The Internet Connected Production Line:
Realising the Ambition of Cloud Manufacturing

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Abstract: This paper outlines a vision for Internet connected production complementary to the Cloud Manufacturing paradigm, reviewing current research and putting forward a generic outline of this form of manufacture. This paper describes the conceptual positioning and practical implementation of the latest developments in manufacturing practice such as Redistributed manufacturing, Cloud manufacturing and the technologies promoted by Industry 4.0 and Industrial Internet agendas. In the illustration of the outline of web enabled production a case study is presented based on automotive manufacture. Existing and future needs for customized production and the manufacturing flexibility required are examined. Future directions for manufacturing, enabled by web based connectivity are then examined, concluding that the need for humans to remain ‘in the loop’ while automation develops is an essential ingredient of all future manufacturing scenarios.

1 INTRODUCTION

The Internet and its supporting technologies have had a profound impact on society and business around the world over the past 20 years. The business models of companies in the service industries such as finance, retail and the media have seen fundamental change in response to the opportunities offered by the web and increasing acceptance of this communication channel by customers. The possibilities being realized in industries such as banking and retail are only just starting to filter through to potential realization in a manufacturing setting.

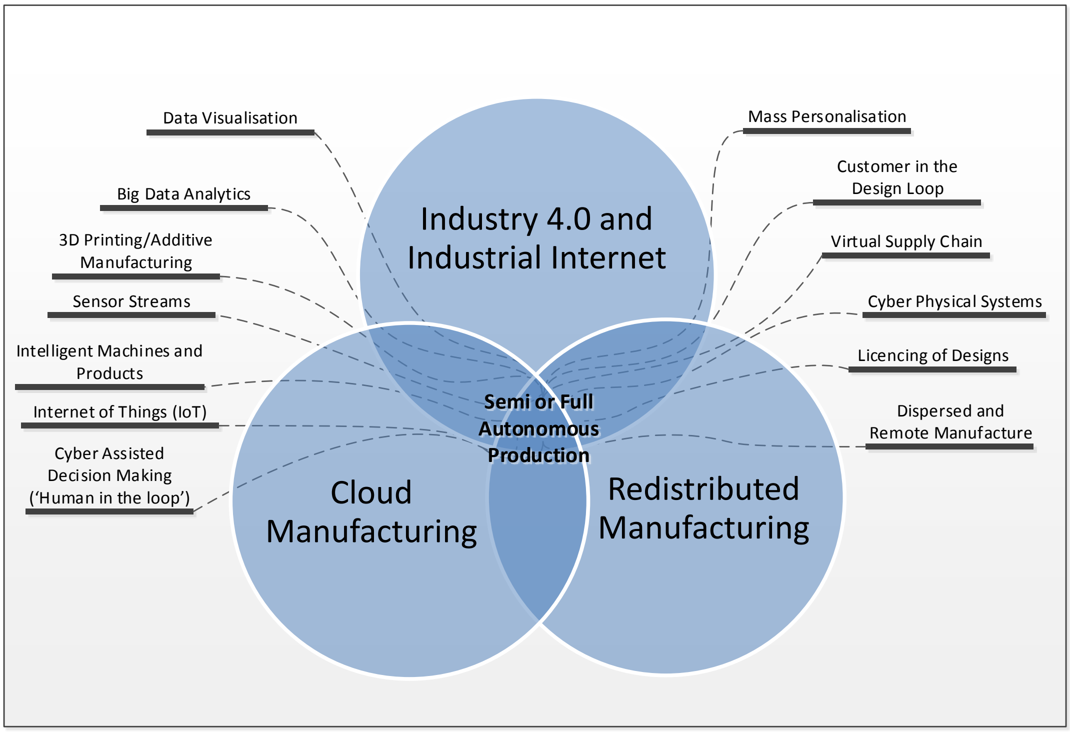
Through a combination of new technology and consumer demand for novel ‘tailored’ products there has been a move away from classic mass production manufacturing models towards mass customization and mass personalization. Mass customization relates to the production of products which may be customized to the individual consumer needs (Mourtzis and Doukas, 2014); the automotive industry is a good example where a customer may select options to modify a mass produced vehicle variant. Major initiatives that promote Internet connected (or at least network connected) production lines, such as Industry 4.0 (Federal German Government, 2016) and the Industrial Internet (Posada et al. 2015), espouse the primacy of interconnected machines and intelligent software forming cyber physical manufacturing entities. In addtion manufacturing paradigms such as Cloud Manufacturing (Zhang et al. 2014) and Redistributed manufacturing (Moreno and Charnley, 2016) (Ellen Macarthur Foundation, 2013) leverage digital connectivity in realising their aims of remote and geographically dispersed production entities.

