Modern Manufacturing Paradigms - A Comparison

Arun N. Nambiar*

Abstract— **Companies aim to increase their profits by continuously striving to offer their customers what they want, when they want and where they want it. This makes it imperative for them to provide customized products at mass production prices while reducing the design-to-market times and lead times. There are many techniques available in the research literature today that purport to help companies achieve these often-times contradicting and complex goals. Some of these techniques like lean principles have gained widespread popularity partly fueled by the success story of companies that pioneered them, Toyota for one. However, others like mass customization and agile manufacturing have not yet taken off as well as they should have been. The reasons for this laggard response might be partly due to the lack of understanding of the underlying fundamentals and partly due to the inability to keep up prolific rate at which newer concepts are being brought to fruition. This work aims to compare these techniques and provide practitioners with an understanding of these techniques thus enabling them to select one or a combination of many of these approaches best suited to their needs.**

Keywords: lean, QRM, agile, holonic manufacturing, mass customization, toyota production system

1 Introduction

Global competition has engendered a trend among companies towards continuously improving operations so that they can provide customers the right products in the right quantities at the right times. Ever since Toyota Production Systems (TPS) became popular after the oil crisis during the 1970s, researchers and practitioners have come up with numerous manufacturing paradigms that purport to be a one-stop technique for companies to achieve these goals. However, not all of these paradigms are geared towards achieving all these aforementioned objectives. Often times, companies get disillusioned after implementing one or more of these techniques and not achieving the expected results. This can be attributed primarily to the lack of clear understanding of subtle nuances of these paradigms and their potential benefits.

In this work, we attempt to dispel some of the confusion in this regard and provide a framework for comparing these various paradigms with one another. Section 2 gives an initial background to the relevance of manufacturing technologies in today's world. Section 3 covers the main thrust of this work - comparing various manufacturing technologies. Section 4 gives the conclusions and identifies future direction of research.

2 Basics

In this increasingly "flat world" [5], markets and supply chains alike have become truly global with each located in geographically diverse locations. This results in increased competition with companies vying for what is often misconstrued as an elusive goal - customer satisfaction. Companies also aim to increase their profits by continuously striving to offer their customers what they want, when they want and where they want it. This makes it imperative for them to provide customized products at mass production prices while reducing the design-to-market times and lead times.

Since the rise to popularity of Toyota Production System (TPS) after the oil crisis in the 1970s, numerous manufacturing paradigms have been introduced to help companies achieve this goal. Some of these paradigms include lean and six sigma, agile manufacturing, mass customization, quick response manufacturing and holonic manufacturing. In the following section, we explore in some detail these paradigms and provide a taxonomic comparison of their benefits.

3 Manufacturing Paradigms

The primary thrust in all manufacturing paradigms is to improve the company's operations so as to make it more profitable. That being said, it is important to realize that each of the manufacturing paradigms have a core objective for which it works best. Here, we discuss the features of some of these manufacturing paradigms such as Toyota production system, lean principles, quick response manufacturing, agile manufacturing, mass customization and holonic manufacturing. We compare these various techniques vis-a-vis their specific objectives.

*California State University - Fresno, Fresno, CA 93740, Tel: 559-278-1443 Email: anambiar@csufresno.edu

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3.1 Toyota Production System

Toyota Production System (TPS) was developed by Taiichi Ohno[13] in 1950s when Japanese companies were trying to catch up with the Western world. Around this time, productivity was significantly lower in Japanese companies with it taking 9-10 workers to do what a single American worker could do. Kiichiro Toyoda, the then President of Toyota Motor Company urged his employees to 'catch up with America in the next three years' [13]. This was the driving force behind the development of TPS. The objective was to produce a variety of models of cars in low volumes. This was in stark contrast to the prevailing mindset of mass production of a few models pioneered and popularized by Henry Ford. The Toyota Production System was not developed overnight; it was a result of constant improvement over a period of 10 years. The underlying philosophy behind TPS is succinctly expressed by Yasuhiro Monden [9] as

> "The ultimate purpose of the Toyota Production System is to increase profit by reducing costs".

