Proceedings of the 2017 International Conference on Industrial Engineering and Operations Management
Bristol, UK, July 24-25, 2017

Leveraging Industrie 4.0 to extend Lean Manufacturing gains.

Wendy Garner
Faculty of Engineering, Environment and Computing
Coventry University, Coventry, CV1 2JH, UK
cex267@coventry.ac.uk

Richard J Bateman
Faculty of Engineering, Environment and Computing
Coventry University, Coventry, CV1 2JH, UK
ac2096@coventry.ac.uk

Steve Martin
Faculty of Engineering, Environment and Computing
Coventry University, Coventry, CV1 2JH, UK
cex222@coventry.ac.uk

Lean Manufacturing has been so successfully implemented that it has become the de facto method of manufacturing. However, all such activities are subject to the law of diminishing returns, leaving many manufacturers wondering where the next big gains are to come from. For many, Industrie 4.0 would seem to offer the solution. However, for an organization balancing competing priorities with limited resources, should the focus be on 'smart manufacturing'- defined as comprising such things as increased production output, quality, safety, and yield? Or 'connected products', defined as applying to Industrie 4.0 to vehicles and industrial machinery in order to facilitate remote diagnostics, remote maintenance, and remote data capture, up to and including servitization? Or should their focus be the 'connected' value chain, defined as applying Industrie 4.0 in order to increase the visibility and coordination of both inbound and outbound activity? This paper explores this very real dilemma for manufacturing organizations and proposes a simple audit tool as a starting point that an organization can use to identify how their practice of Lean might be extended to leverage the benefits of Industrie 4.0.

Keywords: Lean, Industrie 4.0, Six Sigma, 4IR

1. Introduction

1.1 Origins and drivers for Industrie 4.0

There is a well-known proverb "a thousand priests makes a thousand religions" and if one works in the field of manufacturing you could be forgiven for making a new version "a thousand Industrie 4 experts means a thousand version of what Industrie 4 is"! One widely used definition from the EU Briefing paper 'Industry 4.0 Digitalization for productivity and growth' (Davies, R, 2015) defines Industrie 4.0 as *"a term applied to a group of rapid transformations in the design, manufacture, operation and service of manufacturing systems and products"* however most researchers would probably agree that the term is not particularly well defined and the definitions that do exist seem to vary according to the industry perspective of the definer. Almost all the current definitions point towards the idea of 'Smart Factories' with a view to changes/improvement to increased flexibility, enable mass customization, increase production speed, product quality and overall productivity, give a wider customer range, increasing independence on location and development of new business models – for example the move towards 'servitization' or selling services not products (sometimes described as 'selling light not light bulbs').

The Industrie 4.0 Working Group (Kagermann, et al, 2013) believes that action is needed in the following eight key areas: (i) standardization and reference architecture; (ii) managing complex systems; (iii) a comprehensive broadband infrastructure for industry; (iv) safety and security; (v) work organization and design; (vi) training and continuing professional development, (vii) regulatory framework, and (viii) resource efficiency.

1.2 Where to start with Industrie 4.0?

However, the most difficult issue with Industrie 4 is 'where to start'. Most companies, particularly those of small and medium size do not have bottomless budgets or endless supplies of time and labour, so are looking for (impartial) guidance on how they may go about implementing the Industrie 4.0 'philosophy'.

The vast majority of industries have implemented Lean Manufacture systems and methods (in some cases starting decades ago) and if not are looking to begin this journey, so there is a wealth of experience and expertise that already exists about the selection, implementation and management of lean systems available to all sectors of industry. In addition to this, characterizing the Industrie 4.0 philosophy in terms of 'extended lean manufacture' seems to help people in industry to grasp the concepts involved and begin to see the possible benefits and how they might implement some parts in their own organization.

This paper proposes that there are valuable lessons to be taken from the implementation of Lean Manufacturing principles when considering 'how to start' implementation of Industrie 4.0 ideas and principles. Just as there is a logical order of implementation of lean methods, for example - identifying the right solution for the problem, making the scale of the solution equal to the scale of the problem, implementing changes where they will give the most initial benefit ('low-hanging fruit'), supporting with appropriate levels and types of technologies, enhancing training, 'up-skilling' and recruitment of personnel to enable progression along lean lines, etc. – but most of all taking a pragmatic approach – then the same will be true for implementation of Industrie 4.0 related improvements.

2. Lean Manufacture

2.1 The Toyota Production System (TPS) as a source of competitiveness

Lean Manufacturing, regarded as a generic version of TPS has emerged as the *de facto* method of manufacturing which, practiced widely has become synonymous with competitiveness and which has led to many organizations developing 'Toyota like' production systems.

The source of this success lies not just with the tools, techniques and practices employed but with the system itself. The activities, connections – product and information flows – though rigidly standardized, are nevertheless subject to constant challenge and thus, while specifications appear inflexible it is their exactness that provides the foundation – the stability – for a process of problem solving. One that uses a detailed assessment of the current situation (or 'state') and supports a 'future' plan to deliver higher levels of performance in quality, productivity and delivery through incremental systems improvement and process innovation in order to improve the 'value' to the customer. At the heart of this relentless pursuit for perfection are the people within the organization.