It is suggested that instead of thinking of the aforementioned initiatives as separate and even competing there is a level of convergence that can be expressed in the delivery of the Internet connected production line as both a physical and digital entity. Fig. 1 demonstrates this convergence and illustrates how many of the technologies related to Internet connected manufacturing are complementary in their use. In further sections of this paper, the vision of the Internet connected production line is further elaborated with particular attention paid to semantic technologies and the value they can bring. A framework for Internet connected manufacture is then outlined and a case study developed that illustrates the convergence between the aforementioned visions. Throughout this paper the point is made that humans can and should be ‘in the loop’ in automated and even autonomous decision making systems highlighting developments in semantic and data visualization technologies that enable new levels of understanding and interaction with intelligent manufacturing systems.

2 VISION OF THE INTERNET CONNECTED PRODUCTION LINE

A common theme to all of the aforementioned subjects outlined in the preceding section of this paper is the ubiquity of Internet technologies and their use in connecting once disparate entities to form a digital “nervous” system for manufacturing. An important facilitator of the required interconnectivity is provided through the concept of Servitization in combination with Webservices technology expressed through a Service Oriented Architecture (SOA) (Tzima and Mitkas, 2008). When products and services are sold as bundled offerings (Servitization) the digital interactions between different company entities and even the customer may be conveyed through web based applications on a request and provision based protocol (Baines et al., 2009) (Wu et al., 2015). Much of the richness in the digital communication now possible is provided by semantics, whereby meta-data to describe manufacturing parameters and other data points promoting a meaningful exchange between engaged parties. Much has been said on the ubiquity of big data and its potential to bring new insights for organizations. Leveraging big data does require an infrastructure and framework in order to ensure data production, analysis and consumption points are all linked together in a coherent way. The latter point is especially poignant as potential data producers within the manufacturing organization are many and varied; production line/ machine based sensors, intelligent products (products capable of data production both in the field and while in manufacture) and new product design applications are just some of the actors streaming real time information that will form part of the digital nervous system in the internet connected production line vison.

Figure 1. Convergence of the major Internet connected manufacturing visions and constituent



2.1 Internet Connected Production Line Goal

While the question must be asked 'what is the goal for Internet connected manufacturing?' Building on Wu et al. (2015) vision for Cloud Manufacturing, the following aim can be formed for an Internet connected production line:
'To provide an outline template for distributed production benefiting from autonomous decision making based on a real time view of the organisation and its environment'. An additional question that may also be asked regarding the location of the production facilities if all parts of the manufacturing process are digitally linked. Along with trends in economics and geopolitics, re-distributed manufacturing can provide part of the answer to the question of production line location.

An additional question that may also be asked regarding the location of the production facilities if all parts of the manufacturing process are digitally linked. Along with trends in economics and geopolitics, re-distributed manufacturing can provide part of the answer to the question of production line location. In a monolithic factory producing products such as automobiles, the main production assembly resides in one factory with subsidiary factories producing substantial components such as engines and gearboxes (with subsidiary factories as wholly owned facilities of the parent company or as first tier suppliers of an automotive company). In geographically distributed factory facilities, the notion of centralised production recedes as assembly of a product may be localised in a region of a country or at the retail end point or perhaps even in the customer's home. It is certainly true that the amount of Big Data created has increased at an exponential rate (Kambatla et al., 2014) and this is providing new opportunities for the development and production of new products. Among the points made by Li et al. (2015) regarding Big Data and Product Lifecycle Management (PLM) the following points are particularly relevant to the operation and use of Internet connected production lines Li et al. (2015):

- Lifetime prediction for parts
- Access to product design data inside and outside a company – improving design
- Access to production line data
- Monitored products and product service systems
- IT integration and connection with production line sensors and CPS
- Prediction of customers' needs and demand level for products
- Supplier performance measurement and prediction
- Smart maintenance of production lines
- Controlling energy consumption and enabling emission reduction in manufacturing

Distributed Manufacturing is a term that has been gaining in popularity in recent years. As described by Xu (2014), Cloud Manufacturing is a concept that aims to describe how Cloud technologies could be used to link distributed production facilities with both customers and suppliers. Dynamic scalability of production is possible with Cloud manufacturing where products can be produced using generic non-specialised tooling (Wu et al., 2013). In such cases, additional capacity can be called up and integrated into the existing manufacturing operations of an organisation through digital Cloud based links. For the production of non-standard parts and products (with a normal requirement for custom tooling) 3D printing (also known as Additive Manufacturing) may hold one potential avenue for on-demand production (Wu et al., 2013). Distributed Manufacturing through a Cloud Manufacturing paradigm does present a number of problems in the logistics arena. Srai et al. (2016) point out that new innovative approaches are required to support supply chain logistics in redistributed manufacturing models. Srai et al. (2016) note the role of co-location (where producer customer share the same location) and localised production. Last mile logistics and in particular their local consolidation centres will require more responsive online ordering systems for shortened lead to delivery times Srai et al., 2016). Srai et al. (2016) also provide a commentary of product/industry specific manufacturing clusters and the opportunities provided by such business ecosystems.

