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How will Smart City Production Systems Transform Supply Chain Design: a Product-level investigation

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Keywords: Supply Chain Design, Smart City, Production System, Manufacturing Systems, Case Study

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This paper is a first step to understand the role that a smart city with a distributed production system could have in changing the nature and form of supply chain design. Since the end of the Second World War most supply chain systems for manufactured products have been based on "scale economies" and "bigness"; in our paper we challenge this traditional view. Our fundamental research question is: how could a smart city production system change supply chain design? In answering this question we develop an integrative framework for understanding the interplay between smart city technological initiatives (big data analytics, the industrial internet of things) and distributed manufacturing on supply chain design. This framework illustrates synergies between manufacturing and integrative technologies within the smart city context and links with supply chain design. Considering that smart cities are based on the collaboration between firms, end-users and local stakeholders, we advance the present knowledge on production systems through case study findings at the product level. In the conclusion, we stress there is a need for future research to empirically develop our work further and measure (beyond the product level), the extent to which new production technologies such as distributed manufacturing, are indeed democratizing supply chain design and transforming manufacturing from "global production" to a future "city-oriented" social materiality.

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1. **Introduction**

With the onset of the decline of the British Empire from 1945 onwards and the independence of India, the U.S. through its multi-national firms such as GM and Ford set the dominant global "hegemony" of supply chain capitalism. This "dialectic" was based on "bigness" and the internationalisation of factors of manufacturing production[1]. Since the 1980s, this trend for "*bigness*" led to a boom in production "outsourcing" and

[1] A sociological discussion of Hagel's work on "hegemony" and the "dialectic" can be found in the social theory work of Anthony King (2004).

the dramatic shift in the modes of production from the West to East. By outsourcing we refer to the practice used by different companies to reduce costs by transferring portions of work to outside suppliers rather than completing it internally. A trend that accelerated (from 1978 to 2013) with the unprecedented growth of the Chinese economy.

The organizing "materiality"[2] of people, technology, organisations and institutions ("modes of production") in the global manufacturing sector (Leonardi, 2012) came to be that of "JIT" logistics. JIT logistics expanded rapidly as organisations and people in the manufacturing sector increasingly organized themselves to work in high speed environments, focusing on the international movement of goods (through high-technology port spaces, innovations in containers, freight handling, and the expansion of port capacity). For Cowen (2010), JIT logistics was successful because it facilitated very low transaction costs (Williamson, 1981). The result is that production systems now operate far from points of consumption.

A "smart city production system" includes distributed manufacturing, logistics and spatial dispersed units, which cooperate and communicate over processes and networks in order to achieve the optimum manufacturing output (per day) to meet city demand (Kuehnle, 2010). It is subject to principles and modes of complex structures which differ to scale based production systems. However, its impact on manufacturing supply chains are not well understood, thus this this paper aims to address the research question - how could a smart city production system change the nature and form of supply chain design in the manufacturing sector?

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[2] Materiality is defined as the mutually constitutive relationship between people and their material modes of production (Leonardi, 2012).

Our paper is structured as follows: First, we provide a brief literature review on production systems, smart cities, big data (analytics), the Industrial Internet of Things (IIoT), distributed manufacturing and supply chain management. Then, we propose an integrative framework which analyses the interplay of smart city production systems with supply chain design. Lastly, we discuss implications of the study and potential lines of future research related to this issue.

2. Production systems

In attempting to classify the common types of production system, Krafcik (1988) in Figure 1 presents two types of production system – "buffered" and "lean". The production systems of most Western producers throughout most of the post war period were buffered against virtually everything. Inventory and stock levels were high and the production systems frequently had problems of over-capacity. A Fordist production system usually expanded through vertical (moving upstream or downstream the supply chain) or horizontal (acquiring competitors) integration. The core resources of Fordism are physical assets such as plants and machine tools which represented a large share of the total capital investments. The value (supply) chains tend to be discontinuous, implying that a large amount of parts and finished goods are held in inventory to deal with longer production cycle times (lead times) and difficulties to distribute the manufactured products. Other production systems, exemplified by Toyota achieved lean operations. Inventory levels are kept at an absolute minimum so costs could be saved and quality problems quickly detected and solved, bufferless assembly lines assured continuous flow production.