The House of Lean is often used to illustrate the key principles of Lean and how they work together as a complete system. An example of which can be seen is in Fig. 2.1.

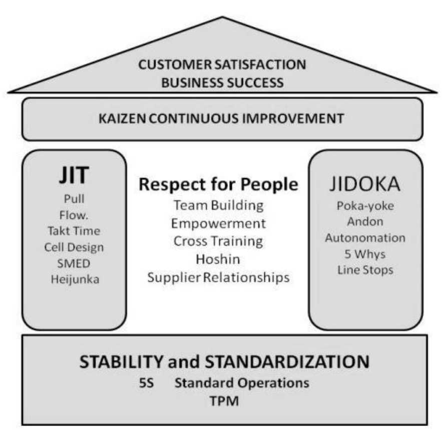

Fig. 2.1 House of Lean

It is this respect for people, central to the principles associated with Lean, which enables, encourages and even expects frontline staff to take responsibility for making improvements to their own jobs. It is this training and empowerment that provides the underpinning to how people work, the way in which they communicate and connect – the customer-supplier relationship and how the production line is designed within a Lean system to minimize 'waste' (Liker, 2004) and thus optimize performance.

2.2 Identifying waste within the process

The greatest enemy of competitiveness is waste-- typically of time, money and resources (materials). In manufacturing, waste is any expense or effort that does not transform raw materials into an item the customer is willing to pay for – 'value' from the perspective of the customer. There are generally considered to be eight types of waste in Lean Manufacturing (Liker, 2004).

The first seven of these eight identified wastes being production process oriented,

- Defects: Repair or rework of a product or service to fulfill customer requirements.
- Over-Production: Producing more than is needed, faster than needed or before needed.
- Transportation: Any material movement that does not directly support immediate production.
- Wait-time: Idle time that occurs when co-dependent events are not synchronized.
- Inventory: Any supply in excess of process or demand requirements.
- Motion: Any movement of people which does not contribute added value to the product or service.
- Processing: Redundant effort (production or communication) which adds no value to a product or service.

whilst the eighth;

- Unused Employee Creativity: Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to your employees

Essentially this is the waste of the talent of those directly employed and is related to management's ability to utilize personnel (and was originally considered by Ohno) but has been better understood more recently.

The idea behind Lean production stems from seeking to eliminate waste or '*muda*' i.e. any activity which involves wasted effort, materials and time at every stage in the supply through the design of, and constant improvement to the manufacturing system.

2.3 Just-in-Time (JIT) and the concept of added value

Just-in-time is a management philosophy – and one of the pillars of the house of Lean – which refers to the production of goods to meet customer demand exactly, in time, quality and quantity, whether the `customer' is the final purchaser of the product or another process further along the production line:

- producing and delivering finished goods 'just in time' to be sold
- partly finished goods 'just in time' to be assembled into finished goods
- parts 'just in time' to go into partly finished goods
- materials 'just in time' to be made into parts.

and JIT is a key feature of Lean production (Morden, 1994). The principle that underpins JIT is that production should be 'pulled through' rather than 'pushed through'. This means that production should be for specific customer orders, so that the production cycle starts only once a customer has placed an order with the producer. Sometimes refer to as 'stockless production' as shown in Fig 2.3, JIT has become synonymous with producing with minimum waste.

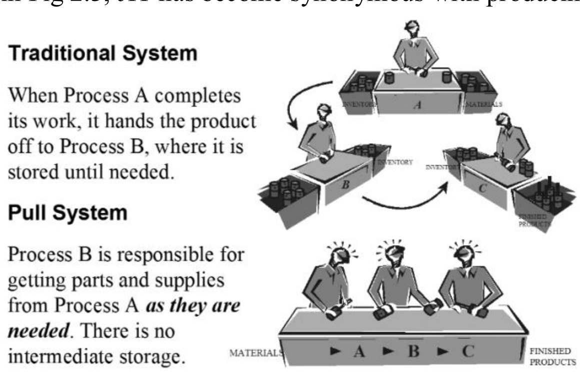

Fig. 2.3 JIT 'pull' production system.

It is a way of working involving the eliminating all forms of waste (where waste is defined as anything that does not add 'value' in the production process and supply chain and which would therefore be perceived from the customers perspective as adding only cost to the product or service.

2.4 Kanban – a scheduling system for JIT and Lean
Kanban is the technique used to support the operation of a Lean production system and is a key component in the promotion of continual improvement within the system, as inventory – seen as a waste within the system – is systematically reduced to expose problems as the limits of system stability are reached (Groover, 2013)

A key component in a 'pull' system, Kanban creates a trigger that signals more production or re-supply throughout the supply chain according to customer requirements (Fig. 2.4.1) by matching levels of inventory to actual rather than forecasted production/consumption requirements. The use of a Kanban system leads to a reduction in overall lead time, lower levels of inventory and provides greater visibility across the supply chain.

