

Journal of

INDUSTRIAL TECHNOLOGY

Volume 21, Number 3 - July 2005 through September 2005

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By Ms. Jami Kovach, Ms. Paris Stringfellow, Ms. Jennifer Turner, and Dr. B. Rae Cho

Peer-Refereed Article

KEYWORD SEARCH

**CIM
Lean Manufacturing / Six Sigma
Management
Manufacturing
Quality
Statistical Methods**

The Official Electronic Publication of the National Association of Industrial Technology • www.nait.org

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Ms. Jami Kovach is a PhD candidate in the Department of Industrial Engineering at Clemson University. She received her BS in Textile Engineering from North Carolina State University and an MS in Textile Technology from the Institute of Textile Technology. Her industrial experience includes several years as a product and process improvement engineer in the US textile industry. She received her MS in Industrial Engineering from Clemson University, and her research interests include robust design, D-optimal design, and quality improvement and management methods.



Ms. Paris Stringfellow is a Master's student in the Department of Industrial Engineering at Clemson University with an emphasis in Human Factors. She received her BS in Industrial Engineering from Clemson, and her research focuses on human inspection training using virtual reality simulators and eye-tracking technology.



Ms. Jennifer Turner is a Master's student in the Department of Industrial Engineering at Clemson University with an emphasis in quality control. She received her B.S. in Industrial Engineering from Clemson University, and her research focuses on production and quality manufacturing methods and applications.



Dr. B. Rae Cho is the Director of the Advanced Quality Engineering Laboratory and an Associate Professor in the Department of Industrial Engineering at Clemson University. He holds an M.S. in Industrial and System Engineering from Ohio State University, and a Ph.D. in Industrial Engineering from the University of Oklahoma. His research interests include robust design, tolerance optimization, statistical decision theory, and military operation research.

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Abstract

In the past, companies adopted the well-known programs of Lean Manufacturing (LM) and Six Sigma (SS) to help develop solutions to manufacturing problems. More recently, several new philosophies for manufacturing improvement have been developed, which include Agile Manufacturing (AM) and Design for Six Sigma (DFSS). Yet, alone, none of these programs provide the competitive advantage that companies need to compete successfully in today's global market. In this paper, we present a production and quality philosophy for competitiveness called the House of Competitiveness (HOC). This philosophy builds competitive advantage for an ever-changing global market by combining LM, SS, AM, and DFSS in order to improve quality, cost, flexibility, responsiveness, and innovation.

Introduction

In today's global market, there is constantly increasing pressure to make products more quickly, with more variety, at the lowest possible cost. In the end, those companies that meet and exceed customers' demands will succeed by remaining competitive. Then, the question is, how do companies become competitive and retain their competitiveness? This question may not be easy to answer because manufacturing systems are complex, and simple solutions to manufacturing problems may not exist. Therefore, companies must choose from available techniques to develop their own solutions. In the past, companies adopted programs,

such as LM or SS, which focus primarily on production efficiency or quality, respectively. However, neither of these systems addresses the total requirements demanded by the current market, which include a simultaneous focus on efficiency and quality, as well as flexibility and new product development. In response to this fact, several new philosophies for manufacturing improvement have been developed, such as AM and DFSS. These new approaches specifically address flexibility by focusing on making an increased variety of products in smaller quantities and responding quickly to dynamic changes in demand. Yet, individually, none of these programs provide the competitive advantage that companies need to compete successfully in today's global market. To further assist companies with improving their competitive advantage, combined systems have been developed by various sources to address what the aforementioned systems used alone could not accomplish. Examples of these systems include Lean Sigma, Six Sigma Plus, Leagile Manufacturing, and the House of Productivity. Yet, even these combination systems are not sufficient to fully address all the issues related to competitiveness. In today's market, the route for survival often requires mass customization of consumer products where companies utilize both production and quality philosophies to infuse flexibility into their design and manufacturing processes. Therefore, to improve competitiveness and ultimately be successful, companies must implement both new and existing production and quality systems. Together, these

systems can adapt to fluctuating customer requirements and enable companies to produce quality, customized products on demand.