Kuhnle (2010) suggests that smart city manufacturing is an emerging trend that on the one hand, while it provides a minimum waste solution to that of the JIT system based on speed, its supply chain will operate on much lower scale volumes and be configured by actual city demand. This type of production system is characterized by low production runs, and focused solely on supplying products which consumers actually demand. They are designed to be flexible and agile to rapidly changing city demand patterns with “dissolvable” supply chains, once the consumer demand has been met. In the next section we conceptually construct the smart city manufacturing framework.

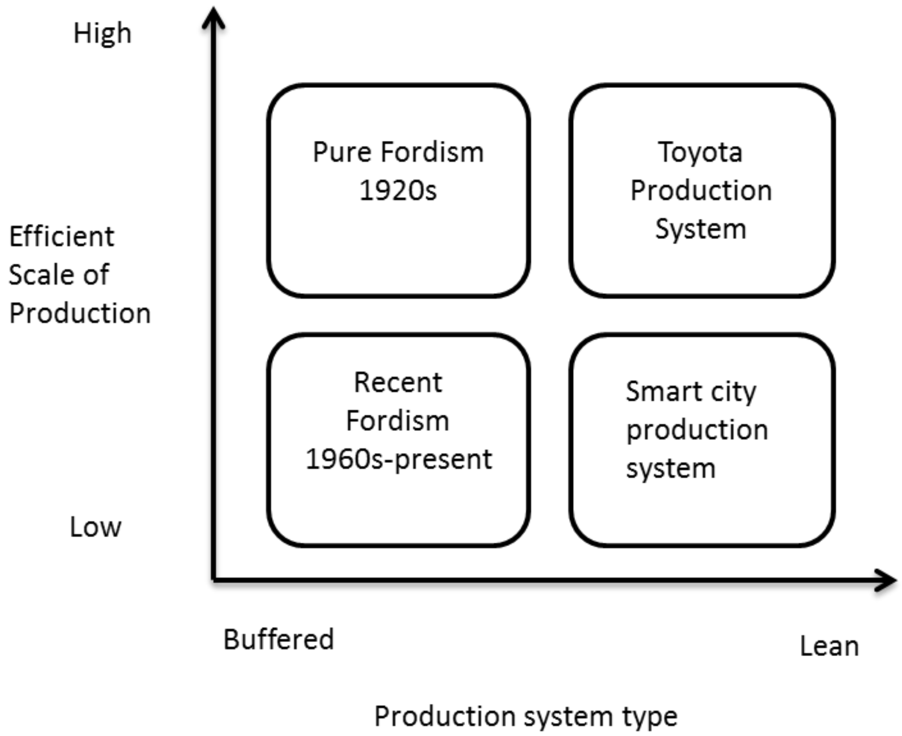

Figure 1: categorisation of production systems

3. Smart City Manufacturing Framework

3.1 Smart Cities

The smart city idea links to some various development phenomena in today’s society: the technological evolution that enables local manufacturing through 3D-printing and similar; the increased pressure for sustainable solutions and decreased emission; and also the urbanisation of people. Katz and Bradley (2013) refer to the beginnings of a “Metropolitan Revolution” which will increase “social pressure” from different stakeholders and institutions (civic authorities, councils, public bodies) for firms to create more sustainable solutions. The scale and speed of urbanisation has meant that many cities have grown beyond their historic boundaries, and have sprawled to form larger metropolitan areas. Furthermore, the advent of information and communication technologies (ICT), such as the internet, has meant that a whole range of everyday transactions have a virtual component leaving behind a trail of information that scholars have coined as "Big Data" (Wamba et al., 2015, p. 234)

3.1.1 Big Data

Big data has the potential to revolutionize the art of supply chain design, nevertheless, there is a paucity of empirical research to assess its potential. The concept of "big data" can be defined as large pools of unstructured data that can be captured, stored, managed and analysed (Manyika, 2011). Big data per se cannot be useful if it is not complemented by process of examination and assessment. In this study, we posit the existence of synergies between smart cities and big data. Indeed, smart cities will provide firms with necessary infra-structure to leverage big data, governance mechanisms to support multi-stakeholder collaboration, IT infrastructure to disseminate it (e.g. wireless urban sensors, public wi-fi) and the potential workers with the necessary skills.

