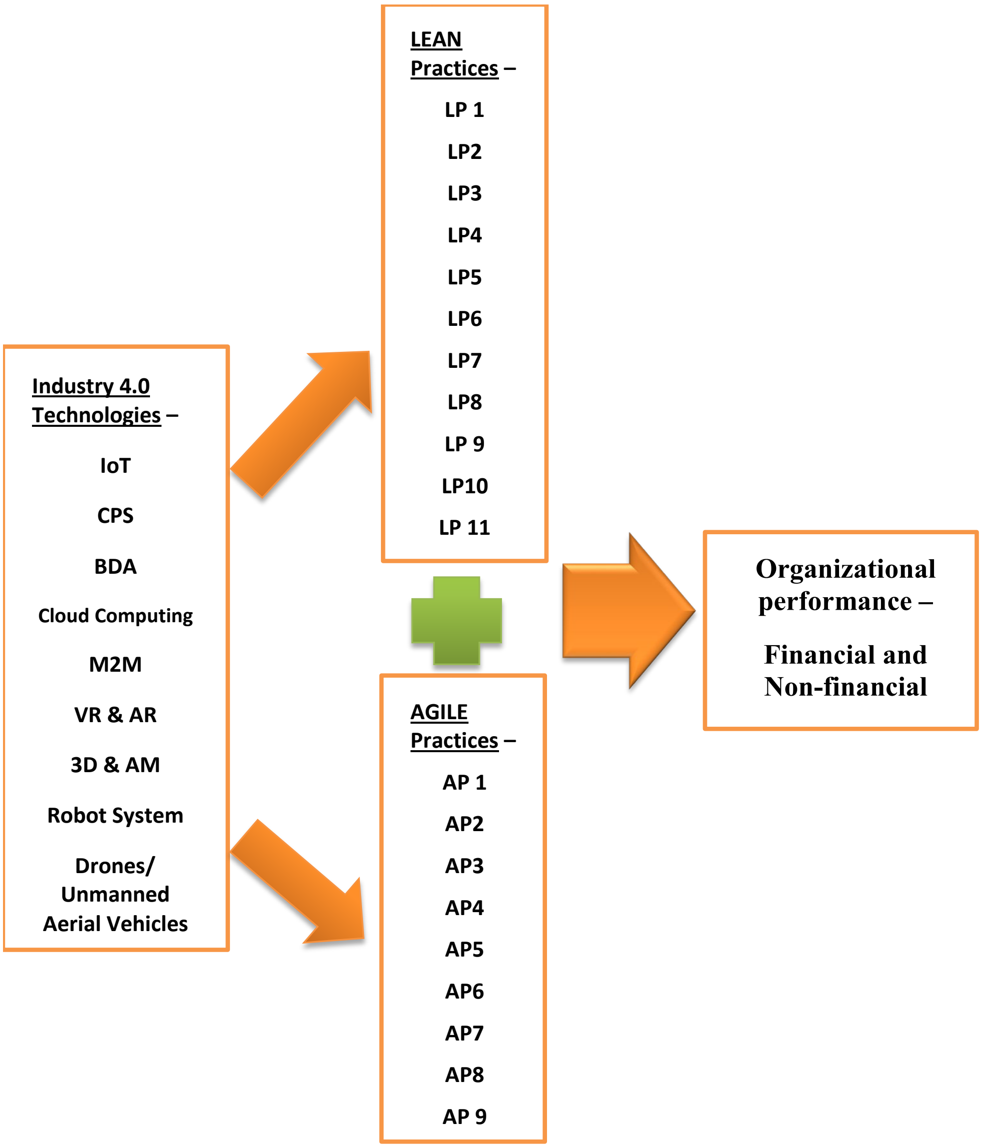

Figure1: Framework

Table 2 and figure 2 show the specific matching of the technologies with the practices of lean and agile strategies. The matching was anecdotally done from literature and subsequent research is geared towards empirical validation using case study research on some supply chains that have been implementing some of the technologies.