2.1.1 Security

Research is underway on ways to establish trust, transparency and legal liability when it comes to distributed and global Internet based business connections. In the realm of Internet of Things research (technology which the internet connected production line relies on for physical to virtual representation and interconnectivity of production line machinery and sensors). Recent research includes the use of Blockchain technology to provide a means for secure transactions in manufacturing supply chains. Abeyratne and Monfared (2016) outline blockchain use in manufacturing highlighting its ability to allow two parties to trust and securely transact with each other without the need for a 3rd party facilitator. Blockchains use in IoT interconnectivity has been outlined by Bahga and Madisetti (2016). In their research Bahga and Madisetti (2016) propose a secure platform for IOT based on Blockchain, allowing for connectivity between peers in a hitherto trust-less network environment. The automated negotiation of contracts is perhaps a natural application for Blockchain and the delivery of the Internet Connected Production Line. Automated Negotiation, as reviewed by Fatima et al. (2015), has gained in interest over recent years.

2.1.2 Metadata

It is also the case that systems for well-coordinated linkages between production cells are still in development. Wang (2015) describes the concept of networked cellular manufacturing though raises a number of concerns and mitigations for cyber security issues. In addition the moves towards standardisation on internet technology (and adoption of web standards) for data transmission in a manufacturing setting is still a work in progress. The W3C (World Wide Web Consortium) likens the current situation in IoT interoperability to the pre internet times and their competing networking technologies often operating with proprietary and incompatible standards (W3C, 2017). W3C (2017) envisage a future situation where a combination of existing web standards are use with semantic meta-data descriptions (perhaps based on RDF (Resource Description Framework) and LinkedData) to provide open interoperability between physical and virtual entities associated with IoT.

3 SEMANTICS FOR MANUFACTURING

For In realising the fine grain interoperation of both physical and virtual systems required by the internet connected production line the use of semantics to provide additional meaning and context to data becomes essential. Indeed the use of semantic meta-data to describe manufacturing parameters and messaging is gaining interest within industry. The development of the AutomationML (2017) standard has in part been one response to this need for interoperability between industrial automation plant and computer systems (Drath et al., 2008). As an XML (Extensible Markup Language) compliant language AutomationML has the ability to model information at different levels allowing for lossless data transfer between entities and, according to Luder et al. (2010), enhanced parameter traceability (for possible reconstruction of an audit trail for automated decision making). The OPC UA (OPC Unified Architecture) is a standard for industrial system intercommunication that is platform neutral (OPC Foundation, 2017). This standard while comprehensive in its specification can be complex and expensive for an organisation to implement. The work of Henßen and Schleipen (2014) examines the role that the AutomationML mark-up language can play in simplifying the use of OPC UA models with existing data sets and streams expressed in XML. According to Henßen and Schleipen (2014) use of OPC UA directly is a complex task, utilising AutomationML mapping to OPC UA opens up the opportunity of streamlined connectivity with OPC UA compliant systems and manufacturing systems. The Industry 4.0 vision states that individual parts of a manufacturing operation such as machinery, IT systems and deployed sensors can be described as autonomous discrete components each with their own semantic descriptions (Grangel-Gonzalez et al. 2016). The work of Grangel-González et al. (2016) highlights the use of RDF (Resource Description Framework) in the provision of an administrative shell for Industry 4.0 components. RDF facilitates a semantic description of data to be exchanged. In the context of Grangel-González et al. (2016) it is used in concert with the Reference Architecture Model for Industry 4.0 (RAMI 4.0) (VDI/VDE, 2015) is the model used to describe product lifecycle, IT systems and manufacturing plants in a holistic shared context of Industry 4.0. Big Data is a core asset of Industry 4.0 implementations with its intelligent processing providing the potential for context aware autonomous operation and self-adaptation. Golzer et al. (2015) investigate the data processing requirements of Industry 4.0 and deduce seven broad categories composed of four data requirements and three processing requirements. The content of the data in the opinion of Golzer et al. (2015) divides into four categories:

- Product data
- Process data
- Business data
- Sensor data

In the processing of data three main categories of processing are put forward by Golzer et al. (2015):

- Decision processing
- Knowledge processing
- Real-time processing

It is possible that two additional categories can be put forward that of context related meta-data and the further contextual processing of that meta-data related to the aforementioned categories. The identification of context and its processing is necessary as it is in the identification and processing of this type of information that an autonomous CPS system can safely react to newly encountered situations. Context aware computing systems seek to identify patterns in heterogeneous data sets in order to determine shared context. The term context engine (Mehra, 2012) is a name given to a computer system that is able to mine Big Data sets and identify a subset of context relevant data streams. A classification of context is provided by Razzaque et al. (2005) providing a number of categories useful for assessing a given system in terms of its context. The types are as follows:

- User context – the user and the role in the system
- Physical Context – physical environment and its constraints
- Network Context – connectivity between entities in a system
- Activity Context – given activates that occur in known or knowable patterns
- Device Context – physical device entities involved in a system
- Service context – functionality of a system