Big data analytics (BDA) is the process of examining large amounts of unstructured data to uncover hidden patterns, unknown correlations and other useful information (Rouse, 2012). Furthermore, BDA is being used in the modelling and analysis of (urban) transport and distribution systems through large data sets created by GPS, cell phone and transactional data of company operations, combined with human generated activity (e.g. social media, public transport) (Blanco & Franco, 2013).

3.2 Industrial Internet of Things

The basic idea of the "industrial internet of things" (IIoT) is to connect devices and things to build communication between device, sensor and other physical objects. Sam Sheard (2013, p. 1) describes the change over the last century in the following way: "The first industrial revolution began in the 18^{th} century when the power of the steam engine was harnessed and manufacturing first became mechanized. The second industrial revolution came about when mass production techniques were deployed in the early 20^{th} century. And the third came over the next few decades as electronic systems and computer technology helped to further automation."

It is the full potential that IIoT brings to the factories that will be deployed when smart devices, smart systems, and smart automation entirely merge with the physical machines, service, fleets and networks by the implementation of cyber-physical production systems (Hessman, 2013). IIoT is a cross cutting topic that is relevant for several areas of the organisation. Many business functions linked to manufacturing are structured into functional silos, IIoT platforms could link essential information by integrated systems and processes (McKinsey Report, 2015). An IIoT platform offers a seamlessly integration of several components. Partners of the connected world build strong partnerships by implementing their services and products for efficient and quick cooperation. The main components of the IIoT platform are the physical things. By linking devices sensors, networks and actuators it provides multiple new opportunities (Behmann and Wu, 2015)

3.3 Additive manufacturing

3D printing began with the use of polymer and over the years other materials such as bio, metals, and even the production of chocolate have been gaining momentum as the technology improves (Petrick & Simpson, 2013; Prince, 2014). It has been described in many ways as being revolutionary (Goulding, Bonafe and Savell, 2013), magical (Massis, 2013) and disruptive (Prince, 2014). 3D printing uses the combination of creativity and software to produce: *"three-dimensional physical objects… based on a digital blueprint"* (Gebler et al., 2014). 3D printing technology ranges from fused deposition modelling (Prince, 2014), developed in the 1980s and which involve layering plastic to create models, to selective laser sintering that uses powdered materials such as aluminium and titanium (Prince, 2014; Goulding et al., 2013).

According to the literature, it is particularly dominant in the medical field as it allows for the customisation of implants, hearing aids, medication (Vorndran et al., 2015) and tissue and bone engineering (Richards et al., 2013). It is currently becoming more popular as the technology matures and awareness grows. Design programs and communities of 3D printing enthusiasts who share knowledge and use open source data, allow for designs to be shared and continuously improved upon. For example, using 3D printing to produce a fully-functioning hand for a girl who was born without one. 3D printing not only has the ability to impact on how products are produced but also how organisations function.

3.4 Supply Chain Design

Supply chains can be defined as: *"a network of connected and interdependent* organisations mutually and co-operatively working together to control, manage and *improve the flow of materials and information from suppliers to end users"* (Christopher, 2011, p. 4). Supply chain management focuses on more than just one aspect of the organisation, from raw materials to end users and suppliers, and can be viewed as consisting of multiple value streams.

3.4.1 The Scale of Production

Modern manufacturing supply chains have been largely based on "*subcontracting", "outsourcing*", and "allied" arrangements in which the autonomy of component enterprises is legally established even as the enterprises are disciplined within the chain as a whole. Cowen provides further support to the notion of the supply chain manager exploiting low cost suppliers: "'If' is no longer the question. Today the undisputed answer to the path to enhanced efficiency, reduced costs, more robust feature sets is outsourcing. Shifting work to third parties, often in different continents, is now a given *for most organizations''* (2010, p. 2). The great corporations once known for their all-inclusive production (for example, General Motors) now outsource most of their parts. As Williamson (1981) indicated the "scale" economies argument is all pervasive as it leads to dramatic reductions in logistic cost structures. As well as lower marginal costs per unit of output, through the setting up of huge production factories in China and the Far East, the rapid lowering of transaction costs through global trade liberalisation and the rise of the Chinese modes of production.