The central concept behind Toyota Production System is to reduce costs by eliminating wastes. The 7 types of wastes that have been identified by Taiichi Ohno [13] include overproduction, waiting, transport, processing, inventory, motion and defects. Toyota aims to continuously reduce costs by putting into effect improvements to eliminate each of these wastes. The basic features of TPS [19] can be briefly stated as

- Reduce cost by eliminating wastes
- Eliminate overproduction through minimum inventories
- Shorten the production cycle by having smaller lot sizes, reducing set-up times
- Producing only what has been ordered

The two main pillars of TPS are Just-In-Time(JIT) manufacturing and Autonomation(*jidoka*) or Automation with a human touch. Techniques like *kanban*, TPM, *kaizen*, SMED, 5S, and *poka-yoke* assist in achieving these two important pillars. Figure 1 shows how the various techniques work in cohesion towards achieving the ultimate objective of reducing costs through elimination of wastes. TPS works best in low product variety and stable product demand type environments, although modifications to the original system have been developed for high-variety, low-volume environments.

3.2 Lean Principles

James P. Womack and Daniel T. Jones introduced the concept of *lean production* in their book titled "The Machine That Changed the World" [22]. The five lean principles highlighted by Womack et al. [23] all of which have the same underlying central concept of *doing more and more with less and less* include

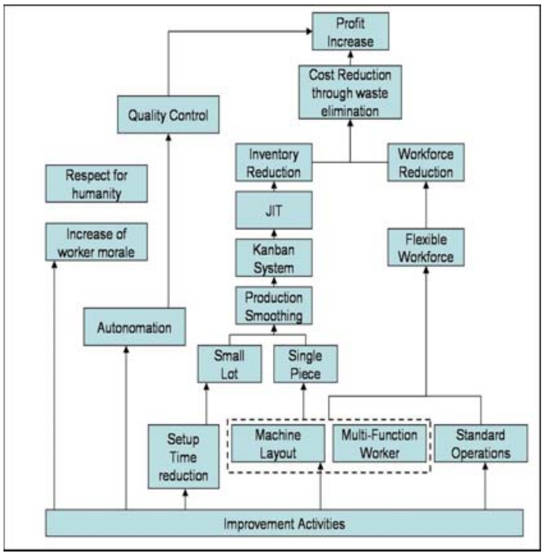

Figure 1: Toyota Production System (Obtained from [9])

1. Identify **value** of product/service to customer
2. Identify **value-stream** using Value-Stream Mapping
3. Ensure **continuous flow**
4. Ensure customers **pull** value using *kanban* systems
5. **Continuously strive** for perfection through *kaizen*

Lean production focused on streamlining the operations in an organization and eliminating wastes.

- **D**efine - identify the *value*
- **M**easure - identify the *value-stream*
- **A**nalyze - study the value-stream and identify *wastes*
- **I**mprove - to eliminate defects and wastes through *TPM*, *SMED*, *kanbans*
- **C**ontrol - implement *poka-yoke* devices

Figures 2a and 2b compare the emphasis in lean methodology and six sigma techniques. Figure 3 shows how lean and six sigma concepts can be combined to focus both on lead-time and variability reduction. Studies [1, 3, 18] have shown that companies achieve high performance levels when six sigma implementations are combined with lean principles.