4. AN EXAMPLE OUTLINE OF AN INTERNET CONNECTED PRODUCTION LINE

One of the main motivations behind an Internet connected production line is the use of TCP/IP (Transmission Control Protocol/Internet Protocol) to provide ubiquitous networking capabilities throughout the manufacturing operation, moving beyond proprietary networking solutions. In addition to addressing the changing nature of consumer demand, from generic products through mass customization towards a future of products designed for a market of one (mass personalization), it is the potential for automation and autonomous operation of distributed manufacturing facilities that the Internet connected production line framework can contribute a holistic template. Fig. 2 displays an outline of an Internet connected production line as a system. It can be seen in Fig. 2 the production line itself is composed of 3 entity types; production line machinery; production line robots; 3D printing. All entity types are capable of providing data streams and exposing control interfaces. In terms of the first two types CPS systems may be inherent providing the possibility for distributed intelligence (and local decision making on the shop floor) combined with central control within the business intelligence layer of the semantic sandwich. Production line decision making may even be componentized as an agent based representation within the business intelligence layer. Both inbound logistics (the supply chain) and outbound logistics are shown in Fig. 2.

Real time digital connectivity with both entities is essential for the Internet connected production line. The meta-data rich communication utilizing internet protocols provides an 'open' format for data exchange. Central to the framework outlined in Fig. 2 is the ability to transform messages produced in one part of the system for process and analysis in another. Physical production line equipment is likely to describe parameters in a particular format which may be proprietary. The use of XML languages such as AutomationML and XML compatible meta-data frameworks such as RDF, along with suitable ontologies, allows for meta-described data produced by a variety of heterogeneous machines to be captured and then transformed into other XML dialects suitable for business systems and intelligent decision support applications. In addition to meta-data transformation it is necessary to employ intelligence within the semantic sandwich illustrated in Fig. 2 to establish context in which parameters are being produced, processed and then acted upon (decision making). In this way the context of semantics is also processed by the business intelligence layer as well as providing decision making assistance. This framework also helps to componentize the production line and business systems of a manufacturing organization. In effect each component could conceptually become a service and exposed in the form of a Webservice. The work of xxx et al. (2015) provides a method for assembling discrete Webservices to form actionable and optimized processes. Such a technique could be applied to the Internet connected production line whereby manufacturers would be able to dynamically assemble new production processes from existing components exposed as services. Once such a process has been assembled the individual components (such as robots and machines) may be virtually represented as agents in terms of enacting intelligent decision making and control (in the live production phase). Automated negotiation would also assist in the selection and integration of services. While offering manufacturing services for clients outside the organization a manufacturer may also wish to utilize this mode of operation to reconfigure current operations. Short run production of highly customized products could benefit from increased understanding of the current production facilities that a framework as presented in Fig. 2 could facilitate. Supply chain integration may also be streamlined via such a framework through the provision of standard API (Application Programming Interface) and common XML based message passing language. Even without full compatibility in the supply chain the functionality of the framework affords a level of adaptation difficult to achieve in a manufacturing environment composed of disparate systems and traditional administrative silos.

From Fig. 2 the integration with existing business systems within the organization is shown. It is the case that the decision making / monitoring dashboards on the semantic sandwich may in fact feed data to a central production management decision making application that already exists within the organization. As mentioned earlier scope exists to integrate an ERP system with the Internet connected production line. Connectivity with other existing business systems within the organization is also encouraged by the framework.

It can be seen that the TCP/IP network is the boundary of the Internet connected production line; apart from the obvious opportunities this presents as with any network there is a necessity for the integration of coherent security measures. As mentioned earlier in this paper coordinated actions at both hardware and software levels are needed to ensure the secure operation of the Internet connected production line. The use of Blockchain technologies in the linking of suppliers with a manufacturing organisation is an interesting development in the software based protection of intercompany transactions.

At this point it should not be forgotten that decision making regarding the overall operation of the Internet connected production line still requires the human in the loop (even when operating in a future fully autonomous mode) . In this respect the value of information presentation and interface design becomes paramount when developing dashboard applications to facilitate human interaction in the control of the manufacturing operation. Along with enhanced interface design metaphors the way a user will view manufacturing processes will change too. A process flowchart metaphor may have added value in such an environment whereby many, once disparate systems are brought together and viewed as a networked cooperating ecosystem (Fayoumi, 2016). The use of Virtual Reality (VR) and in particular Augmented Reality (AR) where analysis, simulations and parameter information may be overlaid on a user's view of a factory environment in real time utilising head mounted devices. It is the case that the dashboards provided as part of the Semantic Sandwich Decision and Control Layer may be viewable by a range of devices including those providing VR and AR visualisations and interactivity. At its core is a decision making and control layer or 'Semantic Sandwich'.

