THE RELEVANCE OF LEAN MANUFACTURING PRINCIPLES IN DIVERSE APPLICATIONS AND DIGITAL ENTERPRISES

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The lean manufacturing model through the elimination of waste creates customer value and efficient manufacturing work flows matched to customer demand. Promoters of the lean model contend that lean manufacturing will become the global manufacturing standard across the totality of industrial applications for the 21st century. This assertion is assessed across a variety of industrial sectors and the relevance of the lean model is considered within a Digital Enterprise Technology Environment, a construct that serves to manage product life-cycles on a global scale.

1. INTRODUCTION

The Lean Manufacturing Model emerged from research conducted through the International Motor Vehicle Program at the Massachusetts Institute of Technology during the latter half of the 1980's. The research was presented to a wider audience through a seminal work, 'The Machine That Changed the World' (Womack et al, 1990) The authors observation of the Toyota Production System (Monden, 1998) with its ruthless focus of eliminating waste, spurned the creation of what became Lean Manufacturing. The authors present a compelling case for the implementation of Lean Manufacturing compared to the Mass Production methods of the time, showing a 2:1 differential in favour of lean manufacturing across a number of dimensions. In a further work, 'Lean Thinking' (Womack and Jones, 1996) the authors present the Lean Model as a construct consisting of five related principles:

1. Value: Defined in terms of the final customer.
2. The Value Stream: Create a stream of activities geared toward delivering customer value through the elimination of non-value added activities.
3. Flow: Introduce working methods that allow the value added activities to flow.
4. Pull: Ensure that all value added activities are synchronised to the customer demand.
5. Perfection: Create a culture of continuous improvement that creates greater customer perceived value and removes successive layers of waste.

The authors contend that the implementation of the first four principles leads to new sources of value, waste and reveal impediments to flow and pull production. Within the lean model, therefore, there exists a continuous cycle of improvement of each of the principles creating a 'virtuous circle' implying a never ending pursuit of perfection. A significant conclusion from the 'Machine That Changed the World' is that the Lean Manufacturing Model will become the standard global production system of the 21st century in all areas of industrial endeavour (p 278).

This is a bold assertion and implies that each of the defined principles is directly applicable to any given manufacturing scenario and that the model is universally relevant. The universal relevance of Lean Manufacturing is considered through lean applications across diverse industrial sectors particularly the Aircraft and Building Construction Industries.
The concept of Digital Enterprise Technology (DET) is presented as a holistic framework combining product design, manufacturing and logistical process within an integrated information technology environment to manage product life cycles within a global context and the relevance of the Lean Model is assessed within a DET environment.

2. APPLICATIONS OF LEAN MANUFACTURING

The literature describing lean applications across diverse industrial and other applications is prevalent. In the Shipbuilding industry, examples of lean influences are given by Koenig et al (2002) Storch and Lim (1999) and the in the United States, the 'Lean Ship Building Initiative' exists as an industry link to implement lean practises, (NSPR, 2006). In more diverse applications, for example, the healthcare profession, working concepts developed through the Toyota Production System are beginning to influence the management of patient care (McCarthy, 2006 and Spear 2005). Also, The Scottish Office commissioned a report to evaluate the application of lean principles to the business management of the public sector (Scottish Executive, 2006). The application of the lean model is assessed below in more detail in the Aircraft and Building Construction Industries.

2.1 Aircraft Industry

Two factors emerged in the early part of the 1990's that were instrumental in the take up of lean principles within the aerospace industry (Ward, 2003). Firstly, the end of the cold war resulted in far-reaching reductions in defence procurement budgets due to reduced military markets and secondly, the aftermath of the first Gulf War saw a fall in demand of passenger traffic forcing airlines to cancel or postpone civil aircraft orders.

The response in America to this unfolding situation was the creation of 'The Lean Aerospace Initiative (LAI)' in 1993. The LAI was founded at the Massachusetts Institute of Technology (MIT) through a consortium of leaders from the U.S. Air Force, MIT, labour unions, defence aerospace businesses and civil aircraft manufacturers that formed an 'evolving learning and research' community implementing lean practices throughout the American aerospace industry to counter diminishing defence budgets and rising production and development costs. A similar initiative emerged in 1998 in the United Kingdom through collaboration between the "The Society of British Aerospace Companies" (SBAC) and the University of Warwick. Both initiatives attempt to accelerate lean deployment through identified best practice, shared communication, common goals and strategic implementation tools gained through the collaboration of consortium members.