3.4.2 Technology

Technological innovations change future supply chain models and the nature of work (Manyika et al., 2011). The success of technology implementation depends on early involvement, a clear defined strategy and capabilities for digital transformation. The aim should not be to apply the latest technology, but to transform the manufacturing organisation in order to benefit from the technology opportunities (Solis, 2013). According to a research study by Capgemini, digital transformation of manufacturing improves company's corporate and financial performance (Bonnet et al., 2012). Schwartz (1999) is of the view that an enterprise that does not keep up to the technological trends eventually faces "Digital Darwinism". Therefore, the objective for the manufacturing manager is to identify the key capabilities that are required for digitalisation. Adoption of new technologies is driven by benefits and values creation to an organisation. Two main drivers have been identified by DTI (2000) which are still relevant today for applying new technologies:

3.4.3 Network design and Relationships

Choi et al., (2001) define a supply network *as "a network of firms that exist upstream to any one firm in the whole value system"* (p. 352). Kim et al., (2011) suggest that network design is critical to manufacturing supply chain management. By network design he is referring to the: "pattern of relationships within the network, not the geographical distances between supply chain partners". Critical to network design is the density of personal relational ties. Thus, networks epitomise relationship patterns that are based on collaboration and a high degree of trust if they are to function effectively. This parallels the idea of a "sharing economy" (Waller and Fawcett, 2013) involving a high level of information sharing amongst network actors. In a totally dense network, all nodes would need to be connected to each other. According to the network approach to supply chain management, companies (buyers and sellers in the market) are interdependent (Håkansson and Snehota, 1995). This follows from how resources are scarce, but also developed in interaction among parties (Gadde, 2004). Adjustments to single actor' needs follow from how these actors represent substantial revenues, or are based on knowledge expertise or unique resources by the other actor.

Since one company is linked to several other parties, interdependence does not only happen between a buyer and a seller, but in complex patterns of companies: a customer has several suppliers; a supplier another supplier; a customer a collaboration partner, and so forth (Anderson et al., 1994). This all means that a decision taken related to one relationship may have effects also for other relationships, such as in the example of choosing to buy from one supplier (and thereby not from another supplier), or in how the exchange with the first supplier affects also that supplier's suppliers and decisions vis-á-vis the supplier's other customers. This is the network of relationships; interconnected relationships and their impact on one another (e.g. Smith and Laage-Hellman, 1992).

The interconnectivity among actors and their relationships does not only mean that business decisions result in more or less buying or selling for other actors. It also means that companies may react in unforeseeable ways to decisions taken (Havila and Salmi, 2000), and in how different exchanges and decisions occur in parallel: the context (represented by the other actors) is constantly changing.

3.4.4 Processes

The manufacturing transformation process consists of several elements, which have to be connected in order to operate appropriately (Feldman and Pentland, 2003). To support it, the manufacturing company should integrate major management disciplines such as: risk management; change management; knowledge management and; project and program management with their production processes. Digital capabilities take advantages of the integration of supporting elements to make the complexity of digitalisation manageable.

3.4.5 Re-configurability

Re-configurability is the ability to rearrange key *"elements"* of the supply chain network, as an alternative permutation from the current state, to enable improvements in the supply or development (cost, quality, flexibility, dependability, speed) of the product or service (Srai and Gregory, 2008). This is achieved through the following: alternative network structures of supply chain partners; changes to the flow of material and information between unit operations; changes to the role, inter-relationships and governance (responsibilities) of network partners; and/or changes to the value structure or composition of the product or service itself. The aforementioned supply chain network *"elements"* can be defined in terms of three key dimensions:

- The "flow of material and information" between and within key unit operations; value and non-value adding activities, process steps, optimum sequence, levels of flexibility, network dynamics (e.g. replenishment modes), infrastructure, and enabling IT systems.
- The "role, inter-relationships, and governance" between key network partners; the nature of these interactions or transactions, number, complexity, partner roles, governance and trust.
- "Value structure" of the product or service; composition and product-structure (incl. components, sub-assembly, platforms, modules), products supply chain attributes, SKUs, products as spares, and through-life support and services (ibid., p. 390).

The dynamic nature, enabling processes and technologies, and scope of this change process, determines the potential for re-configuration of the supply chain.