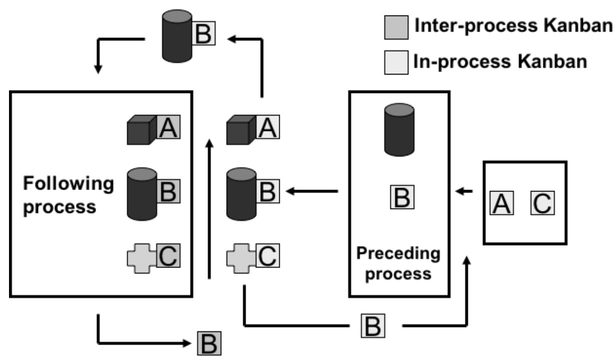

Fig. 2.4.1 Kanban system

While physical cards or tokens continue to be used to signal production or replenishment requirements increasingly electronic Kanban, or a mix of both are being utilized within the supply chain by organizations. Barcode or electronic data interchange technology is employed to replace the traditional card element which has the added advantage of being able to more easily link to MRP/ERP systems.

2.5 Jidoka – building quality excellence into the process
Within the House of Lean Jidoka represents one of the pillars. Jidoka is about ensuring quality at source – building excellence into the quality of product and service, providing a powerful way of preventing defects reaching the customer (Baudin, 2007)

The principle of Jidoka can be broken down into a few simple steps:

1. Discover an abnormality
2. Stop line production
3. Fix the immediate problem
4. Investigate and correct root cause

Detection is the first step in Jidoka. A worker who is source-inspecting the work produced immediately before his or her work station is authorized to stop the line when a defect is identified. A machine performs the same defect detection process using typically simple sensors to detect a problem and then stops and highlights the problems for the operator. It is this autonomation – 'automation with a human touch' – that prevents the production of defective products, eliminates overproduction and, by making it visible, focuses attention on understanding the root-cause of the problem and ensuring that this does not reoccur.

In Jidoka the immediate problem is 'fixed' using a countermeasure which, in the short-term might include a requirement for over-processing or rework. However, to complete Jidoka, not only is the product defect corrected but a problem solving (Kaizen) approach is used to evaluate and change the process to remove the possibility of the same mistake reoccurring. Poka-yoke – devices for error-proofing – are often introduced into the production line, thus relieving the operator of the necessity to use their personal judgement as to whether the operation is normal.

In practice, Jidoka indicates that an automated process has sufficient 'awareness' of itself so that it is able to detect a process abnormality or product defect, halt production and provide an operator or supervisor alert. While Jidoka is a key pillar of Lean manufacturing it falls short of the goal of process solutions that are fully automated. These processes would need to include the additional aspect of self-correction.

2.6 The bigger picture – mapping the value stream

Lean is about creating the most value for the customer while minimizing resources, time, energy and effort expended. Within an organization the approach to deliver this is rooted in purpose, process and respect for people as espoused by the House of Lean and measured generally through metrics associated with quality, cost and delivery. However, for many organizations purchased items can account for half or more of their total costs plus a significant proportion of their achievement in quality, delivery and responsiveness. Thus, while an organization has no obligation to look downstream at their customers or upstream into what suppliers actually do in order to meet their needs, the ability to do so affords a further perspective in delivering competitiveness.

Looking across the value stream (Jones and Womack, 2002) makes it possible to map the path of the product's supply, production and distribution and make visible the path of information associated with this. Doing so enables a picture of the current state to emerge. Determining the performance gap between what a value stream is capable of delivering and what the customer needs and identifying improvement opportunities, results in a future state map value stream that better addresses the customer's current and future needs.

3. Implementation of Industrie 4.0 principles

3.1 Basic Planning Steps

It may be a truism but every plan really does have three stages: (i) Where are we now? (ii) Where do we want to be, and (iii) How do we get there? Applying this to Industrie 4.0, we might argue the 'where do we want to be' stage is still really the same as the normal business plan – all companies want to be better at what they do, want to make more profit, want to have more customers in bigger and more diverse markets, want to create more added value, etc. For these a company will already have appropriate strategies, tactics, plans, etc. in place along with the defined key performance indicators (KPI) which indicate success or otherwise.

For the 'How do we get there?' stage it could be argued that for many companies over the last few years/decades, a large of 'becoming better at what we do' has essentially been the implementation and development of the principles, tools and methods of lean manufacture. Since (as outlined in the previous section), the underlying tenet of lean manufacture is the avoidance of waste or muda across the whole manufacturing spectrum, it is hard to think of a better path to becoming better at what we do – i.e. more efficient, more effective, having a greater understanding of the processes and products we produce, etc.

For the first stage however (where are we now?) the conventional route to discovering this is to conduct some form of lean manufacture 'audit' which is specifically designed to identify areas of weakness, gaps in knowledge, rate importance of problems found, etc. It is therefore logical to suggest that for the beginning steps of Industrie 4.0 implementation a similar concept should be engaged – the next section of this paper outlines the authors proposed framework for an Industrie 4.0 for this purpose.