4.1 The Semantic Sandwich

The Semantic sandwich is composed of the following sub layers:

- Data stream filtering and analysis layer – This layer will filter both existing data sets and data streams produced by production line sensors,
- Semantic / ontology / context layer – This layer will describe discrete data points with semantic descriptions that will indicate the context in which the data has been collected and its potential relevance. This layer is central to the concept of the Internet connected production line in that all data is semantically described (via metadata) for presentation to users in a human readable format and through ontology autonomously processed for use in automated decision making (as a future development of the business intelligence layer).
- The Business intelligence layer – This layer will employ algorithms to process semantically tagged data in combination with business rules drawn from ERP (or similar) business systems to provide decision making capability. This layer is in effect the computational intelligence layer where centralised decision making takes place (although distributed and localised intelligence of CPS may also be embodied in production line machines and robots). Learning is possible within this layer with decision outcomes implemented within the production line and other company business systems (provided by machine learning algorithms). In the future development of this layer is may be possible to provide autonomous production control (with the ability to monitor and amend automated actions).
- Decision Making / Monitoring Dashboards – A range of web delivered interfaces will be capable of detailing every activity within the system, in practice a sub set of the data will be provided by the semantic sandwich layer via friendly interfaces for decision making. The concept of 'Human in the loop' is reinforced within this framework through streamlined access to decision making and the ability to mine audit trails of decisions (and the reasoning behind decisions) and activity that have occurred within the Internet connected production line.

- Enterprise Resource Planning System(s) – Although not officially part of the semantic sandwich this layer is in effect the interface and API for 3rd party ERP software. ERP systems may be linked in to the Internet connected production line and may access data and re-create its decision making and monitoring dashboards through APIs (Application Programming Interfaces) or simply access data streams from the production line.
- Data Resources – data storage resources will be utilised by the Internet connected production line. There will be a necessity to capture and store data streams from the production line and audit trails of decision making within the semantic sandwich layer and monitored activities within the system. A big data repository will be required along with connectivity to other data stores and streams within the organisation.

As can be seen in figure 3 the Semantic Sandwich layer in operation will take in data in the form of streams from the production line and associated machine assets (from the Sensor Fusion Layer). This layer is capable of filtering and mining data in its raw form so that the analysis may begin (for the discovery of broad patterns in the data). Product data (machine data relating to the manufacture of products and data from intelligent products during their assembly) Process data (data from production line machines on the performance of manufacturing operations) and sensor data (from production line machines and the production line facility in general) may be mined in real time or near to real time for analysis, fusion with other data streams and further processing by the semantic/ontology layer. The semantic layer takes processed and filtered data from the sensor fusion layer and establishes the context of the data (based on further processing and data from ERP and other related business systems). The context is then made explicit with metadata descriptions attached to the data. General descriptions for the data are also applied at this stage. Both contextual and general metadata tagging utilises specially developed ontology. The business intelligence layer is able to utilise the metadata tagged data streams and further mine and process data received data from the semantic layer. While all three layers could potentially utilise a range of machine learning algorithms to perform their tasks it is the business intelligence layer where their utility is most likely to be beneficial. Within this layer two additional meta layers may also exist, the meta-heuristic feedback layer and the audit trail wrapper layer.

4.1.1 Meta –heuristic feedback

The meta-heuristic feedback layer is used to identify and maintain a set of heuristics or mining rules that would help in identifying features and patterns in data at the sensor fusion layer level. This feedback would be produced from the analysis of data from the ‘shop floor’ and from ERP and business systems. These rules would be at the level of guidance to detect broad patterns rather than very specific (acting as a meta heuristic for the overall mining and analysis direction of the semantic sandwich functionality as a whole and allowing the system to free itself from local optima in the overall search space represented by the manufacturing/market environment an organisation is currently engaged in).

4.1.2 Audit trail wrapper

The Audit trail wrapper creates an additional meta process description of the data identified and processed within the semantic sandwich. An audit trail process may be tied to an individual product or a particular manufacturing process taking place within the production line. Event based process chains comprising the audit trail may contain meta data descriptions to help establish provenance of the data. Decisions made by the semantic sandwich layer can also be described in the audit trail along with manual human interventions. Imran et al. (2017) provide the following outline points to take account of when collecting and describing the types of provenance that may in the opinion of the authors of this paper be required of data products produced within an internet based manufacturing environment:

- From where a data product was acquired?
- By whom and when the data product was created?
- Who are the authorized stakeholders of the concerned data product?
- In what transformations and computations has it been used?
- What were the inputs for the generated output data item?
- Which criteria were applied in the creation of the data product?

This notion of Audit trail use originate in the field of cyber security and with this in mind the wrapper may act as an invaluable addition to the security protocol within internet based manufacturing in the future.