In this paper, we present the conceptual framework of a production and quality philosophy called the HOC. This system builds a philosophy to enhance a company's global competitive advantage by combining both new and existing production and quality systems: LM, AM, SS, and DFSS. This philosophy is intended to improve quality, cost, flexibility, responsiveness, and innovation in an effort to create and enhance competitiveness in today's market. A system, such as the HOC, is crucial to maintaining the competitive advantage necessary to keep businesses alive and profitable amidst growing market demands for variety and perfection. In the following section, we provide background information concerning production and quality improvement systems. We then analyze these systems to show that no system developed thus far creates an all-inclusive system for competitiveness in today's market. Finally, we introduce our HOC system and describe how the four parts of this system work together to improve the competitive position of companies in the current, ever-changing global market. A comprehensive production and quality system has never been adequately addressed in the industrial technology literature, nor has it been appropriately applied in industry.

Literature Review of Production and Quality Systems

1. Production Systems: Lean Manufacturing and Agile Manufacturing

LM is a well-known production philosophy that focuses on optimizing processes through continuous improvement. It encompasses parts of both Just-In-Time and Total Quality Management. Foster (2004) defines LM as a program that drives out waste, increases value to customers, improves profitability, and improves competitiveness using tools and techniques that focus on teamwork and problem solving methodologies. According to Bamber and Dale (2000), companies that design new and innovative products, but cannot manufacture them efficiently, may

be drawn to LM because this philosophy focuses on making companies competitive by improving their manufacturing efficiency. The key concepts of LM are pull, flow, and continuous improvement. Further discussions of this topic can be found in the works of Storch and Lim (1999), Feld (2001), and Bozzone (2002).

Another well-known, but newer production system discussed by DeVor, Graves, and Mills (1997) is AM, which focuses on a planned approach to constant change. The term AM was first coined at Lehigh University in 1991 as a result of a government-backed program to investigate the future of US manufacturing on a global scale. Adaptation becomes a regular occurrence in AM so that companies are capable of counteracting the influence that change has upon performance measures. Throughout this time of change, many companies continue to focus on their core competencies by developing a wide range of business applications from these products. The philosophy of change found in AM has an ultimate mission of constantly outperforming the competition, even as the market is relentlessly evolving. The key pillar of AM, pointed out by Sharp, Irani, and Desai (1999), is a philosophy of change, which is based on corporate partners, information technology (IT), and the concept of an intelligent worker, as shown in Figure 1. This topic is discussed in detail in the works

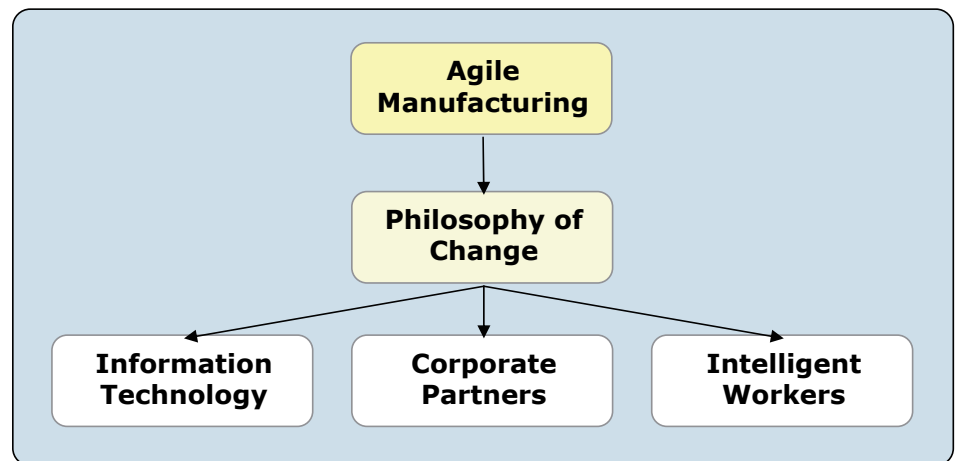
of Gunasekaran (1998), Gunasekaran and Yusef (2002), and Yusef and Adel-eye (2002).

2. Quality Systems: Six Sigma and Design for Six Sigma

SS is a well-known quality improvement methodology used to reduce quality problems with a goal of improving quality such that production can be controlled within six standard deviations from the mean. SS is intensely focused on achieving significant financial results by saving valuable corporate resources, which improves bottom line performance and market competitiveness. SS was developed in the 1980's at Motorola (2004) through a company-wide commitment to improve the quality of their products and has since been utilized by companies all over the world to aid in quality control (Breyfogle, Cupello, and Meadows, 2001; Treichler, Carmichael, Kusmanoff, Lewis, and Berthiez, 2002; Smith, 2003). SS follows a methodology known as DMAIC (Define, Measure, Analyze, Improve, and Control) to guide quality improvement teams. The impact of SS on the world of quality control was so significant that its philosophy spread backwards through the manufacturing chain to the product design phase.