Typical of the success of the work of the LAI in the United States is witnessed in the deployment of lean practices in the maintenance programme for the C5 Galaxy, a four engine cargo and troop carrier (Barrett and Fraile, 2005). Maintenance turn around time was reduced by one third (340 down to 225) freeing capacity to return work outsourced to private contractors.

Independently of the LAI, applications of lean principles within the USA Aerospace Industry are reported. For example, Venables et al (2006) describe working practices based on the Toyota Production System at the Boeing Aircraft Company and Smiths Aerospace during the introduction of lean working practices. Boeing through principally hiring retired Toyota personnel and Smiths through studying the latest lean literature and introducing training courses for its senior managers. Similarly, a successful implementation of lean principles in the aircraft industry is provided by Northrop Grumman in the USA who applies the principles to both its aircraft manufacturing and ship building divisions. Their lean programme has resulted in success in reducing the manufacturing cycle time of aircraft as much as 30%, (Northrop Grumman, 2005).

In the United Kingdom, the SBAC initiative reports the application of lean principles to the 'New Product Introduction (NPI)' programmes at Rolls Royce Aero Engines, Weston Aerospace and Smiths Industries (Haque, 2001). The principles are applied at Rolls Royce to streamline their generic design process by removing wasteful and non-value adding activities. At Weston Aerospace, lean principles are applied to introduce 'single piece flow' to their NPI project management activities to reduce project lead time through a focus of 'Value Stream Analysis' by eliminating the then current method of batching and queuing of project activities. Smiths Industries through lean deployment, introduced a system of 'off line' product development. In this process, 'product elements' are designed, tested and productionised and become available for later customisation and integration into product applications. Due to the diversity of their product range, Smiths Industries are able to gain benefit through the availability of common sub-assemblies enabling a reduction in time from customer selection to product delivery.

Independently of the SBAC initiative, at the operational level, Parry and Turner (2006) describe the application of 'Visual Process Management Tools' based on Lean Principles, at Airbus (UK), Weston Aerospace and Rolls Royce Civil Aerospace. Airbus introduced visual aids to communicate the output of value stream mapping that focused on delivery to customer, the effective use of resources, identification of bottlenecks and work in progress and the display of relevant measures for continuous improvement. Weston Aerospace have developed a lean manufacturing facility and use a single visual management board to drive business processes across the whole of their activities. Rolls Royce communicate their ERP generated production schedules via a 'Visual Control Board' that enables process ownership at the operator level providing a focus toward continuous improvement.

2.2 Building Construction Industry

Green and May (2005) suggest that though the concept of 'Lean Construction' attracted academic interest since the early 1990's, the dissemination of lean principles within the United Kingdom Construction Industry gained prominence with the publication of the British government sponsored 'Egan' Report - *"Rethinking Construction: The Report of the Construction Task Force",* (Egan, 1998). The report recommended that the adoption of lean principles would return similar improvements that had been experienced in the automotive industry from which the lean concept originated. A subsequent report, "Accelerating Change", (Egan, 2002) reports on the improvements within the UK Construction Industry since the adoption of Egan report indicating improvements recorded across 12 key performance Indicators. Some examples include Client Product Satisfaction (16%), Client Service Satisfaction (23%)

and a reduction of 50% of reported accidents per 100 employees. Other improvements include:

- Significant improvement in predictability and timing of construction projects
- Enhanced quality and reduction in defects
- Construction projects are safer and healthier
- Greater client satisfaction
- More repeat business.

However, Green and May (2005), while recognising the influence of the Egan report, suggest that the understanding of the application of Lean Principles amongst practitioners within the construction industry is a 'vague construct'. Green (1999) observes that the report emphasises the more advantageous aspects of the lean model and ignores an observation that the success of the Japanese automotive industry is due in part to Japan's protected home market that allowed the lean model to mature. Conversely, the Egan Report, Green states does not consider the possibility of protecting the UK construction industry form foreign competition to allow lean construction to mature.