5. A RESEARCH AGENDA FOR THE FUTURE

With a move to mass customization and mass personalization the need to rapidly adapt and tailor products to individual customers’ exact requirements will grow. The Internet connected production line is one response to the provision of manufacturing flexibility that will be required to meet this expanding

Figure 2. The Internet Connected Production Line as a system

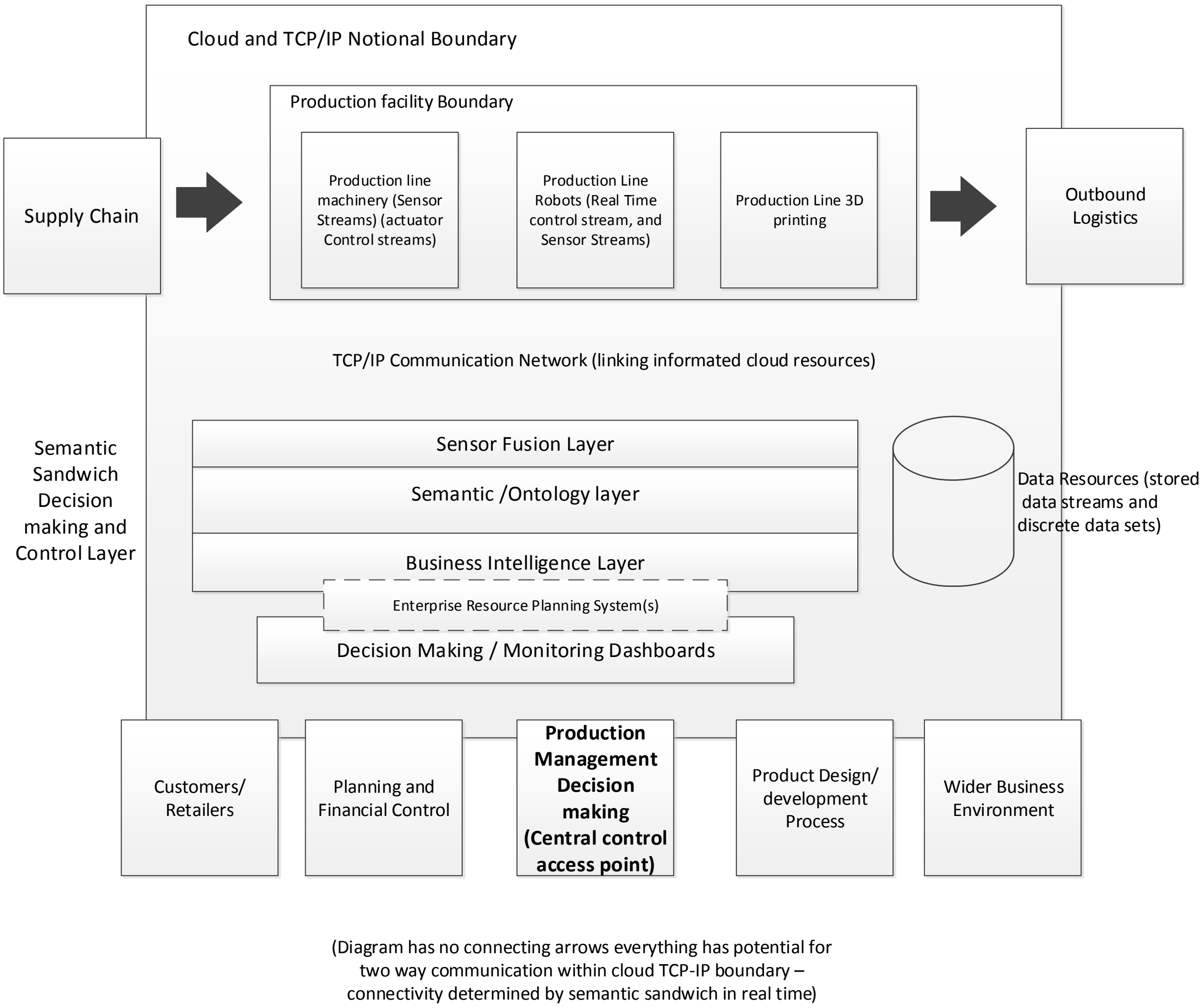
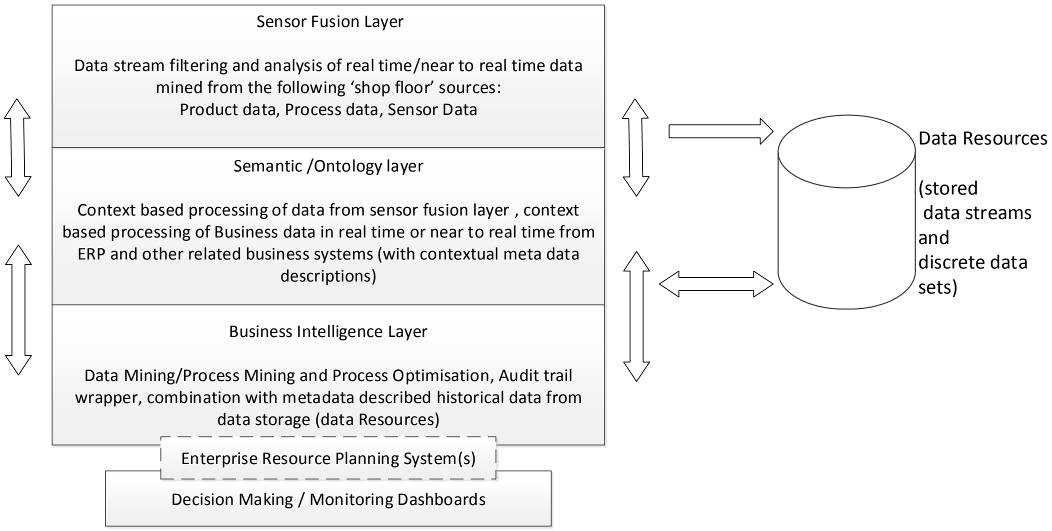