According to Brue and Launsby (2003) this new methodology quickly became known as DFSS, which was developed through a joint effort be-

Figure 1: The components of Agile Manufacturing.



tween the Department of Defense and NASA as a systems engineering tool geared toward emphasizing customer requirements during the design process. The methodology utilized by DFSS is similar to that used during implementation of SS. Although there are a number of variations in the methodology used to carry out DFSS, all generally aim to accomplish the following goals noted by Yang and El-Haik (2003):

1. Identify the customer requirements.
2. Analyze these requirements and prioritize them.
3. Develop a product design based on customer requirements.
4. Develop the various levels of production processes, each based on customer requirements.
5. Modify the production processes so that deviations from customer requirements are minimized.
6. Establish a plan for production control.

3. LeanSigma

The TBM Consulting Group, based in Durham, NC, developed a method called LeanSigma as described by Smith (2003), which evolved out of the idea that LM and SS methods complement one another, and together, the two systems can accomplish far more than either system could achieve alone. The use of this method was studied in conjunction with two companies, Landscape Structures Inc. and Heatcraft, who were already practicing LM, yet still faced quality problems that stifled further improvement. In working with LM alone, quality problems that needed a more focused quality improvement type approach were uncovered at both companies. Using LeanSigma, the project team at Landscape Structures Inc. standardized operating procedures to correct the problems. Additionally, the LeanSigma project with Heatcraft yielded a 40% overall reduction in leak rates and a 75% reduction in quality issues. Many sources of variation in the production process were identified during these projects that resulted in a significant reduction in defects and improved flow and throughput. By using LM and SS together, great improvements in quality and production were achieved.

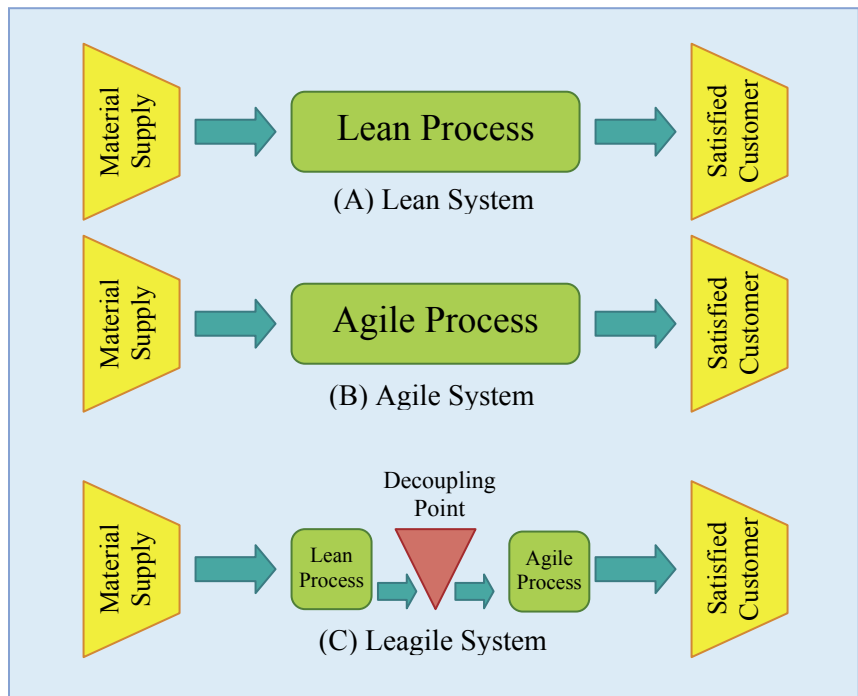
4. Six Sigma Plus

Since 1994, Honeywell International Inc. worked on a major company initiative to implement its Six Sigma Plus program, which is a marriage of the traditional SS variation reduction projects, SS principles used in product design, and LM concepts of waste and cycle time reduction that create a company-wide strategy for improvement. By 2002, Honeywell had productivity improvement gains of \$1.2 billion, a sizeable portion of which they attribute to their Six Sigma Plus program. According to the work of Hill and Kearney (2003), one example of the implementation and results obtained using Six Sigma Plus includes a project completed at a Honeywell chemical plant in Europe. The objective of this project was to optimize a multi-step chemical process. This project used variation reduction tools from Six Sigma Plus to double the production capacity and reduce manufacturing costs by 50%. Also, the use of Six Sigma Plus projects at this plant improved their profit margin from a loss of \$0.9 million per year to a gain of \$3.4 million per year, reduced cycle time from 12 to 10 days, and reduced product travel distance from 300 to 14 km.

