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

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Keywords: Cloud Manufacturing, Industry 4.0, Industrial Internet, Cyber Physical Systems, Internet of Things, Cloud Computing, Redistributed Manufacturing.

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. 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 proposed, 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 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. Internet connected production provides an infrastructure for the opportunities offered by both Cloud and redistributed forms of manufacturing through the utilisation of internet protocol and web data description formats.

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.

The Internet of Things (IoT) forms a vital part of the infrastructure, enabling internet conncted production through the ubiquitous presence and availability of network connected sensors and the efficient near to real time processing the data they collect. It is suggested that instead of thinking of the aforementioned initiatives and connectivity 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.

Turner, C. and Mehnen, J.
The Internet Connected Production Line: Realising the Ambition of Cloud Manufacturing.
DOI: 10.5220/0006894001370144
In *Proceedings of the 14th International Conference on Web Information Systems and Technologies (WEBIST 2018)*, pages 137-144
ISBN: 978-989-758-324-7

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 promote a meaningful exchange between engaged parties.

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. 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 (the subsidiary factories are normally wholly owned facilities of the parent company or first tier suppliers). 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 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

Cloud 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).

2.2 Security

Research is underway on ways to establish trust, transparency and legal liability when it comes to distributed and global Internet business connections. The W3C (World Wide Web Consortium) highlight that further research into IoT security highlighting the need for methods to ensure end to end trust and techniques to verify related metadata (describing data provenance) and its context (W3C, 2017). 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) who propose a secure platform for IoT based on Blockchain, allowing for connectivity between peers in a formally trust-less network environment.

2.3 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 used 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

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. A number of metadata language standards have recently developed for use in manufacturing applications.

3.1 Semantic Standards

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. Mazzola et al. (2016) detail the CDM-Core manufacturing ontology for production and maintenance, citing its use in sensor stream annotation and web services as key benefits. An additional commentary on semantic service composition is provided by Mazzola et al. (2017) in which the authors outline a pattern based approach to the service oriented implementation of manufacturing plans. 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.

3.2 Data Requirements and Context

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.

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. Figure 1 displays an outline of an Internet connected production line as a system. It can be seen in Figure 1 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 in 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 Figure 1.

4.1 Metadata and the Internet Connected Production Line

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 Figure 1 is the ability to transform messages produced in one part of the system for processing 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 (see also section 3.1 of this paper for standards). In addition to meta-data transformation it is necessary to employ intelligence within the semantic sandwich illustrated in Figure 1 to establish the order 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.

4.2 Webservices and the Internet Connected Production Line

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 be exposed in the form of a Webservice. The work of Vergidis 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 activities (in the live production phase). Automated negotiation would also assist in the selection and integration of services (Fatima et al., 2015). While offering manufacturing services for clients outside the organization a manufacturer may also wish to utilize this mode to reconfigure current operations. Short run production of highly customized products could benefit from an increased understanding of the current production facilities that a framework as presented in Figure 1 could facilitate. Supply chain integration may also be streamlined via such a framework through the provision of a 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.