Table 2: Relationship matrix

S/N	Technology (i)	Lean strategy enabled by technology i	Agile strategy enabled by technology i
1	**IoT**	LP1; LP2; LP3; LP5; LP6; LP9; LP10	AP1; AP3; AP4; AP5; AP6; AP7;
2	**CPS**	LP1; LP2; LP3; LP4; LP6; LP10; LP11	AP1; AP3; AP4; AP5; AP6; AP7
3	**BDA**	LP1; LP2; LP3; LP5; LP6; LP10; LP11	AP1; AP3; AP4; AP5; AP7;
4	**Cloud Computing**	LP1; LP2; LP3; LP4; LP6; LP10; LP11	AP1; AP3; AP4; AP5; AP6; AP7
5	**M2M**	LP1; LP4; LP6; L8	AP2; AP5; AP8
6	**VR & AR**	LP2; LP4; LP6; L9; LP11	AP2; AP5; AP7
7	**3D & AM**	LP1; LP4; LP7; L8; LP11	AP2; AP3; AP5; AP8; AP9
8	**Robot System**	LP1; LP4; LP5; LP7; LP11	AP2; AP5; AP8; AP9
9	**Drones/ Unmanned Aerial Vehicles**	LP1; LP4; LP5; LP8	AP2; AP3; AP5

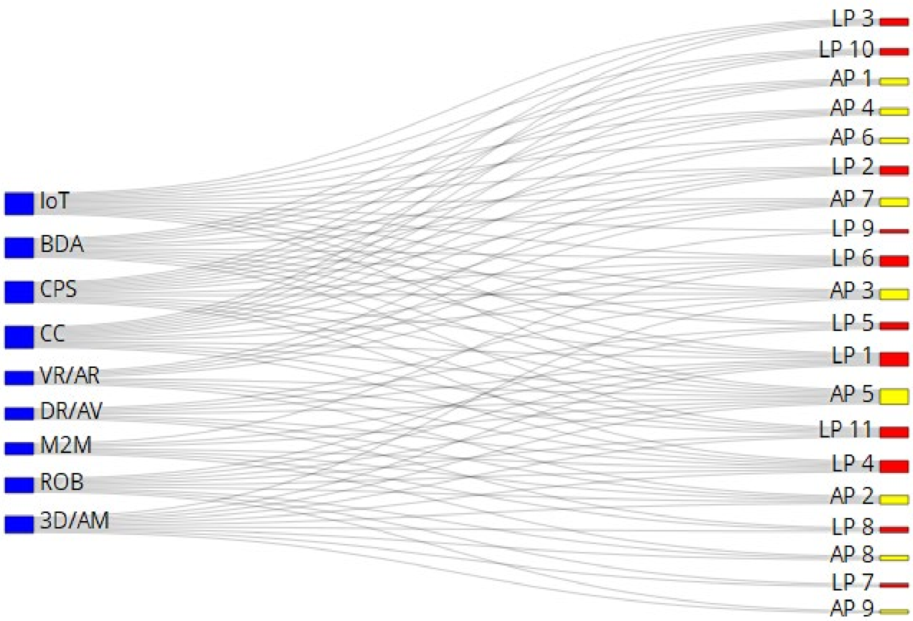

Figure 2: Proposed Conceptual model

IoT is capable of driving JIT practice of lean as well as centralised and collaborative planning practice of agile strategy. Other practices that could be enabled by IoT are as shown in the table and model. Corresponding practices enabled by each of the other technologies are as depicted in the table and model.

6.0. Conclusion

The continuous global competition is compelling companies to expand and connect their "internal improvement processes" with "external customers and suppliers". Success in this phase of competition requires careful adoption of SC strategies alongside innovative capabilities such as Industry 4.0 technologies to enable such SC strategies. Lean and agile are critical strategies whose integration has been proven to ensure efficient use of resources and prompt response to dynamic market environment.
With performance improvement in mind, several studies have considered integration of different strategies/paradigms and their associated impact on SC. However, few have considered how Industry 4.0 technologies could enable these SC strategies for improved organizational performance. This study thus presents a conceptual model that matches diverse practices of Lean and Agile SC with industry 4.0 pillars (as drivers) for overall performance improvement. To achieve the aim, an overview of the relevant industry 4.0 technologies as well as practices of lean and agile strategies is first presented. Subsequently, a conceptual model is developed by specifically linking the principles/practices of lean and agile with industry 4.0 technologies as enablers.

Asides contributing to theory, this work has managerial implications as the identified practices of lean and agile SC can support practitioners to identify practices to adopt in line with organizational goals. Also, the conceptual model provides a "decision supporting tool" to "identify" potential industry 4.0 technologies in the context of lean-agile SC by way of motivating them on specific pillars of industry 4.0 to adopt for specific lean-agile strategies in achieving overall organizational goals.

Theoretically, the work provokes some future research agenda. As it is practically infeasible for companies to implement all the industry 4.0 technologies, it is important to categorize the technologies in order to prioritize which is more important for the most critical lean and agile practices being deployed in the company. Also, the proposed model which is anecdotally based on literature provokes development of empirical research studies and/or case studies to explore and validate the linkage depicted in the model.