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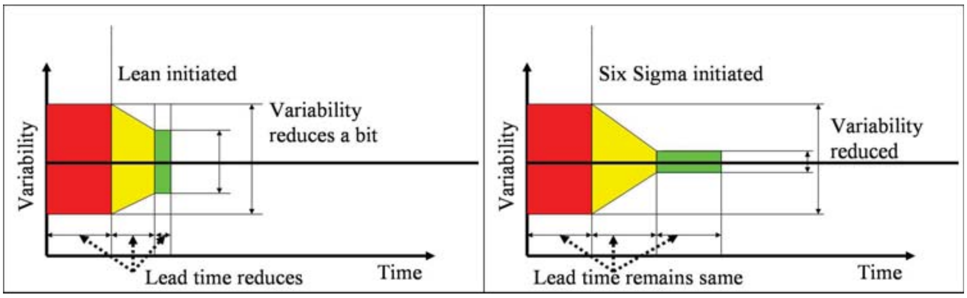


(a) Lean (b) Six Sigma

Figure 2: Comparison of Lean and Six Sigma

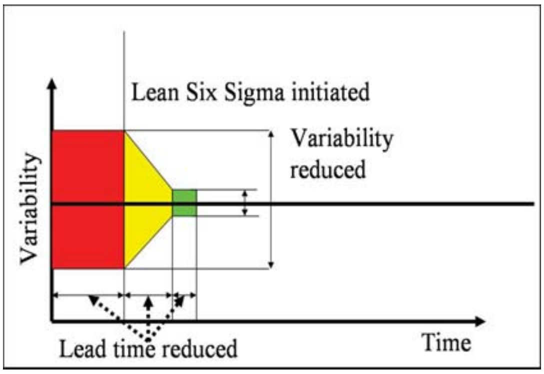


Figure 3: Lean and Six Sigma Combined

3.3 Quick Response Manufacturing

In today's world of increasing global competition, diverse customer demands and sprawling supplier networks, speed is of essence. It is imperative that companies introduce products as quickly as possible to gain market-share. An extension of the time-based competition (TBC) strategy, Quick Response Manufacturing (QRM) focuses reducing lead times. QRM techniques enable companies to cut down on their lead time by almost 75-90% [20]. Just as in TPS, QRM too advocates that machines don't have to be running all the time. QRM infact recommends that critical machines be scheduled only to 70-80% of their capacity. This allows more flexibility thus enabling companies to respond quickly to customer order changes. QRM seeks to improve processes by asking questions quite similar to the *5W1H* technique often employed in TPS and lean principles.

Paired-cell Overlapping Loops of Cards with Authorization (POLCA) cards[20] are used for material and capacity planning and control. While *kanban* cards are suitable for high-volume, low-variety product-type environments, POLCA cards are suitable for high-variety product-type environments. This mechanism uses a combination of push and pull methods. Figure 4a shows a typical POLCA card and Figure 4b shows how POLCA cards control inter-cell movement and help monitor production.

Since the main thrust in QRM is on lead-time reduction, this paradigm can work very well with other techniques such as lean and six sigma principles which focus on reducing wastes and variability respectively. QRM also works well with existing materials requirement planning (MRP) systems. MRP systems can be used to high-level materials planning while the lower level details can be managed through POLCA cards. Once QRM principles and techniques are in place, companies can embark upon the journey of being truly agile.

3.4 Agile Manufacturing

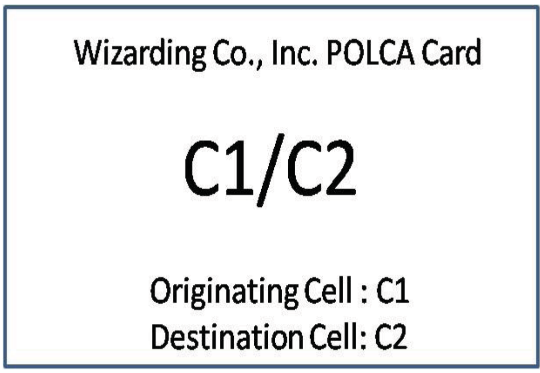
Agile manufacturing or agile production serves as a framework that integrates lean principles with mass customization. Agility can be defined[14] as

> "the ability to respond with ease to unexpected but anticipated events ...the capability that allows for a response to be executed with ease".