3.2 Pragmatism in Industrie 4.0 implementation

3.2.1 Internal and External Industrie 4.0 actions

As mentioned earlier, the Industrie 4.0 Working Group (Kagermann, et al, 2013) have outlined eight key areas of Industrie 4.0: (i) standardization and reference architecture; (ii) managing complex systems; (iii) a comprehensive broadband infrastructure for industry; (iv) safety and security; (v) work organization and design; (vi) training and continuing professional development, (vii) regulatory framework, and (viii) resource efficiency. However, it is obvious that these key areas are at different levels and thus the actual effect that a specific company might be limited by their size and resources. Table 3.2 shows simple suggested internal and external actions which a company could engage with to assist with the Industrie 4.0 journey.

Table 3.2.1 - Internal and external Industrie 4.0 actions in which a company could engage.

	Key Areas of Industrie 4.0	**Scope/level**	**Internal Actions**	**External Actions**
1	standardization and reference architecture	Development at national and international level	Ongoing awareness. Adoption of and adhering to standards	Engagement with standards bodies, trade associations, etc. to be part of standards process
2	managing complex systems	Inside company and along supply chain	Detailed mapping and understanding own systems Possible modelling/simulation to try out different scenarios?	Increase awareness of interactions with external organizations particularly suppliers, etc.
3	comprehensive broadband infrastructure for industry	Development at national and international level	Awareness of options, periodic review to identify improvements and changes	Engagement with providers, ISPs, trade associations, etc. to be part of 'lobby' process
4	safety and security	Development at national and international level	Awareness of standards and laws for safety and security (and others along supply chain)	Engagement with standards bodies, trade associations, etc. to be part of standards development process
5	work organization and design	Inside company and along supply chain	Detailed understanding own work organization and interactions with external organizations	Increase awareness of interactions with external organizations particularly suppliers, etc.
6	training and continuing professional development	Inside company and along supply chain	Investigation/mapping of skillsets available within workforce and gauge 'appropriateness'	Upgrading of HR, training and recruitment processes with eye on future skill set requirements
7	regulatory framework	Development at national and international level	Detailed understanding own companies standing within existing regulatory framework, identify and plan for future changes	Engagement with regulatory bodies, e.g. via trade associations, etc. to be part of regulation development process
8	resource efficiency	Inside company and along supply chain	Investigate and map in detail use of resources within company and along supply chain, paying particular attention to timeliness	Monitor resource efficiency opportunities along supply chain, different modes of supply, alternative suppliers and materials

3.2.2 Efficiency and Effectiveness in Implementing Industrie 4.0

The concepts of effectiveness (doing the right things) and efficiency (how well those things are done) is well understood and form a central part of the continuous improvement principal, however in recent years many lean practitioners have come to understand that the journey from low effectiveness and low efficiency to high effectiveness and high efficiency cannot be a smooth line. Figure 3.2.2 shows the ideal path from one to the other along with the realistic or pragmatic path.

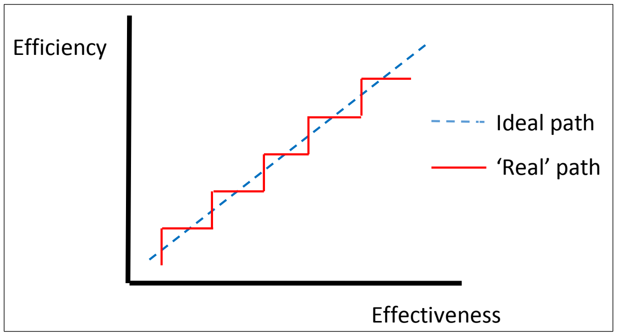

Figure 3.2.2 Journey to improved efficiency and effectiveness

The ideal path would be to be able to increase efficiency at the same time as improving effectiveness, but in practice it is very difficult to get better at doing the things you do (increase efficiency) whilst changing those things you do (effectiveness). The practical or pragmatic path is to do one for a short spell followed by the other – i.e. first change the things you do, then stop changing and concentrate on getting better at doing those things. When efficiency is improved by a reasonable amount then go back and look at improving effectiveness.

It is logical is to assume suggest that there is a logical (or perhaps common sense) order in the addressing of implementing Industrie 4.0 technologies and methods. Figure 3.2.3 shows the same concept of stepwise improvements but with Industrie 4.0 technologies.

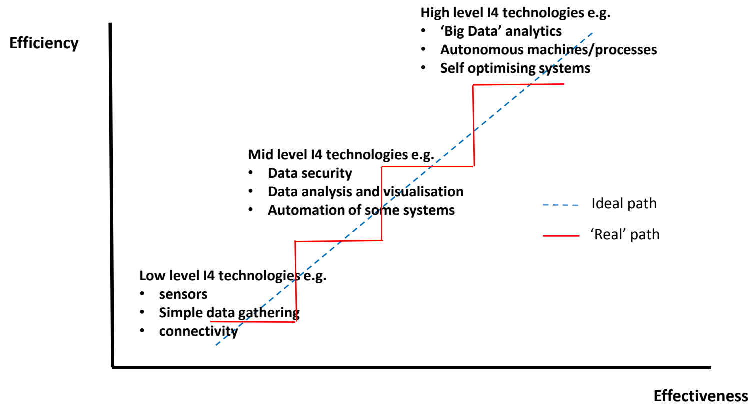

Figure 3.2.3 - stepwise improvements with Industrie 4.0 technologies.