4. Integrative framework

In this section, we propose an integrative framework that encompasses the interplay of smart cities with key aspects of supply chain design. The proposed framework fits the main objective of this study, which was to analyse the interplay between smart city manufacturing and logistics with supply chain design. The integrative framework is presented in Figure 2. Starting with the supply network characteristics, Kim et al., (2011), Choi (2001), Hakansson and Snehota (1995) propose four variables that characterize the structure and design of supply networks: scale (i.e. the volume of transaction relations); technology (i.e. the extent of digital transformation of the supply chain); processes (i.e. actor involvement); and relationships (i.e. the number of ties occupied by a network with respect to the total number of ties). With respect to reconfiguration mechanisms, three types were considered material and information flows, actor roles and governance, and value structure. Another key idea behind this framework is the link between smart cities, IoT and additive manufacturing. In this study, we argue that, in order to seize the smart cities opportunities, firms should explore their synergies with IoT and the additive manufacturing concept.

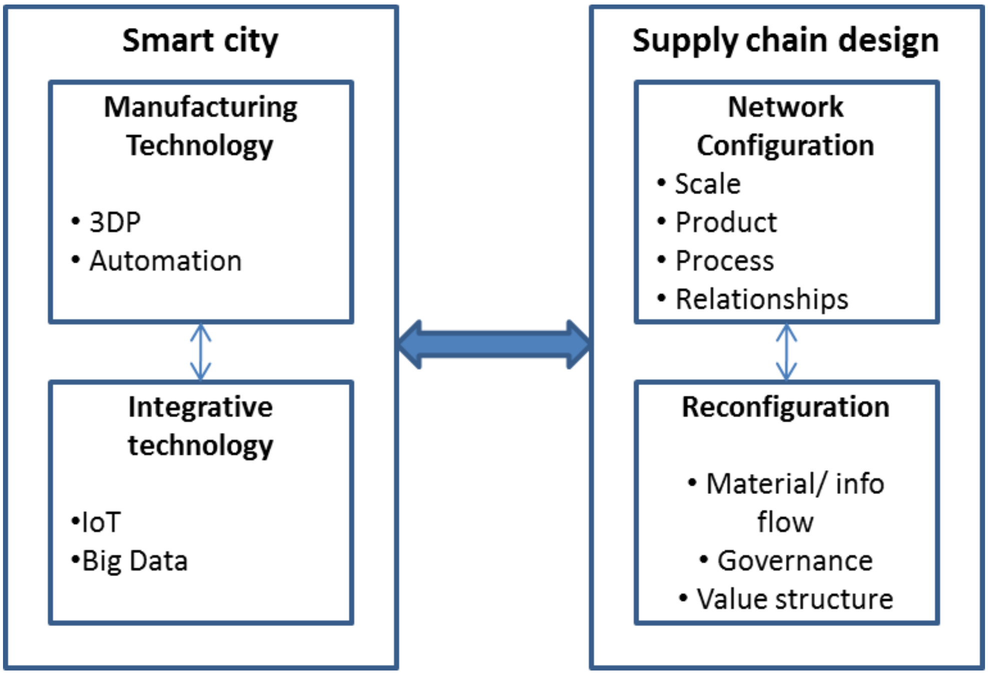

Figure 2: Integrated Framework for Smart City Production System

4. Research method

This research tries to understand how a smart city production system can change future supply chain design. Hence a case study approach focusing on five products scoped around the theoretical framework was adopted. The case study design involved comparison between two different production system – redistributed manufacturing and traditional production system. In order to maximize the ability to draw conclusions and external validity, multiple case study approach are recommended (Eisenhardt, 1989). To incorporate replication logic, this research employed a multiple case study method to gather data. A semi-structured interview tool was designed to gain holistic and rigorous insights. Repeated visits (ranging from 2-3 days) were conducted to discuss additional criteria and ask the same question to different available informants in the company to be able to do data triangulation. Depending on the informant and the area of discussion, each interview lasted between 2– 4 hours.

The data analysis was structured around key concepts derived from the literature – smart cities and supply chain design variables. Adopting Miles & Huberman's (1984) recommendations, initially a with-in case analysis was conducted to identify the different sets of operational practices. Later, a cross-case analysis was adopted to identify similar or differentiating patterns in the data acquired. While the within case analysis identified the unique capabilities of the company's practices, cross case analysis brought about generalisations in the results. A short case description for each product is presented below

Product 1

Product 1 studies the integration of 3DP and virtual/ digital design in the manufacturing of prototype products by a multi-national retailer. Specifically, we focus on the design process involved in the development of new products, in this case, shoes. Previously, when designing a new shoe the customer would produce a design specification which would be sent to the manufacturer who would then send the completed design back to the customer. The product would then go back and forth between the partners until a design was approved, due to geographic distance, this process could typically last weeks and in some cases months. We analyse how the introduction of 3DP and virtual design has removed the need to send design changes back and forth, allowing the customer to create a design and make changes digitally with other actors and then print it at their facility.

