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Review of socio-technical considerations to ensure successful implementation of Industry 4.0

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Abstract

The paper reviews the Industry 4.0 infrastructure and that beyond the potential cost and efficiency gains from implementation, adoption is argued from the perspective of leveraging internal capabilities to devolve Industry 4.0 as the driver for creating competitive advantage. Industry 4.0 and lean manufacturing methods are presented as mutually supportive, where lean methods are enablers for Industry 4.0 implementation, and conversely, Industry 4.0 realizes the extended lean enterprise. The paper further argues that in addition to appreciating the technical aspects of Industry 4.0, it is necessary to understand the socio-technical requirements to ensure successful implementation.

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1. Introduction

Manufacturing is continually evolving and a common view amongst practitioners, academics and observers is that the current stage of manufacturing is at a revolutionary phase based on digital technologies linked to the

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Within manufacturing, business and academia, this revolutionary phase, frequently referred to as 'Industry 4.0', has over recent years been the subject of much comment, debate and research. At the kernel of Industry 4.0 are two enabling technologies, the Cyber-Physical System and the Internet of Things. Through mastering these technologies, advocates of Industry 4.0 visualize an interconnected world that can respond efficiently to the needs of the customer via smart factories, creating a virtual replication of the physical system that enables the real-time intelligent analysis of large data sets. Though the Industry 4.0 model has great potential to advance manufacturing capability and meeting the needs of a more customized and tailored customer base, adoption is not necessarily a guarantee for success. Where, for example, lean/six sigma initiatives have proved successful, it is because the implementation has followed the 'architecture' or rules of the methodology. The methodology becomes part of the culture of the company, where people have received the appropriate training and familiarization as to the relationship of the method to the organization’s capabilities and to customers and wider stakeholders. So too will it be with Industry 4.0, to leverage the potential gains from the model, beyond the necessity to ensure adherence to the technical architectures, there will be a necessity to articulate Industry 4.0 as a Socio-Technical System. In doing so, stakeholders engaged within the Industry 4.0 environment will gain the necessary appreciation of the technologies and the relationship of model within their organizations and to the customer base. Succinctly, the rules of Industry 4.0 are still being written, where the focus is primarily concentrated on successful technical deployment. Consequently, it appears that the socio-technical aspects of Industry 4.0 are being overlooked. To overcome this oversight, this paper assesses the socio-technical features applicable to Industry 4.0 to contribute to the evolving and expanding body of knowledge. The paper is organized as follows: Section two presents an appreciation of the technical infrastructure of Industry 4.0; Section 3 examines why Industry 4.0 should be adopted; Section 4 assesses the relationship of Industry 4.0 to lean/six sigma methodologies; Section 5 considers the socio-technical features of Industry 4.0; and Section 6 closes the paper with some concluding remarks.

2. The Industry 4.0 Infrastructure

Industry 4.0 is so named as “the phenomena” is considered to yield a paradigm shift in the use of manufacturing technology to parallel what are considered the first three industrial revolutions that evolved due to mechanization, electricity and automation. The concept originated in Germany in 2011 and subsequently became a strategic initiative of the German Government and included in their “High-Tech Strategy 2020 Action Plan” [1] and promoted as the future of the country’s industrial and economic growth [2].

Within the factory environment, Industry 4.0 is visualized as a collection of devices, machines, production centres and products that can autonomously communicate with each other, exchange information, invoke actions and control each other independently within what is defined as a Cyber-Physical System (CPS) [3].

Externally, Industry 4.0 has the potential to place the factory at the heart of a highly distributed but heterogeneous network of customers, retailers, suppliers and a myriad of other interested stakeholders through high-speed internet access and the capability to store enormous quantities of data that is available for subsequent analysis.

Through, Industry 4.0, the factory is evolving into what is called a ‘Smart Factory’ [4]. The Smart Factory has a dual existence. Firstly in the physical sense, in terms of machines and systems that people interact with to manufacture products. Secondly, the factory exists as a ‘Digital Twin’ in the virtual world or cyberspace where intelligent algorithms can process the data generated by the physical system, yielding information on the performance, condition and health of the physical system in real time. It is in the ‘virtual world’ where the factory becomes smart – enabling machines to become self-aware of their condition, enabling self-diagnosis leading to prediction of malfunctioning components or possible failures. Similarly, the manufacturing system is able to schedule the factory to satisfy the specific requirements of a customer through understanding the real-time status of each machine within the factory network.
2.1. The Technical Construct of Industry 4.0

The key components of Industry 4.0 include the ‘Internet of Things (IoT)’, ‘Internet of Services (IoS)’ and ‘Cyber-Physical Systems’ (CPS). Collectively, the technologies enable continuous communication and allow a ceaseless trade of information and interaction between people (C2C), people and machines (C2M) and between machines themselves (M2M) [5].