References

Agarwal, A., Shankar, R. and Tiwari, M.K. Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach, *European Journal of Operational Research,* Vol. 173, No. 1, pp.211-225, 2007.

Agrahri, H., Ahmed, F., Verma, V.K. and Purohit, J.K. Benefits of Implement Big Data Driven Supply Chain Management: An ISM Based Model. *International Journal of Engineering Science*, Vol. 7, No. 5, pp. 11426 – 11431, 2017.

Alfalla-Luque, R., Medina-Lopez, C., & Dey, P. K. Supply chain integration framework using literature review. *Production Planning & Control*, Vol. 24, No. 8-9, pp. 800-817, 2013.

Anand, G., and Kodali, R. A conceptual framework for lean supply chain and its implementation. *International Journal of Value Chain Management,* Vol. 2, No. 3, pp. 313-357, 2008.

Ataseven, C., and Nair, A. Assessment of supply chain integration and performance relationships: A meta-analytic investigation of the literature. *International Journal of Production Economics*, Vol. 185, pp. 252-265, 2017.

Azevedo, S.G; Carvalho, H and Cruz-Machado, V. LARG index: A benchmarking tool for improving the leanness, agility, resilience and greenness of the automotive supply chain, *Benchmarking: An International Journal,* Vol. 23, No. 6, pp. 1472-1499, 2016.

Babiceanu, R. F., and R. Seker. Big Data and Virtualization for Manufacturing Cyber-Physical Systems: A Survey of the Current Status and Future Outlook." *Computers in Industry*, Vol. 81, pp. 128–137, 2016.

Bahrin, M.A.K., Othman, M.F., Azli, N.H.N., Talib, M.F. Industry 4.0: a review on industrial automation and robotic. *Jurnal Teknologi*, Vol. 78, pp. 6–13, 2016.

Bidet-Mayer, T. Industrie du futur: une compétition mondiale [Industry of the Future: A Global Competition]. Paris: Presses des MINES, 2016.

Botti, A., Monda, A., Pellicano, M. and Torre, C. The Re-Conceptualization of the Port Supply Chain as a Smart Port Service System: The Case of the Port of Salerno. *Systems*, Vol. 5, No. 2, pp. 2-10, 2017.

Buer, S.-V., Strandhagen, J. O. and Chan, F. T. S. The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda*. International Journal of Production Research,* Vol. 56, No. 8, pp. 2924–2940, 2018.

Carvalho, H and Cruz-Machado, V. Integrating Lean, Agile, Resilience and Green Paradigms in Supply Chain Management (LARG_SCM), in: Li, P. (Ed.), *Supply Chain Management*. InTech, pp. 27–48, 2011.

Carvalho, H.; Duarte, S and Cruz Machado, V. Lean, agile, resilient and green: divergencies and synergies, *International Journal of Lean Six Sigma*, Vol. 2, pp. 151–179, 2011.

Christopher, M; Peck, H and Towill, D. A taxonomy for selecting global supply chain strategies, *The International Journal of Logistics Management*, Vol. 17, No. 2, pp. 277-287, 2006.

Cudney, E. and Elrod, C. Incorporating lean concepts into supply chain management. *International Journal of Six Sigma Competitive Advantage*, Vol. 6 No 1/2, pp. 12-30, 2010.

de-Vass, T; Shee, H and Miah, S. The effect of "Internet of Things" on supply chain integration and performance: An organisational capability perspective. *Australasian Journal of Information Systems*, Vol 22, pp. 1 – 29, 2018.

Drath, R., and A. Horch. 2014. Industrie 4.0: Hit or Hype?. *IEEE Industrial Electronics Magazine,* Vol. 8, No. 2, pp. 56–58, 2014.

Duarte, S and Cruz-Machado, V. An investigation of lean and green supply chain in the Industry 4.0, *Proceedings of the 2017 International conference on Industrial Engineering and Operations Management* (IEOM), Bristol, UK, pp. 255-265, July 2017.

Duarte, S and Cruz-Machado, V. Exploring Linkages Between Lean and Green Supply Chain and the Industry 4.0, *Proceedings of the Eleventh International Conference on Management Science and Engineering Management,*Kanazawa, Japan, pp. 1242 – 1252, July – August 2018.