For example, it is obvious that the use of advanced Industrie 4.0 technologies like 'Big Data and analytics' and autonomous decision making can only really be introduced once the system is relatively sophisticated. Decision making can only become automated if one first truly understands what the decisions and their cases and criteria are, but automation of say an existing Kanban system could be relatively straightforward. If data is needed to make a specific decision (either manual or automatic) but that data is not currently collected then introduction of some kind of sensors would be a necessary starting point. Overall, the starting point does not have to be over complicated and should be focused on attacking those places which will yield a big payoff.

4. Proposed Framework of Industrie 4.0 Audit Tool

4.1 Overview

In the report by Boston Consulting Group (Russman et al, 2015) the difference between an optimised lean manufacturing cell and a future vision of an Industrie 4.0 facility is visualised. It shows that the boundaries of the facility have been replaced by an integrated value chain, facilitated by transparency and real time communications. Greater flexibility is achieved through 'smart' agility which enables improved customisation and smaller batches. And more automation and intelligence in the manufacturing resources and facilities will generate efficiencies that will displace the lower skilled labour and require a smaller number of higher skilled labour to monitor and control.

However, what is also shown is that this evolution to Industrie 4.0 is a journey which for many will start with a lean facility. When implementing lean, many companies use a 'Lean Audit Tool' to establish the gaps and to plan the journey/development for improvement. Adapting the lean Audit tool from (Tapping, 2003) the next steps to industrie 4.0 can be articulated.

Table 4.0 – Adapting lean audit tool to Industrie 4.0 audit tool

	Traditional	Lean	SMART
Manufacturing process	• Batch manufacture • High level of WIP • High Queues • Functional Layout • Push system of material launch (e.g. MRP) • Uncontrolled inventory • No load levelling • No Takt image	• Single piece flow • Flowlines • Balanced line to takt • Pull system of material launch • Controlled inventory (supermarkets, FIFO) • Load leveling • Takt	• Small batch manufacture • Enabled products are directed through the factory • Self-organized and optimized flow • Highly agile production control • Automatic material call

	• Material collected from shared storage • Under and over shipments to customer often occur • Focus on manufacturing facility	• Material delivered to point of use • Shipments conform to customer requirements • Focus on Supply chain	• Value chain (including suppliers) seen as a 'whole'
Maintenance	• Reactive maintenance to breakdowns • Limited spares available • Communication of breakdown is manual • Resultant machine availability is poor • Maintenance tasks are held as local knowledge	• Productive maintenance is evident • Fixed schedule • Spares available through stores • Communication of breakdown is manual via electronic means • Machine availability is improved • Maintenance tasks are standardized and documented manually	• Machines are smart through embedded systems • Collect data to predict breakdowns • Machines access database to request spares • Communication of breakdown is automatic and in real time • Machine availability is maximized through intelligent systems • Maintenance information is up to date and received electronically, including relevant history
Quality	• Quality department responsible • Unknown process capability • Improvement as directed • Inspection is done at inspection stations	• Everyone responsible and empowered • Process capability known • Continuous improvement is part of the culture • Inspection is done at workstations • Poke Yoke	• Everyone responsible • Machines check products continuously and ensure process capability. • System recognizes behaviours and adapts • Augmented reality reduces manual inspections
Visualization	• Limited visual controls • No standardization • Updated manually weekly/monthly • Difficult to understand • No response to issues	• High level of visual control • Standardized across work cells • Updated regularly manually (daily/weekly) • Simple to understand • Generates response manually	• Progress and location of goods can be seen in real time • Available on handheld devices for easy access • Automatic response available for certain scenarios
Intelligence and Cyber security	• Operations supported by monthly MRP runs • Manual management decisions • Cyber security not required	• ERP systems for fully integrated business decision support • Facilitated decisions via simulation for planning operations • Cyber security not required	• SMART manufacturing will enable factories to self-optimize in real time • High level of requirement for cyber security due to the 'enabled environment' of the Industrie 4.0

4.2 Processes

Traditionally manufacturing processes were uncontrolled and machined high batch sizes to gain machine efficiencies. Material was pushed into manufacturing factories to keep machines busy and resulted in high levels of inventory and at the same time creating many of the 7 wastes. Machines were scheduled in isolation and products were moved around the factory with no organised approach. With lean thinking much of this was changed through the application of value stream management. Machines were now considered as part of a 'big picture' and products were planned and managed so that they flowed through the facility in single piece flow according to Takt time, with limited queues and inventory to delay the product meeting the delivery date. The emergence of the enabling technologies associated with industrie 4.0 will allow manufacturing facilities to become more agile and adaptive. Smart Product, Smart machine, Smart operator (Stephen Weyer et al, 2015). Manufacturing processing will have the ability to be self organised and optimised to increase utilisation. This will result in increased flexibility through the opportunity for small batches of different variants to be produced cost effectively. Pull and FIFO systems will be replaced by self controlled products that can navigate independently through the production process and can be adapted and amended at short notice to provide agility in the market place.