The Cyber-Physical System is at the core of the Industry 4.0 structure. The main component of the CPS is the ‘Embedded Device’. Succinctly an embedded device consists of hardware and software integrated into a mechanical or electrical system (or object) that is designed for some purpose. A cyber-physical system is a collection of these embedded devices that communicate with one-another and interact with the physical world via sensors and actuators in a feedback loop [6]. The CPS leads to a more ubiquitous use of computing capability and embedded devices can be included in almost every engineered product.

The IoT is a special case of the CPS where the medium of network communication is the internet. The term ‘Thing’ refers to scenarios where network connectivity and computing capability extends to objects (things), sensors and everyday items not normally considered computers. The ‘things’ generate, exchange and consume data with minimal human intervention [7]. Such objects are equipped with ubiquitous intelligence and form a highly distributed heterogeneous network. Because the communication medium is the Internet, the objects are not confined to a restricted geographical area (such as the immediate factory shop floor) but could exist in principle, anywhere. Through the IoT, the network could include globally distributed manufacturing sites and the supplier base.

3. The Case For Industry 4.0 Implementation

The question arises “Should manufacturers and service providers adopt the digital revolution that embraces Industry 4.0?” With respect to driving down cost and increasing efficiencies, there is a compelling case to answer in the affirmative. The PWC 2016 Global Industry 4.0 survey [8] predicts an annual average cost reduction of 3.6% allied with efficiency increases of 4.1% across each industrial sector within the survey. Additionally, other tangible benefits are of adoption are proclaimed including higher quality, increased flexibility and productivity, faster product launches and continuous improvement [9]. These metrics are not dissimilar to those proclaimed by past proponents of lean manufacturing or six-sigma programmes and over time, the cost reductions and efficiency gains will reach an equilibrium level. So why not just continue with trusted improvements programmes?

The answer to whether to adopt Industry 4.0 lies not just because of the potential gains but also the consequences of non-adoption. Historically, companies that have ignored or failed to recognize emerging technologies have at best lost market share, subsequently they come back into the market late and as a consequence are no longer the dominant player in the market and at worse such companies cease to exist. These historic observations apply equally to the method of production as well as the technical attributes of the product.

One reason for the failure of mass production was the inability of the system to evolve to cater for a customer base requiring increased product attributes and greater variety [10]. With respect to advances in product technology, Bower and Christensen [11] argue many companies that failed to embrace new product technologies are focused on the current needs of their mainstream customers and ignored their future requirements. In understanding how a firm maintains connectedness to their customers has been assessed in the historical literature. In his seminal paper, Marketing Myopia [12] published in 1960, the economist Theodore Levitt placed the needs of the customer before any other business requirement. His view was the role of a business was to create customers and keep them. The respected management scientist, Peter Drucker, argued that it is essential for a firm to remain aligned to its chosen markets [13] and would need to evolve their business models to adapt to market changes. With respect to the understanding of the strategic contribution of manufacturing, Wickham Skinner also published what is regarded as a...
seminal paper [14] that elevated the manufacturing function as the competitive business driver. Manufacturing in Skinner’s opinion should be an externally facing function meeting the needs of a customer rather than an internal facing function focused on minimizing costs. In assessing the decline of American manufacturing in the latter half of the 20th century, Hayes and Wheelwright [15] continued the theme of promoting manufacturing as a strategic competitive lever and proposed a four stage model of manufacturing effectiveness (Figure 1). The initial purpose of the model was to contribute to the reversing the decline in American manufacturing that was acutely felt during the 1970’s and 80’s [16].

Pre Industry 4.0, the four stage model had achieved universal acceptance, gaining a classic status within the operations management landscape [17, 18]. Given that Industry 4.0 is currently accepted to be at an early stage of evolution, it is likely that manufacturers that perceive themselves to be at stages 3 and 4 of the model are there on the basis of mastering current matured technologies. The four-stage model applied in reverse can illustrate the potential consequences of non-adoption of Industry 4.0. The current dominant world class manufacturers will no longer ‘redefine industry expectations’, nor be ‘the best in industry’. They will only be as good as other competitors who have also failed to introduce the Industry 4.0 model. The strategic impact of their manufacturing operation will halt and ultimately, the manufacturing function ‘will hold the organization back’.