Negative aspects aside, the lean construction literature provides example of successful lean implementations. In the United States, Garnett et al (1998), illustrates the improvements achieved in the American Construction Industry by implementing lean principles. Similarly in the United States, Arbulu et al (2003), discuss define the application of Value Stream Mapping to improving the Supply Chain for delivery of pipe supports for use in power plants that highlighted some 96% of the time in the original supply chain was non-value added. Naim and Barlow (2003) discuss a supply chain strategy for customised housing in the United Kingdom that combines lean methods of eliminating waste with an 'agile' production approach using market knowledge to exploit profitable opportunities in a volatile market place.

3. DIGITAL ENTERPRISE TECHNOLOGY

Digital Enterprise Technology (DET) is a holistic framework that combines product design, manufacturing and logistical process within an integrated information technology environment. Maropoulos (2003) defines DET as:

"*The collection of systems and methods for the digital modelling of the global product development and realisation process, in the context of life-cycle management*"

Through this '*collection*', Maropoulos constructs a DET Framework, replicated in Figure 1, as a synthesis of technologies and systems from five main technical areas. In a further work, Maropoulos et al (2004) define the purpose of DET is to 'shorten product development and realisation, by estimating and therefore controlling quality, cost and delivery factors for products at an early stage in their lifecycle'.

The framework is not necessarily a theoretical construct and for example, provides the basis of work by Monostori et al (2003 (i) and 2003 (ii)) in introducing the Digital Enterprise concept in Hungary.

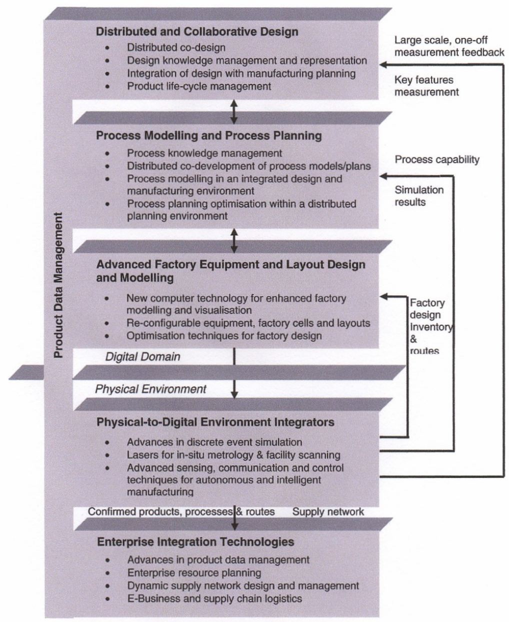

Figure 1 DET Framework Maropoulos (2003).

3.1 The Relationship between DET and the Lean Model

A theme that emerges from Lean Thinking, (Womack and Jones, 1996), is that the logical destination for a company embarking on a lean implementation is the enterprise (and extended enterprise) wide dissemination of the lean model. Similarly, Hines and Rich (1997) create a 'Value Stream Mapping' construct based on lean principles that can be applied across the extended enterprise. Essentially, therefore, the lean model is a holistic approach of eliminating waste and providing customer value throughout the extended enterprise. The 'holistic' concept is similarly shared between the lean model and the DET approach. But beyond this shared holistic philosophy, is there a more definitive relationship between the Lean Model and DET? Moreover, is it essential that for a Digital Enterprise to be lean for the Enterprise to be successful?

The preceding section demonstrated the diverse applications of the lean model. In creating the DET Framework, Maropoulos (2003), classifies manufacturing activity into four categories:

1. **High Value/complexity product integrators:** Examples include satellites, aerospace, shipbuilding.
2. **Smaller Scale, heavy engineering products:** Examples include land transport systems, articulated trucks, excavators.
3. **Automotive and high precision products:** Examples include products and components for the defence, aerospace and automotive industries.
4. **Lower complexity/higher volume products and electronics.** Examples include home appliances, mass produced light weight products for domestic or industrial use and electronic components manufacture.