5. Lean and Agile Manufacturing

The following case study examines the success of AM in a real world setting. In this examination, a questionnaire was used to assign an agility index to different business aspects. This case considered AM practices at GEC-Marconi Instruments in the United Kingdom. From the analysis performed by Gunasekaran, Turtiroglu, and Wolstencroft (2002), it was concluded that AM cannot be fully successful on its own; first a company should be lean. Without the prerequisite of leanness, the transition to agility may be difficult to accomplish. Given this result, other systems have tried to combine LM and AM. The combined benefits of efficiency and flexible manufacturing has the potential to provide a competitive advantage, but the feasibility of combining two seemingly different production philosophies such as LM and AM has often been questioned. However, in the recent case study by Prince and Kay (2003), the use of a LM and AM combination system is demonstrated in the highly competitive power cable industry. By implementing LM at the beginning of the process and AM during the final stages of the process, the company realized benefits far greater

Figure 2: Lean, Agile, and Leagile Manufacturing systems (Mason-Jones et al., 2000).



than using either philosophy alone.

These ideas are further reinforced by the work of Mason-Jones, Naylor, and Towill (2000) in a reengineering project to streamline an electronics production system through the implementation of a Leagile system. Leagile Manufacturing combines LM and AM through the use of a decoupling point, which separates the production line into two parts at the point of product differentiation, as shown in Figure 2 (Naylor, Naim, and Berry, 1999). Upstream of the decoupling point, LM principles are practiced, which is based on level, planned production, where as, downstream of the decoupling point, AM is used to focus directly on satisfying customer orders. The results of integrating LM and AM using a decoupling point improved supply chain performance and accounted for 58% of the company’s overall improvement, which exceeded earlier projections.

6. The House of Productivity

AMR Research, Inc. developed a system called the House of Productivity as described by Krivda (2004), which encompasses the waste reduction and reduced cycle time of LM, high performance and consistent processes of SS, and the reference process and benchmarking of Supply Chain Operating Reference, a type of agile system. This system is depicted in Figure 3, and its goal is to improve performance and productivity in the areas of cost, efficiency, cycle time, and consistency. By implementing the House of Productivity a company creates

a cycle of continuous improvement. This philosophy has been realized at 7-Eleven where they have reported 29 consecutive quarters of sales increases as well as improved execution of fundamental company goals. Furthermore, they strongly feel their success is a direct result of their stores “doing a better job of providing the product the customer is looking for” (Krivda, 2004).

Analysis of Current Approaches to Production and Quality

The overall effect of current systems clearly improves production performance, but the improvement is limited to certain areas. Table 1 provides a brief checklist of the characteristics afforded

by each system. As noted in the table, LM’s goal of seven zeros motivates its highly efficient production capability. However, Hopp and Spearman (2001) emphasize that this goal imposes limitations on both product quantity and type because of the required smooth production flow. Although AM is the most flexible of the manufacturing philosophies, in the realm of efficiency, Gunasekaran and Yusef (2002) note that it cannot achieve the efficiency of LM due to its primary characteristics. While both production systems address basic improvement issues, they lack a more focused problem solving approach, which is SS’s main strength. However, as noted in Table 1, none of the

Figure 3: The House of Productivity (Krivda, 2004).