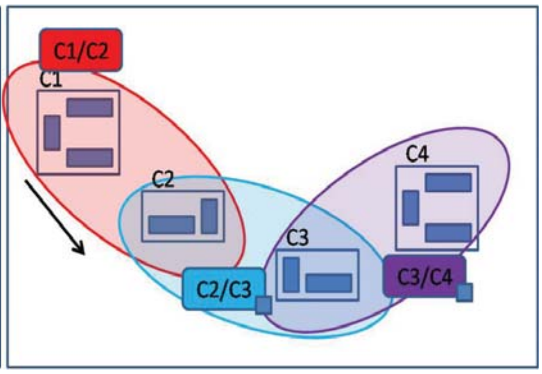
Agility provides the organization with a competitive edge in today's world of global competition and cost-conscious consumer. The reader is referred to Oleson[14] for a more detailed historical perspective on agility.

Flexibility and responsiveness are the hallmarks of an agile enterprise. In order to implement agile manufacturing principles, companies need to focus on various aspects of its processes as seen in the aforementioned taxonomic framework. It has been shown [10] that majority of the research has been in the area of product design and production planning. There needs to be more research into the impact of facilities design and location and logistics on the agility of an enterprise.

A comparative study[21, 24] of lean and agile manufacturing showed that while lean principles has its benefits under stable market conditions , agile manufacturing is better suited to the vagaries and volatility of today's markets and tends to focus more improving the company's



(a) POLCA Card



(b) In Action

Figure 4: POLCA Cards in Action (Adapted from [20])

competitiveness. However, it has also been shown[12], in order to be truly agile, companies must have lean principles implemented while the reverse is not necessarily true. Lean and agile production can be combined [2, 6, 7, 17] to help companies reduce operating costs while being responsive to customer demands.

3.5 Mass Customization

Coined by S. M. Davis [4] and popularized by Joseph B. Pine II[16], mass customization is defined as [16][1]

> "providing **tremendous variety** and individual customization, at **prices comparable to standard** goods and services...with **enough variety** and customization that **nearly everyone** gets exactly what they want".

The Venn-diagrams shown in Figures 5a and 5b puts in perspective the product variety available in the aforementioned strategies. It can been seen from Figure 5b that mass customization fits in somewhere in the middle in the spectrum which has *craftsmanship* at one end and *mass production* at the other end.

Mass customization definitely results in improved market share and reduced inventory levels in a company. It also leads to customer "delight" as opposed to mere customer satisfaction when combined with lean and agile principles [15]. However, due to certain limitations discussed above, this concept has not yet taken off despite its immense potential. The yawning gap between research in the field and its implementation needs to be addressed. Moreover, it has been shown [11] that the bulk of the focus has been on product design and configuration. According to the author, the supply and logistics aspect which forms a vital component of mass customization also needs more focus too.

[1]emphasis added

3.6 Holonic Manufacturing

Holonic manufacturing systems (HMS) was introduced in the late 1980s purporting to be the next-generation manufacturing system with features such as scalability, reconfigurability, adaptability, and responsiveness. HMS is a network of holons which interact with one another and achieve specific functions like controlling production, responding to unforeseen or unexpected conditions.

The term *holon* was originally coined by Koestler[8] who attributed properties of the "whole" and "part" to individual constituents of a system. Koestler argued that each constituent of a system behaved at times like the entire system and at other times exhibited unique component-level behavior. An hierarchy based on holons is called *holarchy* which is quite contrary to traditional hierarchies with no defined upward or downward control paths.

Each holon has a control unit, a coordination module and an internal database. The coordination module maintains communication with other holons and control systems. The control unit with the help of built-in algorithms helps achieve the objectives using information stored in the database. A network of holons and the resulting holonic manufacturing system facilitates better control of manufacturing systems and easy reconfiguration of systems in response to changes in product volume and variety.