4.3 Maintenance

Poor machine availability due to breakdowns and reactive maintenance has been improved greatly by lean thinking and the Total Productive Maintenance (TPM) proactive mind set. Communication of maintenance was transformed from manual T cards to digital modes and limited spare parts availability has improved through maintenance schedules and well controlled spares inventory. Lean has also standardized and devolved maintenance task and reduced the reliance on killed local knowledge. However the future manufacturing machines have embedded systems and collect data to predict breakdowns. Machines communicate breakdowns in real-time and access databases to request spares. Machine availability is maximized through intelligent systems and analytics are used to optimize production and to predict maintenance (Valdeza et al, 2015). To sustain a framework of self-aware/ self-maintained machines, a prognostic self-monitoring system is the trend of the SMART manufacturing systems and big data environment (Jay Lee et al, 2014).

4.4 Quality

Historically quality was the responsibility of the inspection department. With process capability unknown the role of the inspector was to find defects. With the implementation of lean quality was 'built' into the product. The process capability was known and controlled, workers were empowered to improve processes and eliminate the waste of defects. Tools such as Poke Yoke were used to ensure quality issues were not passed through the manufacturing process. Smart manufacturing moves quality forward further. Machines now have the capability to check products continuously and ensure process capability. Systems reognise behaviour and adapt accordingly and augmented reality can be used to reduce inspections.

4.5 Visualisation

Visualisation and transparency were tools that were largely introduced to support lean manufacturing. Prior to this visualisation was limited to dated information displayed on manual charts, which were difficult to understand and prompted little response. Lean introduced a high level of visualisation to communicate with employees to support empowerment. Standardsied communication boards were prevalent within manufacturing cells which were simple to understand and updated regularly and prompted response and contermeasures for improvement. The advent of Smart manufacturing has enabled the progress and location of goods to be seen in realtime along with performance measures and other key data. The logistics wastes are reduced by horizontal integration with supply chain and tracking of components (Price Waterhouse Cooper, 2016)

4.6 Intelligence and Cyber security

Two technologies, namely the Internet of Things (IoT) and Cyber Physical Systems (CPS) are expected to connect the factories, machinery and production to allow for realtime information exchange and autonomous working of production units (Gilchrist, 2016, Qin, Liu and Grosvenor, 2016). This advancement has been exponential in comparison to the dated MRP and manual management decision making of the past and even the fully integrated business support systems such as ERP and the faciltated decision making using simulation. The future integrated manufacturing systems will be able to take a customer design, analyze the requirements produce an optimum manufacturing process which factors in cost, logistics, security, time, energy/emissions, suitability and many other considerations (MacDougall W, 2014). However the this new era brings with it new challenges such as cyber security.

4.7 Value Stream Maps

Value stream mapping has been adapted to show the development of the factory of the future. Figure 4.7.1 shows a typical lean production facility. This future state maps employs single piece flow, pull control, supermarkets and FIFO.

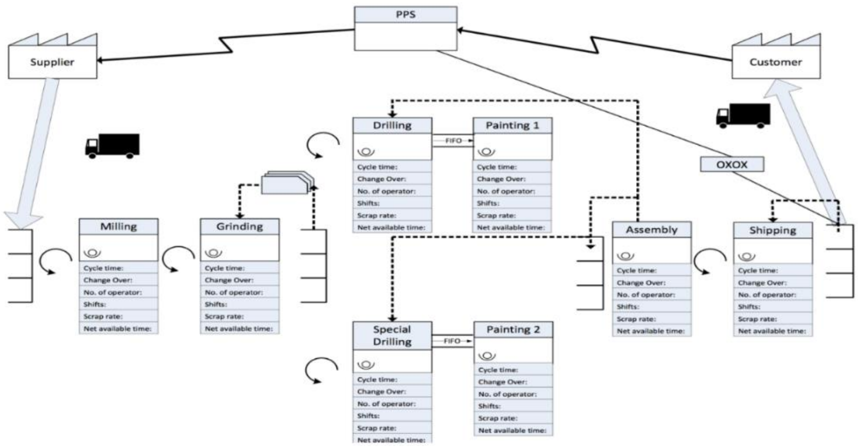

Figure 4.7.1 Value stream – Lean Manufacturing

Figure 4.7.2 shows the development of the lean facility to equip products and the production with sensors, actuators, and a minicomputer. This is important to control and execute movement of products along the production. At this stage the sensors and actuators will be connected with the internet to establish a network (internet of things). New symbols have been introduced to show enabled products and enabled machines.