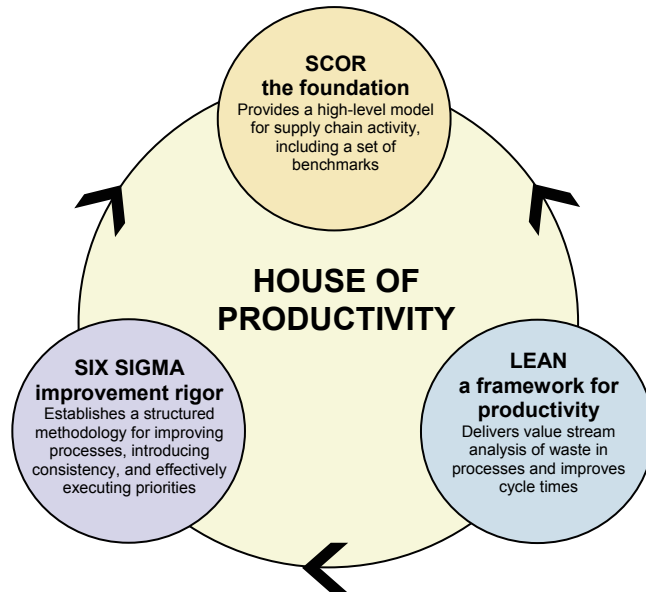


Table 1: Checklist of system characteristics.

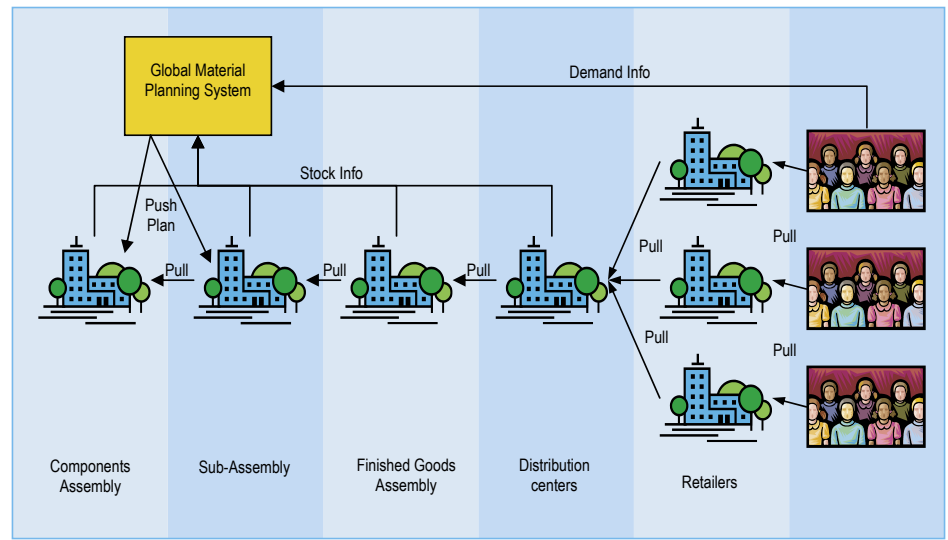
Characteristics of a Competitive System	Traditional Systems				Combination Systems				New Comprehensive System
	LM	AM	SS	DFSS	Lean Sigma	Six Sigma Plus	LM and AM	House of Productivity	
High product quality			✓	✓	✓	✓		✓	✓
Short lead time	✓	✓			✓	✓	✓	✓	✓
Large product variety		✓					✓		✓
High efficiency	✓			✓	✓	✓	✓	✓	✓
High flexibility		✓					✓		✓
Quick response (to changes in the market)		✓					✓		✓
Innovation				✓		✓			✓

aforementioned systems promote new product innovation. Where these other philosophies lack innovation, DFSS advocates it. Another benefit to DFSS noted by Yang and El-Haik (2003) is its focus on design process efficiency. The work of Smith (2003) and Hill and Kerney (2003) show that LeanSigma and Six Sigma Plus systems only addresses quality, lead time, and efficiency, while other vital characteristics are left unaccounted for. The combination of both LM and AM encompass all aspects of a production system except for product quality and innovation. AMR Research, Inc.'s House of Productivity addresses partial aspects of both production and quality improvement systems; however, features such as large product variety and flexibility are not accounted for (Krivda, 2004). Upon inspection, we may observe that none of the aforementioned systems incorporate all that is needed to ultimately become or remain competitive in today's ever-changing global market. Hence, the need for an all-inclusive system that will address each of these characteristics is evident. Such a comprehensive system is developed in this paper and is shown in the last column of Table 1. In the following sections, we investigate commonalities and differences between LM and AM and between SS and DFSS.