3.7 Comparison of Paradigms

From the brief discussion above of the various manufacturing paradigms, it is evident that each of these techniques serve some objectives more than others. These paradigms, albeit all focused towards the general goal of increased profitability and improved customer satisfaction, focus on achieving specific objectives. Techniques such as TPS and lean principles are focused mainly on waste elimination and quality improvement. QRM, and

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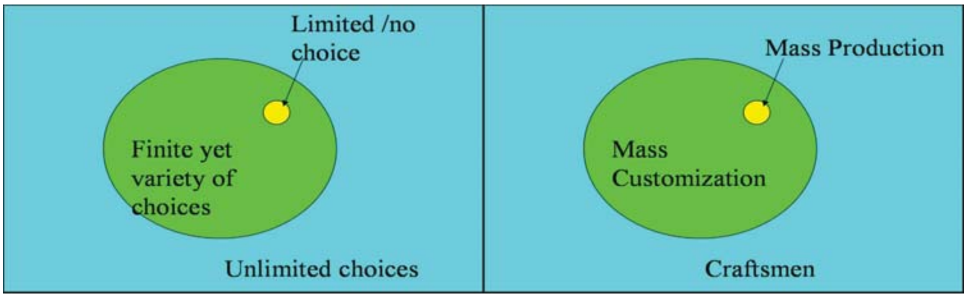

(a) Product variety

(b) 3 Manufacturing Strategies

Figure 5: Comparison of Strategies vis-a-vis Product Variety

Table 1: Taxonomic Comparison of Manufacturing Paradigms

Feature	**TPS**	**Lean/6σ**	**AM**	**MC**	**HMS**	**QRM**
Customization				✓	✓	✓
Flexibility			✓	✓	✓	✓
Inventory reduction	✓	✓				✓
Lead Time		✓	✓	✓		✓
Organization-focus		✓	✓			✓
Quality	✓	✓	✓			✓
Reconfigurability			✓		✓	
Responsive			✓	✓	✓	✓
Waste elimination	✓	✓	✓			

agile manufacturing help making the organization respond quickly to changing customer demands and thus ride the wave of new customer demands maximizing profits in the early stages of product introduction. Mass customization is focused on improving the company's ability to manufacture these diverse products through modularity and other techniques. HMS helps with the reconfiguration and scaling of manufacturing systems in response to the changes in product volume and variety. However, that being said, it is important to realize that despite the specific primary focus for each of these paradigms, all paradigms contribute in one way or another towards making the company more agile, reducing operating costs, improving the market-share and increasing profitability. A taxonomic comparison of aforementioned manufacturing paradigms is given in Table 1. The intend is to facilitate easy identification of the required manufacturing paradigm to achieve a specific objective.

4 Conclusions and Future Work

Global competition, stringent regulations, higher operating costs, scarcity of resources and last but not the least, demands from increasingly informed customers are some of the issues facing companies in today's world. Companies world over are constantly on the look out for techniques and practices that will enable them to reduce their operating costs while increasing their market-share thereby generating higher profits. As elusive as that goal might seem, numerous manufacturing paradigms have been introduced by researchers and practitioners alike which aim to do just that. However, it is imperative to realize that not all of these paradigms achieve all of the above objectives. Some techniques like QRM and agile manufacturing help improve responsiveness, while others like TPS and lean principles help improve operations by reducing wastes and still others such as mass customization help improve market-share through customized products. Hence, in this work, we have attempted to provide a taxonomic categorization of these various paradigms vis-a-vis the aforementioned objectives of responsiveness, customization, quality, wastes etc. The hope is that this helps companies identify specific techniques for their specific objectives as they embark upon this journey of achieving higher profitability through reduced costs and improved customer satisfaction.

References

[1] E. D. Arnheiter and J. Maleyeff. The integration of lean management and six sigma. *TQM Magazine*, 17 (1):5–18, 2005.

[2] J. Ben Naylor, M. M. Naim, and D. Berry. Leagility: integrating the lean and agile manufacturing paradigms in the total supply chain. *International Journal of Production Economics*, 62(1):107–118, 1999.