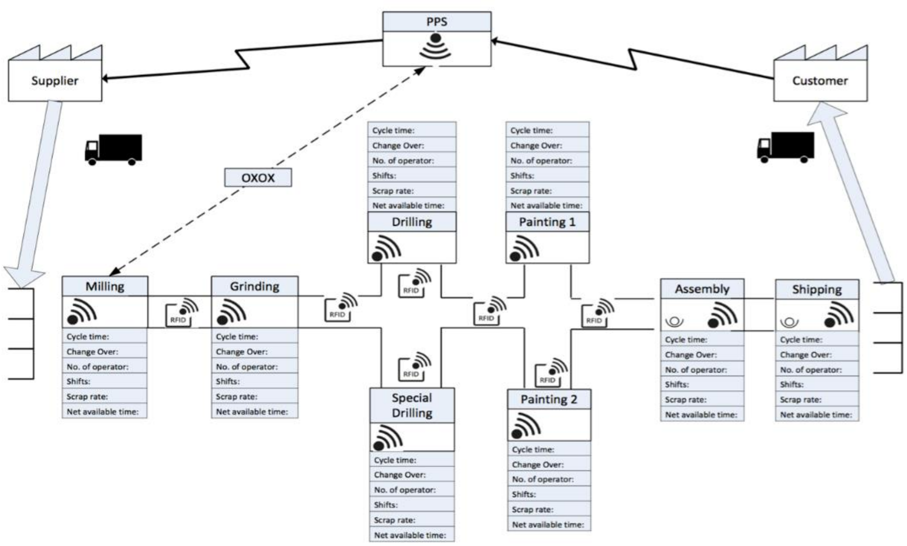

Figure 4.7.2 Value stream - embedded systems and their connectivity

Figure 4.7.3 shows the final development to a Smart facility. This stage equips products/production with analytical skills. Auto identification technology is used to tell the machine and operator what needs to be done rather than a predefined activity (Lydon B, 2016) and a new symbol is introduced to show that no fixed path is required. There is a high synchronization of data between machines and processes (Valdeza et al, 2015) which is illustrated on the value stream map by the flow of digital information.

The central collation of this data is shown through the cloud, where ‘SMART’ intelligence is illustrate the analytics used optimize production and to predict maintenance (Valdeza et al, 2015). This information is seen to be accessed through various digital mediums, with a simple dashboard added to the value stream map to signify the ease of use. This final value stream map demonstrates an integrated manufacturing systems which will be able to take a customer design, analyze the requirements produce an optimum manufacturing process which factors in cost, logistics, security, time, energy/emissions, suitability and many other considerations (MacDougall W, 2014).

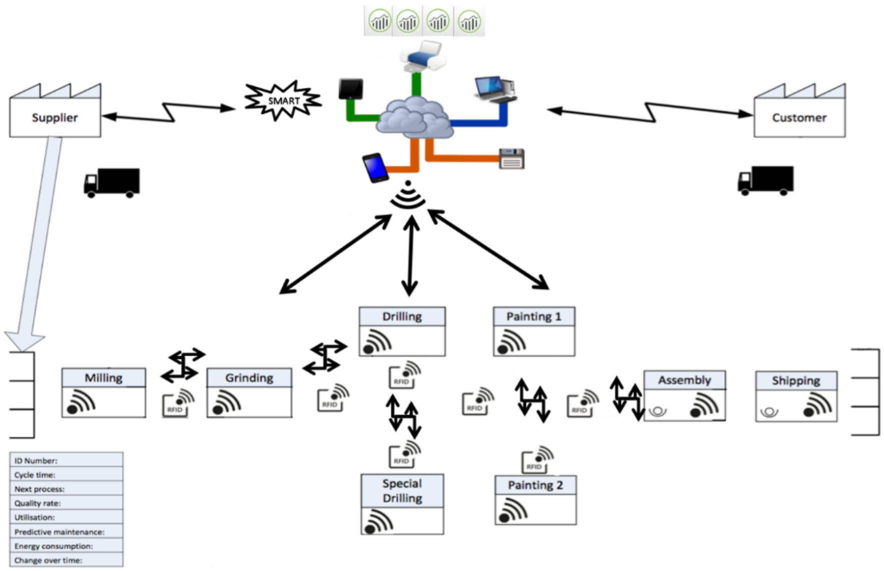

Figure 4.7.3 Value stream – Intelligence in the factory of the future

5. Concluding Remarks

The benefits of implementing Lean manufacturing methods and techniques are indisputable and can be argued to have been the cornerstone of the successful growth of much of the manufacturing industries. Most companies are already far along the lean 'pathway' and those that are not are probably looking to begin. Large amounts of valuable experience is already available to these companies and lessons learned in implementing lean manufacture could be transferrable to those who are looking to implement Industrie 4.0 in their businesses. The main tents of Industrie 4.0 consist of a variety of areas which will need to be addressed to enable truly 'smart' manufacturing and business.

The current situation with Industrie 4.0 (i.e. no-one is truly sure exactly what to do and how to start) can be seen as analogous to the situation with lean manufacture in the early days of its development and implementation. The early days of lean implementation proceeded through a series of phases; beginning with no knowledge, discovery, enthusiasm, (sometimes over-enthusiasm!), pragmatism, systemizing, optimizing and now finally looking for the next thing to achieve the kind of gains found in the first stages of implementation of lean. Industrie 4.0 as an idea can be difficult to 'encapsulate' and thus explain and enthuse industrialists.