Product 2

Product 2 involves full automation in the production process of bed sheets by a multi-national retailer who previously sourced bed sheets from a large number of geographically dispersed suppliers using manual production methods. We suggest that automation has led to the reduction in actors and tiers in the network and has reduced complexity. Further, we explore the cost savings achieved by retailer from process and product improvements, supply chain reconfiguration and assess future feasibility for the production of more complex products.

Product 3

Product 3 involves the integration of digital printing technology for garment manufacturing by a multi-national retailer. Previously, the retailer would add designs/graphics to garments via screen printing techniques that had been used in the textile industry for over 50 years. We analyse how the introduction of digital printing technology has reduced the number of actors and tiers within the supply chain and has enabled the retailer to process garments at faster speeds with increased flexibility and customisation in the production process. Further, we explore the current level of integration of digital printing in the retailers supply chain and future economic and commercial feasibility for production on a mass market scale.

Product 4

Product 4 involves the production of medical implants such as bones and teeth by a world-leading 3DP company. We compare traditional manual methods versus 3DP technology integration where we highlight changes in the supply chain network, specifically the reduction in actors leading to lower complexity and the localisation of production. Further, we examine improvements that have been made from the integration of 3DP compared to traditional production methods such as higher customisation, reductions in design and production lead times as well as highlight its future economic and commercial feasibility.

Product 5

Lastly, product 5 studies the impact of 3DP technology on the design and manufacturing process of complex spare parts in the nuclear and medical industries. The nuclear industry utilise 3DP for manufacturing replacement parts that are usually one-offs. We analyse how the costs and lead times for designing and producing a product using 3DP compared to metrology methods have reduced dramatically. The results of our analysis are presented in a tabular format in the section that follows.

4 Results

Table 1: Traditional production System- Product 1, 2, 3, 4, 5

	Product 1 – Hard products (shoes) – design stage – rapid production	**Product 2 Bed sheets – manufacturing stage**	**Product 3 – garments**	**Product 4 – medical devices (Implants)**	**Product 5 – complex spare parts, (nuclear)**
Technology	Manual production	Manual production, some automation	Analogue/ screen printing	Manual	Metrology
Network	Geographically dispersed suppliers, production far from market	Geographically dispersed suppliers, production far from market	Multiple nodes, Geographically disperse suppliers, production far from market, high complexity	Multiple dispersed nodes	Multiple geographically dispersed nodes, multiple governance structures,
Relationships	Contractual, Multiple actors	Contractual	Contractual, distance issues,	Multiple actors, contractual,	-
Process	Multiple actors involved, geographically disperse, multiple process steps, long lead times, low flexibility	High waste levels, large human resource required – ethical issues	Analogue flatbed; rotary screen presses; geographically disperse actors; multiple production steps; long lead times	Multiple steps in design process, long lead times; Multiple number of steps, low flexibility	Multiple steps in the design and manufacturing stages, geographically dispersed process, high complexity
Product	Physical raw materials, slow design process , low cost, less accuracy in design	Raw material close to production, Long lead times to customer	Limited number of products,	Teeth, bone, nano-tubing	Single, one-offs items, Multiple dispersed raw material locations, Custom small scale, long lead times, high complexity, high cost
Scale of production	Mass production,	Slow mass production,	Small scale production viable, slow, expensive	Small scale,	Small-scale, one-offs, custom manufacture

Re-configurability	Not used previously	Gradual adoption		Large numbers of nodes,	Low number of nodes
IOT/BIG Data	Not used	No IoT integration	Partial IoT, no big data integration	No integration	No integration

Table 2: RDM Based Production System- product 1, 2, 3, 4, 5

	Product 1 – Hard products (shoes) – design stage – rapid production	**Product 2 Bed sheets – manufacturing stage**	**Product 3 – garments**	**Product 4 – medical devices (Implants)**	**Product 5 – complex spare parts (nuclear)**
Technology	3DP	Full Automation	Digital printing		3DP
Network	Localised network,	Local production	Few nodes, Localised production, close to market	Few nodes, local network, single country governance	-
Relationships	Collaborative, few actors			Decentralised	Collaborative
Process	Design team localised, high flexibility, few players, short lead times, , digital data,	Low waste, fast production process	Fast production on Simple, low cost products, around 15 materials viable, short lead times, low waste process., high flexibility,	Few steps, flexible, localised process, short lead times,	Few steps, flexible, localised process, short lead times,