ISBN: 978-988-18210-5-8
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[3] E. A. Cudney and J. S. W. Fargher. Lean and six sigma: Integrating lean and six sigma in a systematic approach. In *Proceedings of the IIE Annual Conference and Exposition, May 2005*, 2005.

[4] S. M. Davis. *Future Perfect*. Addison-Wesley, Reading, MA, 1987.

[5] Thomas L. Friedman. *The World is Flat - A Brief History of the Twenty-first Century*. Farrar, Straus, & Giroux, 2005.

[6] C. M. Greene, B. Ellis, and M. Waller. Can lean & agile exist simultaneously? comparative analysis through literature case studies. In *Proceedings of the IIE Annual Conference and Exposition, May 2008*, pages 217–222, 2008.

[7] H. Katayana and D. Bennett. Agility, adaptability and leanness: A comparison of concepts and study of practice. *International Journal of Production Economics*, 60–61:43–51, 1999.

[8] A. Koestler. *The Ghost in the Machine*. Harvard Business School Press, Boston, MA, 1968.

[9] Y. Monden. *Toyota Production System - An Integrated Approach to Just-In-Time*. Engineering & Management Press, Norcross, GA, 1997.

[10] A. N. Nambiar. Agile manufacturing: A taxonomic framework for research. In *Proceedings of the 39th International Conference on Computers and Industrial Engineering, Troyes, France, 6-8, July, 2009.*, 2009.

[11] A. N. Nambiar. Mass customization: Where do we go from here? In *Proceedings of World Congress on Engineering, Vol I, London, U.K, 1-3 July, 2009*, pages 687–693, 2009.

[12] R. Narasimhan, M. Swink, and S.W. Kim. Disentangling leanness and agility: An empirical investigation. *Journal of Operations Management*, 24(5): 440–457, 2006.

[13] T. Ohno. *Toyota Production System : beyond large-scale production*. Productivity Press, Portand, OR, 1988.

[14] John D. Oleson. *Pathways to agility*. Wiley, New York Chichester England, 1998.

[15] D. T. Pham and A. Thomas. Fighting fit factories: Making industry lean, agile and sustainable. *Manufacturing Engineer*, 84(2):24–29, 2005.

[16] Joseph B. Pine II. *Mass Customization - The New Frontier in Business Competition*. Harvard Business School Press, Boston, MA, 1993.

[17] J. Prince and J. M. Kay. Combining lean and agile characteristics: Creation of virtual groups by enhanced production flow analysis. *International Journal of Production Economics*, 85:305–318, 2003.

[18] R. Shah, A. Chandrasekaran, and K. Linderman. In pursuit of implementation patterns: The context of lean and six sigma. *International Journal of Production Research*, 46(23):6679–6699, 2008.

[19] S. Shingo. *A Study of the Toyota Production System from an Industrial Engineering Viewpoint*. Productivity Press, Cambridge, MA, 1989.

[20] R. Suri. *Quick Response Manufacturing: a company-wide approach to reducing lead times*. Productivity Press, New York, NY, 1998.

[21] H-D Wan and F. F. Chen. Reconfiguration of manufacturing systems considering leanness and agility. In *Proceedings of the IIE Annual Conference and Exposition, May 2004*, pages 1403–1407, 2004.

[22] James P. Womack, Daniel T. Jones, and Daniel Ross. *The Machine that Changed the World: Based on the Massachusetts Institute of Technology 5-Million-Dollar 5-Year Study on the Future of the Automobile*. Scribner, 1990.

[23] J.P. Womack and D.T. Jones. *Lean Thinking: Banish Waste and Create Wealth in your Corporation*. Free Press, New York, NY, 2003.

[24] Y. Y. Yusuf and E. O. Adeleye. A comparative study of lean and agile manufacturing with a related survey of current practices in the uk. *International Journal of Production Research*, 40(17):4545–4562, 2002.

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