1. Comparison of Lean and Agile Manufacturing

It may seem that these two systems conflict; however, AM actually builds on many of the principles of LM. The primary objective of any production system is to provide customers with the products they need in a timely and cost efficient manner. Given this objective, many similarities between LM and AM can be identified. Both systems demand high quality to achieve their maximum potential, but neither has a structured program for solving difficult quality problems. In these systems, production flow is controlled through a pull system where actual customer demand determines production. Since demand drives production, inventory needs to be minimized in all areas. In order to smooth production flow, both systems utilize the concepts of small lot sizes,

Figure 4: An Agile Manufacturing system showing the use of demand information as a check on the pull system.



quick changeovers, and cellular production. Furthermore, these systems place a high value on supplier partnerships to improve efficiency through supplier quality and reliability. For implementation of either system, a fundamental culture change must occur where the system is driven by management support and worker involvement.

Although these systems share many of the same fundamentals, there are also many distinct differences between them. The main objective of LM is to produce a limited number of products efficiently, while AM focuses on simultaneously producing a larger variety of interrelated products. AM is a planned approach to deal with constant change; therefore, it has to be more flexible than LM and adaptation must become part of the normal state of operation. Additionally, in an AM system, low inventory levels may have to be sacrificed to some degree to allow for product variety. In AM, it may be a challenge to smooth production flow due to product variety; lot sizes as small as one will need to be a reality rather than a goal, as is practiced in LM. Furthermore, even the efficient changeovers of LM may not be sufficient in AM, where changeovers will occur often because of product variety. Therefore, these changeovers would

need to tend towards an instantaneous nature. Finally, production flow is further controlled in AM by the idea of cellular manufacturing. In AM, this idea is transformed into virtual production cells in order to provide additional production flexibility to handle high product variety (Prince and Kay, 2003).

LM values long term supplier partnerships whereas AM focuses on short term partnerships with suppliers after the point of product differentiation. Furthermore, LM traditionally produces commodities or staple products, whereas AM focuses on more innovative products where new product development is needed to provide customers with variety in order to build a larger customer base. AM again uses partnerships to support new product development through the use of virtual enterprises in which suppliers and customers form temporary partnerships to introduce new products. This type of alliance allows companies to share the risks and benefits of new product development by sharing resources to get products to market quickly in order to capture the largest possible market share. To create successful partnerships, AM uses IT to facilitate communication between partners. Furthermore, IT is used to expedite planning and production processes and provides a check and balance system

to the pull process of LM, where it is possible for information to become distorted between steps throughout the production chain. As shown in Figure 4, AM uses customer feedback and the pull system together to determine production requirements. Finally, AM requires a culture change above and beyond that of LM since management and workers must learn to deal with constant change and adaptation.

2. Comparison of Six Sigma and Design for Six Sigma

SS and DFSS are fundamentally related because DFSS incorporates many of the same ideas and techniques that make SS so effective in managing quality. Most importantly, both SS and DFSS require a cultural change within a company to shift towards valuing quality. The SS philosophy encourages users to consider the context of the data as a whole and not merely respond to a single out-of-control point as if it were an unusual occurrence. With this larger view in mind, the root cause of quality opportunities can be identified and then addressed and corrected (Breyfogle et al., 2001). Therefore, when using either of these quality systems, a new managerial paradigm should be adopted that shifts from an error-tolerant mentality to an intolerant one (i.e. zero-defects).

While SS and DFSS possess a number of commonalities, they are still two distinct systems for improving quality. For example, SS is a reaction-based tool that responds to out of control occurrences during production; however, DFSS is a proactive tool because it is integrated much sooner in the life of the product and consequently yields a higher level of customer satisfaction and profit. Also, DFSS is not a “quick fix” since it should be incorporated into an existing product development methodology and utilized throughout the life of a product (Treichler et al, 2002).

A New Approach: The House of Competitiveness

As discussed in the previous section, a comprehensive system for competitiveness does not exist. Today, as the global market continues to become more ag-

gressive, quality in manufactured goods has become expected and is treated like a commodity rather than a competitive advantage. Instead, the new key to future competitiveness is to deliver products to customers faster and in greater variety than ever before (Hopp and Spearman, 2001). To be successful in today’s market, manufacturing must be founded on the building blocks of both production and quality. Although the combination of these foundations may appear to be a paradox, it is possible that through the right balance, these two blocks actually support one another. A well-organized system naturally reveals quality opportunities, and a high quality system resolves these issues to further improve efficiency. Therefore, both of these characteristics must be maintained through structured programs implemented throughout all levels of a company.