Figure 3. The Semantic Sandwich



demand. It is the case that more research needs to be conducted into security issues surrounding both data transmission and the safe completion of digital contracts. A future where autonomous production is a reality will also require accurate descriptions and capture routines for data. The use of semantic technologies is vital to provide both fine grain control over production and greater understanding of products, customers and the manufacturing operation as a whole. In such a world informated products may be able to take an active part in their construction while on the production line and then report back to the consumer and the manufacturer about such factors as their health status and use. Such levels of data necessitate the further development of decision support systems and their automation, though the users should always be able to view the complete production system and question its operation receiving back plain language explanations of the decisions made; this requirement is necessary regardless of the level of autonomous operation in production systems of the future.

In delivering personalized products to customers new relationships may be formed with some suppliers. With the Internet connected production line in place it is possible to envisage a ‘Gig’ based supply chain (a term derived from the Gig economy where individuals have highly flexible contracts and working arrangements with organizations (Benson, et al., 2015) whereby suppliers are connected to a digital marketplace and receive specifications for short run or individual tailored components. Automated negotiation technologies along with Blockchain may be used to select a supplier and securely contract with them for the delivery of parts.

6 CONCLUSIONS

This paper has outlined the potential components of an Internet connected production line. This concept addresses the need for more flexible manufacturing to meet the demand for customised and personalised products. In adopting a redistributed view of manufacturing the Internet connected production line demonstrates how large factory manufacturing can evolve into regional production facilities near the customer. Both Industry 4.0 and the Industrial Internet visions popularise a wide variety of technologies and approaches to manufacturing, the concept in this paper illustrates how such technologies can be implemented within a production line and outlines the advantages for doing so.

Central to the Internet connected production line is the use of open standards web technology and networking protocols. Along with this is the use of semantic descriptions for data and intercommunication with the factory and outside suppliers, logistics providers and customers. It is in the harmonisation of data descriptions that holds the best route to interoperability between systems in organisations and human understanding of increasingly complex manufacturing processes and a rapidly changing business environment. The integration of machine intelligence and coordination of multiple CPS systems, promoted by the Internet connected production line, may also lead to the realisation of an overall information and control system necessary for future automation efforts and the future promise of autonomous production. The ability for humans to remain in the loop while automation develops to a future state of maturity is an essential ingredient in all future manufacturing scenarios.

REFERENCES

Mourtzis, D., and Doukas, M., 2014. Design and planning of manufacturing networks for mass customization and personalization: challenges and outlook, *Procedia CIRP*, vol. 19, pp.1-13.

German Federal Government, The new High-Tech Strategy Innovations for Germany [Online]. 2016, Available: https://www.bmbf.de/pub/HTS_Broschuere_eng.pdf accessed on 30/04/2018.

Posada, J., Toro, C., Barandiaran, L., Oyarzun, D., Stricker, D., De Amicis, R.,. Pinto, R., Eisert, P. Dollner, J., and Vallarino, I. 2015. Visual computing as a key enabling technology for industrie 4.0 and industrial internet, *Computer Graphics and Applications*, *IEEE*, vol.35, no.2, pp.26-40.

Moreno, M, and Charnley, F., 2016. Can Re-distributed Manufacturing and Digital Intelligence Enable a Regenerative Economy? An Integrative Literature Review, In *Sustainable Design and Manufacturing* Springer International Publishing, pp. 563-575.

Ellen Macarthur Foundation, 2013. *Towards the Circular Economy*, vol. II, Ellen MacArthur Foundation, Cowes, Isle of Wight, UK. 2013.

Zhang, L., Luo, Y., Tao, F., Li, B. H., Ren, L., Zhang, X., Guo, H., Cheng, Y., Hu, A., and Liu, Y., 2014, Cloud manufacturing: a new manufacturing paradigm, *Enterprise Information Systems*, vol. 8, no.2, pp. 167-187.

Tzima, F. A. and Mitkas, P. A., 2008. *Web Services Technology*, IGI Global, Hershey, USA.

Baines, T. S., Lightfoot, H. W., Benedettini,O, and Kay, J.M., 2009. The servitization of manufacturing: A review of literature and reflection on future challenges, *Journal of Manufacturing Technology Management*, vol. 20, no. 5, pp. 547-567.