4. Industry 4.0 and Lean/Six Sigma Initiatives

As Industry 4.0 is regarded as a paradigm shift in manufacturing deployment, the relationship between the lean and Industry 4.0 are being examined [19, 20]. Lean manufacturing is a customer focused methodology that seeks to deliver customer perceived value through the minimum use of resources and the elimination of waste. Six Sigma is structured problem solving methodology based on the DMAIC [Define, Measure, Analyse, Improve, Control] phased implementation procedure. Though each initiative evolved independently of one another, many companies and organizations that embrace continuous improvement combine both methodologies together to deliver business improvements [21].
Through embarking on a lean/six sigma improvement project, beyond the core focus of delivering customer value and enabling cost reduction, a number of benefits become apparent which may appear less tangible, but will be seen as enablers to adopting Industry 4.0.

In the first instance, through creating a culture of continuous improvement, both the management structure and general workforce will not only accept change but actively drive change. Secondly, there is likely to be an embedded problem solving structure where people apply sound scientific methods to implement sustainable solutions to problems. And finally, the production and service system within a lean/six sigma environment is likely to be stable, productive, and efficient with minimal production delays, defects and rejections. Thus the lean environment is an enabler to implementing the Industry 4.0 to leveraging a step change in operational performance within a company.

Conversely, Industry 4.0 provides the infrastructure to potentially enhance the lean/six sigma capability of an organization both at the operational and enterprise level.

At the operational level, performance and operational data metrics can transmit in real time through the CPS network enabling enhancements at the operational level and could include:

1. **Electronic Kanbans**: Rather than rely on conventional Kanban cards, a production order can be automatically transmitted to the downstream process upon sensing that the desired inventory level has been reached.

2. **Production Surveillance**: Key production metrics (production rates, downtime, set up time) can be automatically captured. Intelligent protocols anticipate production problems (machine failures, performance deterioration) and communicate the information to key production personnel via hand held smart devices (smart watches, tablets).

3. **Total Productive Maintenance**: Sensors detect when components need replacing (i.e. oil filters) or oil replenishments are necessary and send signals to maintenance staff. Additionally, signals can be transmitted alerting the need for a maintenance activity triggered by operational hours or calendar date.

4. **Data Analysis**: The data captured in real time can be stored for later analysis. Conventional statistical methods could be applied to the data for continuous improvement activities. Other predictive analytical methods can be applied to assess system behavior and performance over appropriate time cycles.

5. **Virtual Value Stream Mapping**: Value Stream Mapping (VSM) is a core activity within lean initiatives [22]. The concept of Virtual Reality (VR) [23] could be extended to create virtual VSM’s. In this VR environment, an understanding of the conventional VSM process will not be needed. Rather than having to understand the interaction of the various VSM symbols, interested stakeholders could be immersed in a virtual value stream where current and future state models could be observed.

The lean enterprise is visualized as the natural destination for lean thinking, to create a value chain that links the customer, retailer, manufacture and the extended supply chain [24]. Indeed, the Lean Aerospace Initiative (LAI) based at the Massachusetts Institute of Technology (MIT) considers that the lean enterprise is the key to driving down procurement costs and improving delivery time lines for both commercial and defense aerospace provision [25]. The LAI is a partnership of academics, aircraft manufacturers, commercial airlines, the U.S. Air force, aerospace suppliers and a host of other interested stakeholders. The exchange of information and data through the partnership in terms of variety, volume and velocity is constrained to the available technologies of the time.

The connectedness capabilities of Industry 4.0 have the potential to promote the exchange of data and information in each of the dimensions of variety, volume and velocity in a real time environment. The only restriction to the exchange would be due to security and authorization protocols. That capability provides the strategic lever to realizing the lean enterprise vision.
5. Socio-Technical System Considerations for Industry 4.0

The technical architecture for Industry 4.0 proposed by Platform Industrie 4.0 is the ‘Reference Architectural Model for Industrie 4.0 (RAMI4)” [26]. The architecture is visually presented as a three dimensional coordinate system consisting of a series of layers, where each layer represents the different functionalities of the manufacturing system. Though there is a ‘Business’ layer within the architecture there is value additionally in considering the socio-technical features of Industry 4.0.

The term socio-technical system is applied to describe systems that involve a complex interaction between humans, machines and the environmental aspects of organizational systems [27]. There is wide acceptance that considering the social and technical interactions has practical relevance in organizational development particularly when seeking to promote change [28, 29].

Previous ‘revolutionary shifts’ in industrial activity ushered in new ways of working and were the catalyst for the creation of new disciplines. The classic industrial revolution created the ‘factory system of manufacturing’; mass production brought the division of labor, and elevated the concept of Scientific Management, and led to the disciplines of Industrial Engineering, and Operations Management; the automation revolution transferred the responsibilities of manual worker to one of a control worker and promoted the discipline of ‘control engineering’.