To implement these ideas, we propose a new production and quality management philosophy, called the HOC, as an innovative and comprehensive approach to address all the characteristics necessary for a competitive system. This philosophy, depicted in Figure 5, begins with LM and SS, which provide a foundation of proven production and quality improvement methods. Then, AM and DFSS are built on top of this solid foundation in order to incorporate the flexibility and innovation needed to cope with today’s current market demands. The marriage

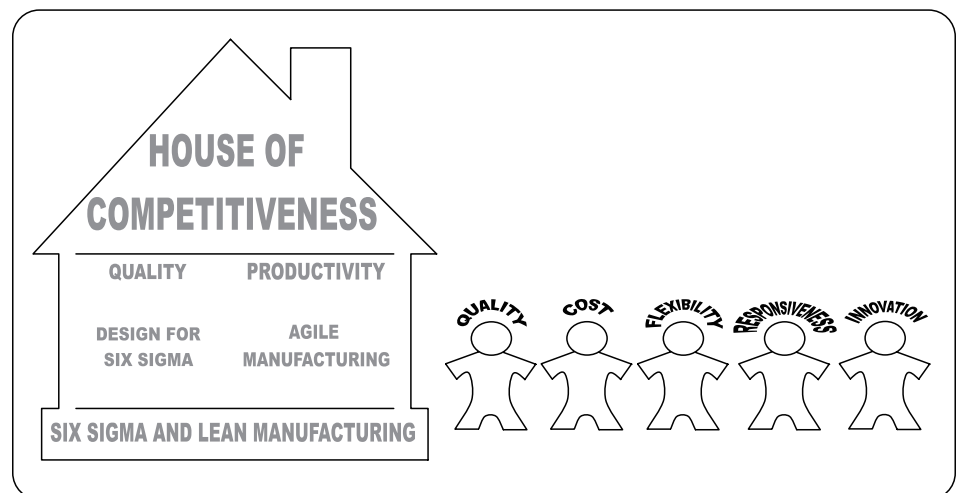
between these four systems creates a comprehensive production and quality philosophy, which results in high quality, low cost, flexibility, responsiveness, and innovation.

The HOC is intended to help companies maintain or improve their competitive advantage in the global market. Although aspects of this system can be very useful in well-established industries, this system is ideal for new or developing manufacturing industries. The HOC offers companies a complete problem solving package through the use of LM, SS, AM, and DFSS methodologies. Together, these systems address both production and quality, while also improving flexibility and innovation. This type of system should be considered for use by globally minded companies who are eager to reach a variety of markets using a flexible manufacturing system supported by quality throughout all levels of the company.

1. Integrating the Systems of the House of Competitiveness

How Do Lean Manufacturing and Agile Manufacturing Work Together? AM builds on LM by producing a larger variety of products using the efficient production base developed through LM. AM uses the inventory practices of LM to keep inventory as low as possible, which helps reduce the risk of obsolescence. The flexible manufacturing system necessary in LM provides a basis for the increasingly

Figure 5: The House of Competitiveness.



flexible system that is needed in AM to handle the fluctuations in demand for multiple products. To smooth production flow, AM uses the concepts of small lot sizes, quick changeovers, and cellular production from LM, but adapts them for use in the production of a larger variety of products. Using IT, AM builds on the pull system of LM by adding a system of checks and balances to stabilize demand by improving communication with customers. Furthermore, AM builds on the idea of partnerships with suppliers from LM and creates both long and short term partnerships with suppliers depending on the location within the supply chain. Additionally, IT is used to facilitate the communication of partnerships for new product development. In an attempt to gain customers in as many markets as possible, AM develops products around the core competencies of the LM production system in order to provide customers with more variety.

How Do Six Sigma and Design for Six Sigma Work Together? Since DFSS is based on the principles of SS, they share

many objectives. These two systems fit together nicely because DFSS focuses on new product quality, while SS focuses on product quality in production and can be implemented at any stage in the production process. DFSS can be used to develop new products, and then traditional SS methodologies can be used to help control production. Together, DFSS and SS enable the production of both new and existing products to become more predictable. This feature supports the smooth production flow needed in both LM and AM.