Wu, D., Rosen, D. W. Wang, L. and Schaefer, D., 2015. Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation, *Computer-Aided Design*, vol. 59, pp.1-14.

Kambatla, K., Kollias, G., Kumar, V., and Grama, A, 2014. Trends in big data analytics, *Journal of Parallel and Distributed Computing*, vol. 74 no.7, pp.2561-2573.

Li, J., Tao, F., Cheng, Y., and Zhao, L., 2015. Big Data in product lifecycle management, *The International Journal of Advanced Manufacturing Technology*, vol. 81, no.1-4, pp.667-684.

Opresnik, D., and Taisch, M., 2015. The value of Big Data in Servitization, *International Journal of Production Economics*, vol. 165, pp.174-184.

X. Xu., 2012. From cloud computing to cloud manufacturing. *Robotics and computer-integrated manufacturing*, no. 28, vol.1, pp.75-86. 2012.

Wu, D., Thames, J. L., Rosen, D.W., and Schaefer, D., 2013. Enhancing the product realization process with cloud-based design and manufacturing systems, *Journal of Computing and Information Science in Engineering*, no. 13, no. 4, p.041004.

Srai, J. S., Harrington, T. S., and Tiwari, M. K., 2016. Characteristics of redistributed manufacturing systems: a comparative study of emerging industry supply networks, *International Journal of Production Research*, vol. 54 no. 23, pp.6936-6955.

Abeyratne, S. A., and Monfared, R. P., 2016. Blockchain ready manufacturing supply chain using distributed ledger, *International Journal of Research in Engineering and Technology*, vol. 05, no. 09, pp. 1-10.

Bahga, A., and Madisetti, V. K., 2016. Blockchain Platform for Industrial Internet of Things, *Journal of Software Engineering and Applications*, vol. 9, pp. 533-546.

Fatima, S., Kraus, S., and Wooldridge, M., 2015. *Principles of Automated Negotiation*, Cambridge University Press, 2015.

Wang, J. X. 2015. Cellular Manufacturing: *Mitigating Risk and Uncertainty*, vol. 31. CRC Press, Hershey.

W3C, 2017. Web of Things at W3C, [Online]. https://www.w3.org/WoT/ accessed on 30/04/2018.

AutomationML, 2017. Specification of AutomationML, [Online]. https://www.automationml.org/o.red.c/dateien.html? accessed on 30/04/2018.

Drath, R., Luder, A., Peschke, J., and Hundt, L., 2008. AutomationML- the glue for seamless automation engineering, In *2008 IEEE International Conference on Emerging Technologies and Factory Automation*, IEEE, pp. 616-623.

Lüder, A., Hundt, L., and Keibel, A., 2010. Description of manufacturing processes using AutomationML, In *Emerging Technologies and Factory Automation (ETFA), 2010 IEEE Conference on*, pp. 1-8.

OPC Foundation, 2017. OPC Unified Architecture, [Online] https://opcfoundation.org/about/opc-technologies/opc-ua/ accessed on 30/04/2018.

Henßen, R., and Schleipen, M., 2014. Interoperability between OPC UA and AutomationML, Procedia CIRP, vol. 25, pp.297-304.

Grangel-González, I., Halilaj, L., Auer, S., Lohmann, S., Lange, C., and Collarana, D., 2016. An RDF-based Approach for Implementing Industry 4.0 Components with Administration Shells. *Working Paper*, Dept. Enterprise Information Systems, University of Bonn, Germany.

VDI/VDE, 2015. Reference Architecture Model Industrie 4.0 (RAMI4.0), Status Report, [Online] http://www.zvei.org/ accessed 30/04/2018.

Gölzer, P., Simon, L., Cato, P., and Amberg, M., 2015. Designing Global Manufacturing Networks Using Big Data, *Procedia CIRP*, vol. 33, pp.191-196.

Mehra, P., 2012. Context-aware computing: beyond search and location-based services, *IEEE Internet Computing*, vol. 16, no. 2, pp.12-16.

Razzaque, M. A., Dobson, S., and Nixon, P., 2005. Categorization and modelling of quality in context information. in: R. Sterrit, S. Dobson, M. Smirnov (Eds.), *Proceedings of IJCAI 2005 Workshop on AI and Autonomic Communications*, Edinburgh, Scotland, August 2005.

xxx.

Fayoumi, A., 2016. Ecosystem-inspired enterprise modelling framework for collaborative and networked manufacturing systems, *Computers in Industry*, vol. 80, pp.54-68.

Imran, M., Hlavacs, H., Haq, I.U., Jan, B., Khan, F.A. and Ahmad, A., 2017. Provenance based data integrity checking and verification in cloud environments. *PloS one*, vol.12, no.5, pp. 0177576.

Benson, A., Sojourner, A., and Umyarov, A., 2015. Can Reputation Discipline the Gig Economy? Experimental Evidence from an Online Labor Market, Report No. *IZA DP No. 9501*, Institute for the Study of Labor, Bonn. 2015.