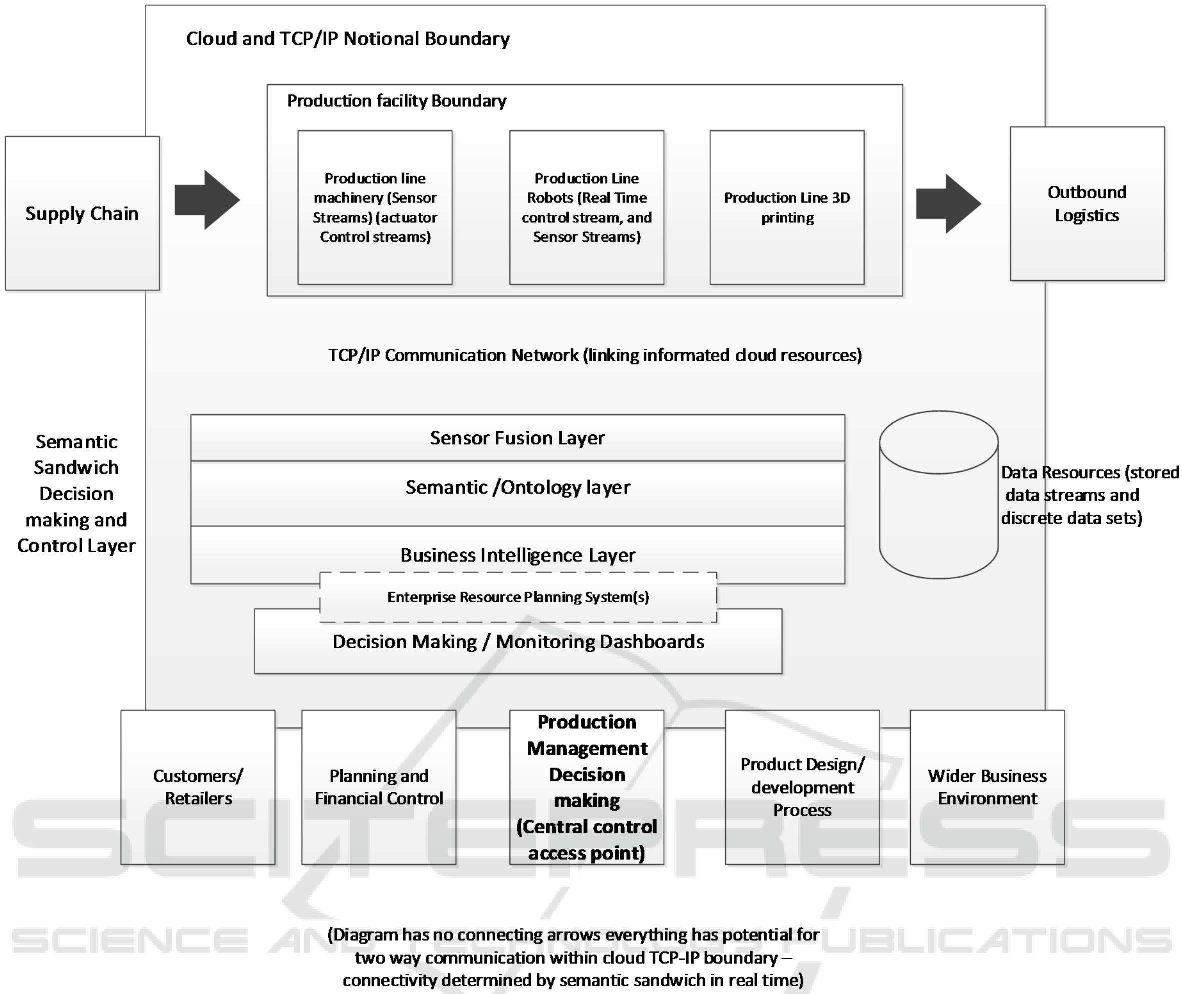

Figure 1: The Internet Connected Production Line as a system.

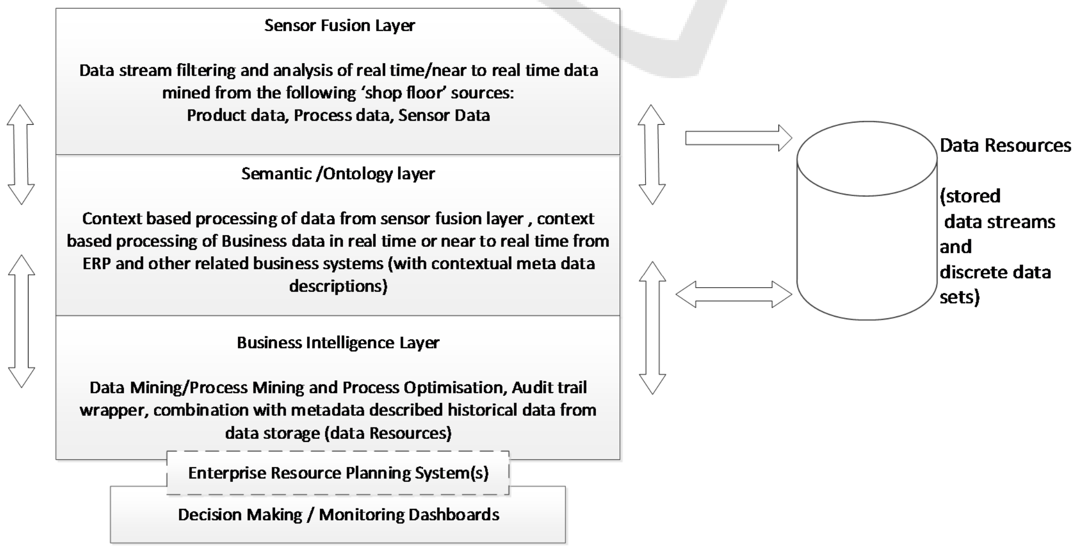

Figure 2: The Semantic Sandwich.

4.3 Decision Making in the Internet Connected Production Line

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 (potentially even in a limited oversight role 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 simulation systems used with Virtual Reality and Augmented Reality headsets/ viewing devices may also be beneficial in the human interaction with future manufacturing operations (Turner et al., 2016).

4.4 The Semantic Sandwich

The semantic sandwich (shown in Figure 2) 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
- 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).
- 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.

4.5 Meta–heuristic Feedback

Meta-heuristic feedback functionality is used within the semantic sandwich 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. This information is then utilised by the audit trail wrapper to detail the decisions made in human readable format.

4.6 Audit Trail Wrapper

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. This notion of audit trail use originates 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. It is also the case that for humans to play an active role in the development of automated and eventually autonomous production there is a need to understand at some level how and why decisions are made by machines. The audit trail may provide insights in that particular direction

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 challenging expansion in 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 when in 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.

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. 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.

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