Product	Digital/virtual materials, fast design process, high cost, higher design accuracy and visibility, customised,	Viable on simple products only.,	Greater customisation of products, local value capture, reduced inventory, Not yet economically viable for High end products, Sustainable	Teeth, bone, knee implants 3DP, Greater customisation, short lead times	Closer proximity of raw material, greater customisation, faster lead times, customised, low cost
Scale of production	Small-scale production (one-offs)	Fast mass production	Flexible, Mass production not economically viable, potential for high speed production	Small-scale, flexible, fast,	Faster cycle times on one-off, on demand production, production close to consumption
Re-configurability	Used for prototyping designs , not commercially viable	Already fully Integrated, digital	To make fully viable and integrated on a commercial scale, production time and costs of printing need to be reduced; Value captured locally.	Small number of nodes, Development of 3DP nano tubing, localised nodes, Value captured locally.	Small number of nodes, Development of 3DP nano tubing, localised nodes, Value captured locally.
IOT/BIG Data	Potential for big data innovations	Limited IoT integration	Big data used in demand fulfilment, partial IoT integration	Limited big data and IoT integration	IoT integration potential

5 Discussion and Conclusion

5.1 Traditional verses RDM based production system

Traditional production technology appears to be labour intensive, requires economy of scale and the establishment big plant sizes. Whereas new technologies such as 3DP, fully automated production process and digital printing requires relatively less labour and smaller sizes of plant. For example, in the case of complex spare parts, the use of 3DP technologies removes many labour intensive activities involved in the redesign and production of a product. Design manager, product 5: *"Why do you need to m*ake one when you can now simulate digitally such good simulations of replacement parts or or whatever you want. That process will become so much quicker and more efficient *where you just say, Let's just do it virtually".*

The digital printing of garments compared to its previous analogue methods that would involve machinery equipment on an industrial scale with a significant workforce in support is another illustrative case. Production manager, product 2: *"for some of our* simple bed sheets, a roll of fabric *comes along, is rolled out automatically, it's cut automatically, a machine sows round the edges automatically, it's packed automatically, you end up with a bed sheet in a pack, no one's touched it. There are* simple products that lend themselves to automa*tion"*.

It also appears that a balance can be achieved between the scale of production and customisation of product and size. For example digital printing, reaching a local scale of consumer personalisation. It is important to mention that product produced by these technologies may not be economical. Thus, application of these technology, in some cases, can be limited to those manufacturing activities where cost is higher such as prototyping. Further, the 3DP of hard products (shoes) would only be viable in the prototyping stage due to traditional methods of production being much faster and cheaper.

The impact of these technologies is also seen to reduce the number of steps in the manufacturing process, for example, director of general merchandise, product 1: *“the* way we buy and develop a product in textiles *hasn’t changed for probably a hundred* years. We sketch something, product spec it, give it to somebody, they make a physical *garment, they come back, we say, “We like this, don’t like that, make another one.”* They come back then we change it again and then eventually through about three or *four iterations we end up with something we want to buy. That’s going to go, because* what will happen is you won't be making any physical garments twenty years from now, it will all just be prototyped virtual*ly”.*

The potential to link these technologies with IIOT and Big Data is immense where a viable business model can developed, by linking demand to production and production to supply in real time. However, this study also reveals that these technologies may not be applicable to all types of products even by linking IIOT and Big Data. For example, production manager, product 3: *“You know the data collection is ridiculous, there’s so* much volume and the question is, right – *so now the big data people are saying it’s small data, it’s the elements of the data that are useful for you, what are you going to do with it?”*

5.2 Supply chain reconfiguration requirements

Our findings suggest that these smart city technologies require a reconfiguration of supply chains because products are more integrated in nature due to consolidation of production processes, hence eliminating supply chain nodes. It also brings changes to supply chain governance because collaboration with supplies is required. It is understood that this technology can be applied different measures, as long as an economical viable supply chain can be designed. The characteristics of these technologies include: quick response to demand especially with the application of IIOT and Big Data; consolidation poof varied process; production of products with minimum modularity. All these characteristics have to be incorporated in supply design.