Geerts, G.L. and O'Leary, D.E. A supply chain of things: The EAGLET ontology for highly visible supply chains. *Decision Support Systems*, Vol. 63, No. 1, pp. 3–22, 2014.

Ghobakhloo, M., and Azar, A. Business Excellence via Advanced Manufacturing Technology and Lean-Agile Manufacturing, *Journal of Manufacturing Technology Management,* Vol. 29, No. 1, pp.2-24, 2018.

Goldsby TJ, Griffis SE, and Roath AS. Modeling lean, agile, and leagile supply chain strategies. *Journal of Business Logistics*, Vol. 27, No. 1, pp. 57–80, 2006.

Govindan, K; Azevedo, S.G; Carvalho, H. and Cruz-Machado, V. Lean, green and resilient practices influence on supply chain performance: interpretive structural modeling approach, *International Journal of Environmental Science and Technology*, Vol. 12, pp. 15–34, 2015.

GTAI (Germany Trade & Invest), Industry 4.0 – Smart Manufacturing for the future. Germany Trade and Invest, Berlim, Germany, 2014.

Haddud, A. and Khare, A. The Impact of Digitizing Supply Chains on Lean Operations', *Marktorientiertes Produkt- und Produktions management in digitalen Umwelten*, pp.27-46, 2018, doi: 10.1007/978-3-658-21637-5_3.

Harrison, A. From leanness to agility. *Manufacturing Engineer,* Vol. 76, No. 6, pp.257-60, 1997.
Hofmann, E and Rüsch, M. Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, Vol. 89, pp. 23–34, 2017.
Hormozi, A.M. Agile manufacturing: the next logical step. *Benchmarking: An International Journal,* Vol. 8, No. 2, pp.132-143, 2001.
Huo, B. The impact of supply chain integration on company performance: an organizational capability perspective. *Supply Chain Management: An International Journal*, Vol. 17, No. 6, pp. 596-610, 2012.
Ivanov D.; Tsipoulanidis A. and Schönberger J. Digital Supply Chain, Smart Operations and Industry 4.0. In: Global Supply Chain and Operations Management. Springer Texts in Business and Economics. Springer, pp. 481 – 526, 2019.
Jasti, N.V. K. and Kodali, R. A critical review of lean supply chain management frameworks: proposed framework. *Production Planning and Control*, Vol. 26, No. 13, pp. 1 – 18, 2015.
Kagermann H and Helbig J. Recommendations for implementing the strategic initiative INDUSTRIE 4.0 (2013),http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf
Kagermann, H., Helbig, J., Hellinger, A., & Wahlster, W. Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry*; Final Report of the Industrie 4.0 Working Group*. Forschungsunion, 2013.
Kainuma, Y. and Tawara, N., A multiple attribute utility theory approach to lean and green supply chain management, *International Journal of Production Economics*, vol.101, no.1, pp. 99-108, 2006.
Kamble, S., Gunasekaran, A. and Gawankar, S. Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives. *Process Safety and Environmental Protection*, 117, pp.408-425, 2018.
Krishnamurthy, R., and. Yauch, C.A. Leagile manufacturing: A proposed corporate infrastructure. *International Journal of Operations and Production Management,* Vol. 27, No. 6, pp.588-604, 2007.
Lee, J., S. Han, and J. Yang. Construction of a Computer-Simulated Mixed Reality Environment for Virtual Factory Layout Planning. *Computers in Industry* Vol. 62, pp. 86–98, 2011.
Lin C, Chiu H and Chu P, Agility index in the supply chain. *International Journal of Production Economics*, Vol. 100, No. 2, pp. 285–299, 2006.
Lotfi, M and Saghiri, S. Disentangling resilience, agility and leanness Conceptual development and empirical analysis", *Journal of Manufacturing Technology Management* Vol. 29, No. 1, pp. 168-197, 2018.
Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S. and Barbaray, R. The industrial management of SMEs in the era of Industry 4.0*. International Journal of Production Research,* Vol, 56, No. 3, pp. 1118–1136, 2017.
Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. *The industrial management of SMEs in the era of Industry 4.0. International Journal of Production Research, 56(3), 1118–1136,* 2017.
Mrugalska, B and Wyrwicka, M.K. Towards Lean Production in Industry 4.0*. Procedia Engineering* 182, pp. 466 – 473, 2017.
Naylor, J.B., Naim, M.M. and Berry, D. Leagility: integrating the lean and agile manufacturing paradigms in the total supply chain, *International Journal of Production Economics,* Vol. 62, No. 1, pp.107-118, 1999.
Nuñez, D., Fernández, G., & Luna, J. Cloud system. *Procedia Computer Engineering, Vol. 62, pp.* 149–164, 2017.
Ohno, T. Toyota Production Systems: Beyond Large Scale Production, Productivity Press, New York, 1988.
Organization for Economic Co-operation and Development (OECD) (2016). Enabling the next production revolution: the future of manufacturing and services - Interim report, available at: https://www.oecd.org/mcm/documents/Enabling-the-next-production-revolution-the-future-of-manufacturing-and-services-interim-report.pdf
Pfohl, H-C; Yahsi, B and Kurnaz, T. The Impact of Industry 4.0 on the Supply Chain. *Proceedings of the Hamburg International Conference of Logistics* (HICL) – 20, pp. 31 – 58, 2015, doi: 10.13140/RG.2.1.4906.2484.
Purvis, L., Gosling, J. and Naim, M.M. The development of a lean, agile and leagile supply network taxonomy based on differing types of flexibility. *International Journal of Production Economics,* Vol. 151, pp.100-111, 2014.
Richards, C.W. Agile manufacturing: Beyond lean?' *Production and Inventory Management Journal,* Vol. 37, No. 2, pp.60-64, 1996.
Ruiz-Benítez, R.; López, C. and Real, J. The lean and resilient management of the supply chain and its impact on performance. *International Journal of Production Economics*, 203, pp.190-202, 2018.
Sanders, A; Elangeswaran, C. and Wulfsberg, J. Industry 4.0 Implies Lean Manufacturing: Research Activities in Industry 4.0 Function as Enablers for Lean Manufacturing. *Journal of Industrial Engineering and Management (JIEM*), Vol. 9, No. 3, pp. 811-833, 2016.