To successfully begin implementation of lean practices, the usual starting point is some kind of audit or gap analysis tool. This tool allows a company to firstly identify areas of strength or weakness and/or problems which need solutions and then identify and apply appropriate lean techniques in the places detected. This paper argues that a similar starting approach is required with implementing Industrie 4.0 and thus a suitable audit tool is necessary. The paper outlines a proposed Industrie 4.0 audit tool, which being based on existing lean audit tools (the style and operation of which will be familiar to practitioners of lean) will be easy to use and understand and will help companies 'plan their Industrie 4.0 journey'.

Acknowledgements

The authors would like to acknowledge the contribution of Thomas Muller, Post Graduate Student, Coventry University, 2016

References

Baudin, M., "*Working with Machines: The Nuts and Bolts of Lean Operations with Jidoka*", Productivity Press, UK (2007)
Bonnie F. Daily, John W. Bishop, Jacob A. Massoud, (2012) "*The role of training and empowerment in environmental performance: A study of the Mexican maquiladora industry*", International Journal of Operations & Production Management, Vol. 32 Issue: 5, pp.631-647
Davies, R, '*Industry 4.0 Digitalization for productivity and growth'*, (EU Briefing paper) Available at: http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI(2015)568337_EN.pdf, (2015)
Gilchrist, A., "Industry 4.0 The Industrial Internet of Things" (2016), available from:

http://lib.myilibrary.com/Open.aspx?id=937455&src=0 [17 January 2017]
Groover, M.P, "*Fundamentals of Modern Manufacturing*", Publisher: Wiley (2013)
Lee,J. An Kao.H. (2014) *'Service innovation and smart analytics for Industry 4.0 and big data environment'*, Proceedings of the 6th CIRP Conference on Industrial Product-Service Systems
Jones, D.T. & Womack, J.P., *"Seeing the Whole: Mapping the Extended Value Stream"*, Lean Enterprise Institute, (2002)
Kagermann, H. and Helbig, J. and Hellinger, A. and Wahlster, W.*,"Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry; Final Report of the Industrie 4.0 Working Group"*, Forschungsunion, Germany, 2013
Liker, J, *"The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer",* McGraw-Hill Professional; (2004)
Lydon, B. (2016) '*Industry 4.0: Intelligent and flexible production'*. InTech 63 (3), 12 – 17
MacDougall W., (2014), *"Industry 4.0: Smart Manufacturing for the future".* Berlin: Germany Trade & Investment
Monden, S.Y., *"Toyota Production System: An Integrated Approach to Just-In-Time"*, Springer US, (1994)
Price Waterhouse Cooper , *"Industry 4.0: Building the digital enterprise"* available from: https://www.pwc.com/gx/en/industries/industry-4.0.html [16 January 2017]
Qin, J., Liu, Y., Grosvenora, R. (2016) *'Changeable, Agile, Reconfigurable & Virtual Production: A Categorical Framework of Manufacturing for industry 4.0 and Beyond'*. Procedia CIRP 52, 173 – 178
Russman et al (2015), "*Industry 4.0: The Future Growth in Manufacturing*", Boston Consulting Group (BCG) Available:https://www.bcgperspectives.com/content/articles/engineered_products_project_business_industry_40_future_productivity_growth_manufacturing_industries/?chapter=2
Tapping D (2003), Value Stream Management, Productivity Press
Valdeza, A.C., Braunera, P., Schaara, A.K., Holzingerb, A. and Martina Zieflea, M., *"Reducing Complexity with Simplicity - Usability Methods for Industry 4.0"*, Proceedings 19th Triennial Congress of the IEA, Melbourne, 9-14 August 2015
Weyer, S. Schmitt, M. (2015) *'Towards Industry 4.0 – Standardization as the crucial challenge for highly modular, multi-vendor production systems'*. IFAC-PapersOnLine 48-3 (2015), 579-584

Biography

Wendy Garner is a Principal Lecturer with over 25 years' experience in manufacturing industry. Initially employed by Rolls Royce as a manufacturing engineer and production control manager she moved into academia and applied lean systems into the automotive industry. Because of her experience in both high volume and low volume industries, Wendy has focussed her research to the adaptation of lean into low volume manufacture and the service sector.

Richard Bateman is a Senior Lecturer in the Department of Mechanical, Manufacture and Aerospace Engineering at Coventry University where he is course director for both the MSc in Production Engineering & Operations Management and the MSc in Digital Technologies for Engineering. He is a Chartered member (CITP) of the BCS, a member of the IET and worked for 20 years in various roles in the computing and manufacturing industries and at Brunel University before taking up his current post at Coventry University. He has worked on a number of manufacturing themed EU and TSB funded research projects.

Steve Martin With an early career of over 10 years in project management spent in the automotive industry prior to joining Coventry University Dr Steve Martin has continued to enjoy a close relationship with manufacturing engineering industry in the capacity of mentor, coach, trainer, consultant and researcher. With a background in Lean Manufacturing and Continuous Improvement Steve's applied research in this area now extends beyond manufacturing industry to include the application of Lean Thinking to the service sector including Health, Higher Education and Transport and the emerging influence of the IIoT and Industry 4.0 on providing 'smart' solutions to performance and improvement.