2. A Roadmap for Integrating the Four Systems of the House of Competitiveness

Since structured quality management systems are needed to support highly efficient manufacturing, production systems should be coupled with quality systems to further improve efficiency. Combining these two philosophies creates one unified idea of continuous improvement, becomes a strong tool for attacking problems, and accomplishes far more than either system could

achieve alone. Given this evidence for how production and quality systems complement one another, a roadmap for integrating the systems of the HOC is presented in Table 2. When LM, AM, SS, and DFSS are used together, as in the HOC, they contribute to satisfying the current market demands and the desired manufacturing characteristics that flow out of these demands in the following ways. The nature of LM effectively identifies quality issues; however, once problems on the surface have been solved, LM offers no further problem solving tools. Therefore, more complex quality problems require a specific problem solving approach such as SS (Smith, 2003; Bossert, 2003). Yet, because LM and SS fail to address issues such as flexibility and innovation, the use of only these two systems does not create a comprehensive system for competitiveness. However, this combination does provide a good foundation for building a comprehensive production and quality system.

The next building blocks needed for an all-inclusive competitive produc-

Table 2: Roadmap for integrating the four systems of the HOC: LM, AM, SS, and DFSS.

Market Demands	Manufacturing Characteristics	Goals	Results	HOC System
<ul style="list-style-type: none"> ▪ Large product variety ▪ Short lead time ▪ High product quality ▪ Low cost 	<ul style="list-style-type: none"> ▪ Efficient ▪ Flexible ▪ Innovative ▪ Responsive to market changes 	<ul style="list-style-type: none"> ▪ Eliminate waste ▪ Increase flexibility 	<ul style="list-style-type: none"> ▪ Efficient production 	
		<ul style="list-style-type: none"> ▪ Design for constant change ▪ Increase product variety 	<ul style="list-style-type: none"> ▪ Efficient production of many products ▪ Innovation 	
		<ul style="list-style-type: none"> ▪ Eliminate defects 	<ul style="list-style-type: none"> ▪ High quality products and processes 	
		<ul style="list-style-type: none"> ▪ Design quality into products 	<ul style="list-style-type: none"> ▪ High quality new products 	

tion and quality system must address production flexibility and product innovation, as in AM and DFSS. In the HOC, pairing AM and DFSS with the strong foundation of LM and SS fills this gap. This lean base provides the ideal platform for introducing a larger product variety through AM, without sacrificing efficiency. In addition, the personnel trained in SS can apply their expertise to new product development (a key requirement of AM) using DFSS, while still maintaining quality in production through traditional SS methods. DFSS allows a company practicing AM to successfully produce high quality, cost effective new products developed from its core competencies. The fast paced nature of an AM environment leaves little room for error; hence, DFSS can be used to design quality into new products, therefore reducing product-to-market time. Because LM and AM alone do not emphasize maintaining product quality, the incorporation of SS and DFSS methodologies into the HOC enables the integration of a high level of structured product quality into the entire production process. Hence, the marriage of these four ideas results in a highly flexible and accurate process that easily adapts and adheres to constantly changing customer demands.

3. House of Competitiveness Implementation Challenges

Because the HOC is a manufacturing philosophy, the way in which a company will use it depends on the company's business strategy, which includes its culture, target markets, long term goals, and many other business factors. Therefore, to develop solutions specifically for their own needs, companies should choose from among the different techniques that the HOC encompasses and implement them to the extent necessary given their current business situation. The more techniques employed and developed within a company, the greater the likeliness of improving the company's competitive position within their target markets. However, each company must determine what balance of these four systems best suits their business's needs. Some industries may find that the costs or sacrifices of some

of these techniques are not necessary, while others may find they are not only needed, but that they are absolutely necessary for survival.

The purpose of the HOC is to provide a globally competitive manufacturing philosophy to assist companies in developing or retaining their competitive advantage. By combining both new and existing production and quality systems, the HOC encompasses all the methods necessary to improve competitiveness. Through the use of this new philosophy, companies can expect results such as high product quality, short lead times, large product variety, high efficiency, high flexibility, quick response (to changes in the market), and increased innovation.

Summary

In this paper, we introduced a comprehensive production and quality philosophy, the HOC, to assist companies with improving their competitive position in order to compete more effectively in today's turbulent market. To develop this concept, LM, AM, SS, and DFSS were reviewed, and case studies were presented to show how these systems have been combined in the past. None of these systems, either alone or in combination, created an all-inclusive system to achieve the competitive advantage necessary for success. The need for such a system then led to the development of the HOC, which considers both production and quality. The HOC is founded on the robust quality principles of LM and SS while incorporating the flexibility and innovation of AM and DFSS to provide a comprehensive system capable of leading the way in a growing global market.

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