Industry 4.0 is currently evolving through current knowledge. How Industry 4.0 will impact on the way people work, their interaction with the technologies, and what new ways of working and disciplines that will emerge is still under review [30]. The digital technologies that underpin Industry 4.0 while bringing significant opportunities will also usher substantial challenges. Due to the nature of the heterogeneous network of Industry 4.0, there are significantly more degrees of freedom in the social – technical relationship that was not conceivable in the context of conventional technologies [31].

The complexities that can arise from the increased socio – technical interaction will be managed through changes of how people at each organizational level interact within the technical system:

• The executive level of the firm, while previously relying on the lower tier management structures to understand the current operational status will need to have a more direct relationship at the operational level. In optimizing the contribution of Industry 4.0, executives will need to know the right questions to ask and equally important, understand the answers they are given.

• That relationship is necessary to enable the executive level to maintain connectedness to the customer base and the wider heterogeneous community. As changes to customer and market trends become apparent, the executive level can make informed decisions on maintaining strategic relationships without solely relying on lower tier recommendations.

• The conventional relationship of a management system predominantly controlling workers will give way to active engagement. The engagement will be a mutual transfer of knowledge between the management and operational levels. Management decisions will be optimized on the basis of the shared knowledge.

• While it is probable that a management hierarchy will exist within the context of Industry 4.0, the decision process within the hierarchy will be through the collective understanding of the shared knowledge. In terms of the dissemination of the shared knowledge, it is likely that the management hierarchy divisions will become blurred leading to a more homogeneous sharing of knowledge.

• Workers at the operational level will not be passive agents who carry out their tasks without any reference to their external environments. Rather they will be elevated to the status of a ‘knowledge worker’.
Predicting the new working disciplines that will emerge from the implementation of Industry 4.0 as the concept matures will likely become clearer as the future unfolds. Currently within the portfolio of expertise driving the digital revolution are technical experts (control engineers, computer scientists), data analysts (creating business intelligence from integrating the large data sets available from the network), and the managers and knowledge workers at the operational level. Within the conventional industrial context, these disciplines are largely distinct. In a post Industry 4.0 world there will probably still be a need for these distinct disciplines to exist. However there is a case to introduce an additional form of knowledge professional, one which merges the essential elements of each discipline and is able to provide an informed holistic view of the total system. From understanding the complexities of the Cyber-Physical System with the ability to interrogate the available large data sets to create meaningful business intelligence, to understanding the operational requirements of deployment at the operational level.

The function of this new breed of knowledge professional will be multi-faceted and will include advising each distinct discipline on the optimal course of action to maintain alignment within the heterogeneous network and particularly to the dynamics of the customer base and market trends.

6. Conclusions

There is always value in considering the adoption of technologies and working practices that have potential to drive down costs and increase efficiencies. Industry 4.0 promises to deliver on these metrics. But similar to previous methodologies, over time the cost and efficiency gains will reach an equilibrium level. The real incentive to implementing Industry 4.0 is in maintaining competitive advantage as the future unfolds. In adopting Industry 4.0, companies have the ability to maintain the manufacturing function as a strategic enabler to meet the diverse needs of an increasingly complex customer base. It is likely that failing to adopt an Industry 4.0 roadmap, manufacturers no matter how efficient they are in the current industrial landscape, will over time regress relative to Industry 4.0 practitioners.

Theodore Levitt argues that the primary purpose of a business is to create customers and keep them. Customers are increasingly more demanding requiring greater product quality and variety. Additionally, customers are challenging traditional methods of engaging and buying from providers. Peter Drucker advocates that a firm’s alignment to their chosen markets must change as the market changes. Maintaining the connectedness to the customer base and predicting changes in market trends requires intelligence. The real time heterogeneous nature of Industry 4.0 and the capability to harvest a vast amount of customer and market related data provides the capability to remain dynamically linked to the customer base and market trends. With the appropriate analytical methods applied to the data, the intelligence necessary to maintain customer and market alignment can be obtained.

The emergence of Industry 4.0 does not necessarily subvert sound business or operational methodologies. Within this paper, the relationship between lean/six sigma initiatives and Industry 4.0 is assessed and the methodologies are shown to be mutually supportive. While further research is required, it is likely that rigorous well proven business practices will be elevated through Industry 4.0 initiatives to provide increasing value added contributions.

While it is essential to have well defined technical architecture to support Industry 4.0, the deployment of the initiative will also rely on appreciating socio-technical features. Further research is necessary to understand the full socio-technical impact of Industry 4.0 on how people can work effectively in a digital environment. It is clear that stakeholders at all levels will need to change their approach to how they work. The conventional management hierarchy will be less of a control structure and become a shared knowledge stream. While it is difficult to predict what new disciplines will emerge from Industry 4.0, it is probable that a new knowledge professional will surface that will have a far-reaching understanding of the technologies to guide optimum deployment within a company.
References