For each of these categories, 'Key Industrial Characteristics' and 'Technology Requirements' are defined. For example, characteristics include, life cycle duration and management, and supply chain capabilities. Technology requirements include the importance of early evaluation of designs for manufacture, modelling and analysis for manufacture and assembly using 3D digital modelling. Maropoulos suggests that the conditions that apply to category 1, the key characteristics being 'unit of one, high customisation and life-cycle based manufacture' will over time prevail over most manufacturing sectors. The DET framework introducing computer modelling, graphic visualisation and disrupted information management will according to Maropoulos serve to 'positively impact on the global product development and realisation under increased mass customisation and reduced product life cycles' with the benefit of the 'minimisation of risk in global product realization'

Across each of the industry categories defined by Maropoulos, the lean model can be shown to apply. The previous section illustrated applications in aerospace and shipbuilding while the origins of the lean model are found in the automotive industry. A survey of lean implementation programmes 'Lessons in Lean' (The Manufacturing Foundation, 2004) provides examples of lean applications in both category 2 and 4 industrial sectors.

While it is clear that DET and the lean model are applicable across the same industrial sectors, the observation is not a coincidence. Product life-cycles are either short or reducing. The concept of concurrent engineering and design for manufacture are central to the lean model (Womack et al 1990, Henderson and Larco, 2003), enabling products to productionised quicker than previous sequential methods of introducing product designs into manufacturing. The 'Distributed and Collaborative Design' construct of the DET Framework enhances the capability of realising product designs. The examples in the previous section relating to lean principles applied to managing 'New Product Introduction' serve to support further the design function. The 'Process Modelling and Process Planning' construct has a lean analogy in the 'Value Stream' concept, such that this DET construct can be applied to create value in terms of customer needs. The DET construct of 'Advanced Factory Equipment and Layout Design and Modelling' can be applied to create production flow and minimise inventory. In the Physical Environment of the DET Framework, the Physical-to-Digital Environment Integrators provide the basis for continuous improvement, particularly from the ability for recording production performance through real-time shop floor monitoring systems. Finally, the DET construct of 'Enterprise Integration Technologies' provide the basis for lean shop floor operations and supply chain management.

Though it is possible to establish a relationship between DET and lean principles, the available literature discussing lean concepts within a DET environment is sparse. However, Ranky (2003 (i)) attempts to define the network requirements for a distributed lean manufacturing system in digital environment that consists of individuals or teams of operators working in front of multimedia workstations or machines and robots within a real-time network that interact with each other. In a second publication, Ranky (2003 (ii)), discusses the architecture requirements for a lean flexible, just-in-time controlled manufacturing system operating in cells or modules dealing with a high level of distributed data processing and automated material flow. Ranky suggests that without the appropriate 'lean infrastructure architecture' combining lean, flexible, market driven just-in-time principles coupled with advanced networking, production and quality control methodologies within a seamlessly integrated digital factory, even the best and leanest manufacturing system will not be able to produce to its full potential on the shop floor.

5. CONCLUSIONS

Clearly, the lean manufacturing principles replicated in the introduction from *Lean Thinking*, (Womack and Jones, 1996) are applicable across diverse industrial applications and the principles are influencing the management of less obvious endeavours such as health care and local government management. Constructs such as creating value, reducing waste and continuous improvement are becoming a '*mind set*' across all areas of industrial, commercial and public activity. However, the application of lean principles is more embedded in some industries than others. Within the Aircraft Industry, particularly through the influence of the LAI consortiums both in the UK and the USA, lean principles are maturing. In the Building Industry, lean concepts are not necessarily understood even though the application of lean principles are returning benefits. However, within the Building Industry, the lean model is a relatively new construct, and through a combination of further training, consultancy and academic partnership (as observed in the LAI consortiums) will over time embed more thoroughly lean principles within the Building Industry.

The DET construct is shown to apply across a range of industrial sectors each of which it is possible to apply lean principles. The DET and lean approaches share a holistic philosophy of enterprise wide application. Moreover, each element of the DET Model is shown to have a synergy with a lean principle. However, this relationship is inferred rather than proved. The literature discussing lean and DET relationships or applications is sparse, though Ranky (2003 (ii)) concludes that within a DET environment, matching the system architecture with the needs of the lean system provide the greatest benefit to an organisation. That there is a definitive relationship between the lean model and DET is likely and that for DET to be effective, the underlying business model should be lean.

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