Shah, R. and Ward, P. Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management*, Vol. 21 No. 2, pp. 129-149, 2003.
Soltan, H., and Mostafa, S. Lean and Agile Performance Framework for Manufacturing Enterprises. *Procedia Manufacturing,* Vol. 2, pp.476-484, 2015.
Stankevice, I., Vilkas, M. and Duobiene, J. Aligning innovation practices with trajectories of development of leanness and agility capabilities. *Proceedings of the European Conference on Innovation and Entrepreneurship* -ECIE, Portugal, pp.798-805, 2018.
Strozzi, F., Colicchia, C., Creazza, A. and Noe, C. Literature review on the 'Smart Factory' concept using bibliometric tools. *International Journal of Production Research,* Vol. 55, No. 22, pp.6572–6591, 2017.
Swafford P.M, Ghosh, S, and Murthy, N. Achieving supply chain agility through IT integration and flexibility. *International Journal of Production Economics*, Vol. 116, No. 2, pp. 288–297, 2008.
Swafford, P., Ghosh, S. and Murthy, N. The antecedents of supply chain agility of a firm: scale development and model testing, Journal of Operations Management, Vol. 24 No. 2, pp. 170-188, 2006.
Tortorella, G. L. and Fettermann, D. Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies. *International Journal of Production Research*, Vol. 56, No. 8, pp. 2975–2987, 2017.
Tortorella, G., Miorando, R. and Marodin, G. Lean supply chain management: Empirical research on practices, contexts and performance. *International Journal of Production Economics*, Vol. 193, pp. 98-112, 2017.
Verdouw, C. N., A. J. M. Beulens, and J. G. A. J. van der Vorst. "Virtualisation of Floricultural Supply Chains: A Review from an Internet of Things Perspective." Computers and Electronics in Agriculture, Vol. 99, pp. 160–175, 2013.
Vitasek, K., Manrodt, K. and Abbott, J. "What makes a lean supply chain." *Supply Chain Management Review*, Vol. 9 No. 7, pp. 39-45, 2005.
Wagner, T; Herrmann, C and Thiede, S. Industry 4.0 Impacts on lean Production systems. *Procedia CIRP*, Vol. 63, pp.125-131, 2017.
Wang, S., Wan, J., Li, D., Zhang, C. Implementing smart factory of industrie 4.0: an outlook. International Journal of Distrib. Sens. Netw. Vol., 12, No. 1, 2016.
Wang, S.Y., Wan, J.F., Zhang, D.Q., Li, D., Zhang, C.H. Towards smart factory for Industry 4.0: a self-organized multi-agent system with big data based feedback and coordination. Comput. Network., 2015.
Yu, W. The effect of IT-enabled supply chain integration on performance. *Production Planning & Control*, Vol. 26, No. 12, pp. 945-957, 2015.

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