It appears that final product production/ assembly can be located near to consumption. This means consolidation of downstream supply chain. The impact of this on upstream includes reduction of supply chains nodes, nodes size and limited number tiers. For example, moving from physical prototype designing to virtually, technical manager, product 1: *"the first part of the development process I think will change. Just like it has for other industries, so the car industry, they don't make clay models anymore, they've* got rid of all that, they just have software now where they model it sitting in virtual caves, the textile industry is following *suit."*

Our study also suggests that upstream, the supply chain can still be geographically dispersed with less vertical and horizontal complexities in comparison with traditional supply chains. We also found that while new technologies can be integrated into existing business models, a more prevalent challenge comes from the human aspects. Production manager, product 4: "… integration – the biggest thing about these things actually is the behavioural change. Can you imagine, hundreds of years, buyers and designers have been trained to work in a certain way, they want to feel it, they want to touch it, they want to – *what you're saying is, "Why do you need to do that?" So when* we talk about integratio*n, there's technology integration which you c*an get round and *you work round."*

We also found that smart city technologies are mostly viable in the product design rather than in the manufacturing stage, Production manager, product 3: "So on specialist stuff those technologies are quite important, for mass market retailers like ourselves *where we're mass market, we've got to produce thousands if not hundreds of thousands* of something, these technologies in production will have limitations. That will be solved at some point but I can't see this in the near future."

5.3 Conceptualisation of smart city production and supply chain design

This research has explored new production technologies and its current applications in four products. It suggests that these technologies can be part of smart cities development framework inclusive of manufacturing. Our study of smart city products and "hybrid" technologies/products suggests that a new and more distributed manufacturing paradigm can be realised where plant size is small, products are highly customised, and local production chains characterized by fewer supplier nodes, dispersed and organized by city-based demand segmentation and, focused on a collaborative urban stakeholder model.

Such characteristics are also complementing smart cities feature of digital infrastructure involving IIOT and big data where strong linkages between supply of materials, production and demand of products can leverage localized systems of value creation (Porter, 1990). However, a supporting supply chain configuration has to be designed involving change in material flow, role and governance, and value structure support. Following Scott and Davis' (2006) argumentations that supply chains are "open systems" mutually dependent on the surrounding environment and constantly adapting to it, we posit the existence of different synergies between smart cities, the industrial internet of things, distributed manufacturing and supply chains. These effects occur on both sides, i.e. from smart cities-distributed manufacturing to supply chain and from supply chain to smart cities-distributed manufacturing. Moreover, the structuration theory argues that agent and structure co-evolve and interact mutually in complex social interactions (Giddens, 1979). Considering that smart cities are based on the collaboration between firms, end-users and local stakeholders, we add to the present knowledge by recognizing a co-evolution approach, in which the social interactions are also considered.

We believe there is a need for future research to explore, firstly, whether other products to those we have investigated and which are currently being manufactured offshore could be feasibly reshored, and whether new production technologies, such as distributed manufacturing, could break down bourgeoisie control of manufacturing capital and democratize urban production systems, potentially leading inner city urban communities out of austerity. Moreover, further investigation of the smart city production system could enable the building of new manufacturing theory, in the form of advancing current work on "social materiality". To achieve this there needs to be a shift in theoretical focus from "materials" and "forms" to the "development" or "use" of materials and forms (Leonardi, 2012). Thus, whereas "materiality" might be a property of a technology, "socio *materiality"* represents that: "enactment of a particular set of activities that meld materiality with smart city institutions, norms, discourses, and all other phenomena we typically define as social" (p. 15).

It could be argued that we are observing a dramatic theoretical departure from a dialectic of global production theories (of manufacturing technology, organisational forms and social interaction) to a "city manufacturing" materiality, which is based on making personal production and digital manufacturing accessible and comprehensible for a wide range of people (Orlikowski, 2007). Theory building is needed to model this changing “practice” of manufacturing (Cook and Brown, 1999, p. 388) as individuals and groups engaging in “real manufacturing work” will no longer be informed by a particular organisation or group context, but rather be organized by the ways the smart city eco-system reconfigures the materiality of production technology to enable new organisational forms or individual maker communication patterns.

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